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## **Novel Backup Filter Device for Candle Filters**

Keywords: Candle Filter, Fail-Safe, Backup, Safeguard

### **Introduction**

The currently preferred means of particulate removal from process or combustion gas generated by advanced coal-based power production processes is filtration with candle filters. However, candle filters have not shown the requisite reliability to be commercially viable for hot gas clean up for either integrated gasifier combined cycle (IGCC) or pressurized fluid bed combustion (PFBC) processes. Even a single candle failure can lead to unacceptable ash breakthrough, which can result in (a) damage to highly sensitive and expensive downstream equipment, (b) unacceptably low system on-stream factor, and (c) unplanned outages.

The U.S. Department of Energy (DOE) has recognized the need to have fail-safe devices installed within or downstream from candle filters. In addition to CeraMem, DOE has contracted with Siemens-Westinghouse, the Energy & Environmental Research Center (EERC) at the University of North Dakota, and the Southern Research Institute (SRI) to develop novel fail-safe devices. Siemens-Westinghouse is evaluating honeycomb-based filter devices on the clean-side of the candle filter that can operate up to 870°C. The EERC is developing a highly porous ceramic disk with a sticky yet temperature-stable coating that will trap dust in the event of filter failure. SRI is developing the Full-Flow Mechanical Safeguard Device that provides a positive seal for the candle filter. Operation of the SRI device is triggered by the higher-than-normal gas flow from a broken candle. The CeraMem approach is similar to that of Siemens-Westinghouse and involves the development of honeycomb-based filters that operate on the clean-side of a candle filter.

### **Objective**

The overall objective of this project is to fabricate and test silicon carbide-based honeycomb fail-safe filters for protection of downstream equipment in advanced coal conversion processes. The

fail-safe filter, installed directly downstream of a candle filter, should have the capability for stopping essentially all particulate bypassing a broken or leaking candle while having a low enough pressure drop to allow the candle to be backpulse-regenerated. Forward-flow pressure drop should increase by no more than 20% because of incorporation of the fail-safe filter.

## **Approach**

The CeraMem approach is to develop recrystallized silicon carbide (SiC) honeycomb filters of controlled pore size and porosity with the ability to trap and hold fine dust particles and in configurations that provide for low pressure drop. These filters, due to the compact honeycomb configuration, can be installed in the cavities directly downstream of the candle filters thereby requiring no redesign of the candle filter attachment mechanism and plenum.

The fail-safe filters are fabricated by extrusion and firing of controlled particle size SiC powders. The extrusion batch is prepared by mixing coarse SiC powder, fine SiC powder, an organic binder system, and a liquid vehicle. The coarse SiC powder particle size determines the final pore size. The fine SiC powder is used to bond the coarse SiC powder together by an evaporation and condensation mechanism that is driven by surface curvature effects at temperatures in excess of 2,000°C.

After the extrudate is fired, the honeycomb monolith passageways are plugged with high-temperature inorganic cement on both ends in an alternating checkerboard pattern. The plugging pattern modifies the gas flow paths through the monolith so that the gas is constrained to flow through the passageway walls. A schematic of the fail-safe filter and a photograph of fail-safe filters designed for operation with production-scale candle filters are shown in Figures 1 and 2.

The fail-safe filter is housed in a metal shell using high-temperature resilient mat material wrapped around the filter to hold it within the shell and seal it from particulate bypass. The design is very similar to that of a catalytic converter, which has been demonstrated to be a very robust design.

The assembly is then mounted on the clean side of the candle filter. During normal forward-flow operation, the particulate-laden process gas flows through the candle and then the fail-safe device. The candle traps the particulate thereby exposing the fail-safe only to clean gas. At a pre-selected pressure drop or time, the candle filter is cleaned by a high-pressure gas backpulse that is directed through the fail-safe filter. The fail-safe must have a low resistance to gas flow so that adequate pressure can be generated inside the candle to dislodge the filter cake from the candle surface. If the candle filter is broken or leaking, the fail-safe filter will be exposed to the particulate-laden gas stream. The particulate is trapped by the fail-safe preventing it from entering the clean side of the filtration system.

## **Project Description**

In this project, CeraMem fabricated the fail-safe filters and conducted initial ambient condition tests to evaluate if they would operate successfully as fail-safe devices. Filters were also evaluated at the EERC at room temperature. Based on these tests, selected filter types were fabricated and mounted into housing assemblies that were then welded into the EERC's bench-scale filtration system coupled to their pressurized fluidized bed reactor. Tests were then conducted at elevated temperature and pressure to demonstrate the utility of the fail-safe filters.

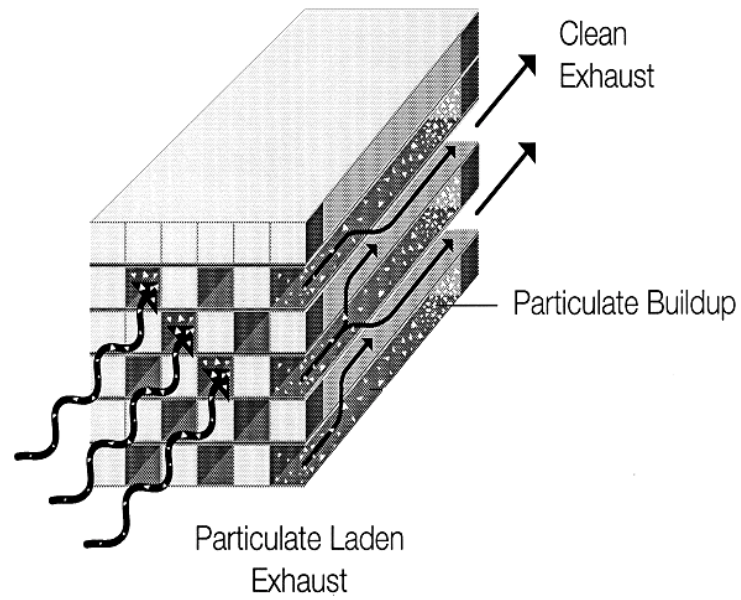


Figure 1. Fail-safe Filter Schematic



Figure 2. Photo of Fail-safe Filters (150 mm Ruler)

CeraMem extruded, dried, and fired SiC monoliths with pore sizes of nominally 25  $\mu\text{m}$ , 35  $\mu\text{m}$ , and 45  $\mu\text{m}$ . The monoliths were 27 mm (1.06 inches) in diameter and 152 mm (6 inches) in length with 0.01 m<sup>2</sup> (0.1 ft<sup>2</sup>) of filtration area. The passageway size was 4 mm and the wall thickness was about 0.8 mm. The passageways were plugged with a silica-bonded SiC cement to form the dead-ended flow configuration. The size of these fail-safes were scaled down to fit with the shorter experimental candles used by the EERC. Full size candles would use fail-safe filters 65 mm (2.6 inches) in diameter due to the greater flow through the full size candles.

CeraMem used a room-temperature bench-scale candle filtration system to evaluate the performance of fail-safe filters in tandem with a candle filter. Coal ash from the EERC was manually fed into the system and drawn through a 305 mm (12 inches) long candle filter (3M Corp. SiC fiber composite candle supplied by the EERC) using an induction fan. The face velocity through the candle filter was about 2.5 cm/s (5 ft/min). After the pressure drop across the candle approximately doubled, the candle filter was isolated from the fan and then cleaned by backpulsing pressurized air via an electronically activated solenoid valve into the clean side of the candle. The electronic pulse duration was 100 ms with a target pulse pressure of 41.3 kPa (6 psig). The pressure profiles in the system during the pulse were monitored with pressure transducers. After the candle was cleaned, the clean filter pressure drop was measured and then ash was reintroduced to the system. Both the 35- $\mu\text{m}$  and 45- $\mu\text{m}$  fail-safe devices were evaluated in tandem with the candle filter as well as the candle without an in-line fail-safe. The 25- $\mu\text{m}$  fail-safe filter was tested at Siemens-Westinghouse under similar conditions, but at elevated temperature, so it was not tested at CeraMem.

All three fail-safe filter types were tested at the EERC at ambient conditions. The intent was to evaluate the change in pressure drop and particulate capture of each fail-safe filter type while being challenged with particulates at loadings representative of normal candle filter operation ( $\sim$  1 ppm), leaking candle filter operation ( $\sim$  20 ppm), and broken candle filter operation (6 g/m<sup>3</sup>). For the low particulate loading challenge tests, a TSI Tri-Jet aerosol generator in combination with makeup air and a cyclone (for the lowest particulate loadings) were used to generate an air stream containing controlled amounts of NaCl particles. For the broken candle filter condition, a TSI dry powder disperser was used with fine coal ash in addition to the TSI Tri-Jet aerosol generator to prepare the particulate-laden gas stream to challenge the fail-safe filters. In addition, the fail-safe filters were backpulsed with compressed air simulating a 34.4 kPa (5 psig) pulse on the clean-side of the candle filter in order to determine the effect of backpulsing on the ability of the fail-safe filters to hold particulate within their pore structures. Near-real-time inlet and outlet particle size analyses were performed using a Model 33 aerodynamic particle sizer (APS) and a Model 3934 scanning mobility particle sizer (SMPS), both manufactured by TSI, Inc. The APS instrument measures particles between 0.7  $\mu\text{m}$  and 20  $\mu\text{m}$  and the SMPS measures particles in the range of 0.01  $\mu\text{m}$  to 1.0  $\mu\text{m}$ .

After the ambient condition tests were completed, the 25- $\mu\text{m}$  and 35- $\mu\text{m}$  fail-safe filters were selected for evaluation at hot gas conditions. Sets of three fail-safe filters were wrapped with Saffil™ mat and then stuffed into 304 stainless steel shells. Ceramic fiber rope seals wrapped with stainless steel mesh screen were compressed onto both ends of the fail-safe filters and held in place by welding retaining rings into the ends of the stainless steel shells. The assemblies were then shipped to the EERC for incorporation into the hot gas test system.

Western subbituminous coal from the Powder River Basin was mixed with Plum Run dolomite prior to feeding the combustor for the 25- $\mu\text{m}$  fail-safe filter test and the first week of the 35- $\mu\text{m}$

fail-safe filter test. Filter vessel ash was also mixed into the feed solids in order to increase the ash-throughput so that the number of backpulse cycles could be maximized over the test period. A Pittsburgh #8 bituminous coal was used during the last two weeks of the 35- $\mu\text{m}$  fail-safe filter test to increase ash-throughput and pulse cycles. The filter vessel operating conditions were nominally 815°C (1,500°F) operating temperature, 826 kPa (120 psig) process pressure, 0.72 m<sup>3</sup>/min (25 scfm) gas flow rate, 2.5 kg/hr (5.5 lb/hr) coal feed rate, and 2 cm/s (4 ft/min) candle filter face velocity.

For the 25- $\mu\text{m}$  fail-safe filter test, one 3M (SiC fiber composite with SiC coating) and two Schumacher (Model Tulle DIA SCHUMALITH DS 10-20 T 60/40x500) candle filters were used. The nitrogen backpulse pressure was set to 34.3 kPa (5 psig) between the fail-safe filters and the candle filters. The system was operated normally for about 130 hours before the 3M candle filter was “broken” by drilling a hole in its side. The system was then operated for an additional 20 hours in this condition. On-line particulate sampling was performed on the filter system outlet using the APS and SMPS instruments. It was necessary to reduce the sample gas pressure using an orifice and cool it using a 6:1 ratio of dry filtered dilution air before running through the instruments.

For the 35- $\mu\text{m}$  fail-safe filter test, one 3M and one Schumacher candle filters were used. The gas backpulse system was set up identically to that for the 25- $\mu\text{m}$  fail-safe filter test. The system was operated normally for about 320 hours before one of the candle filters was “broken”. The system was then operated for an additional 25 hours in this condition. Outlet particulate sampling was conducted as before.

## Results

The pulse profiles for the candle filter with and without an in-line fail-safe filter are shown in Figure 3. Without the fail-safe filter, the peak pressure was approximately 41.3 kPa and the pulse duration was about 800 ms. The mechanical pulse duration is typically longer than the electronic pulse duration in hot gas filter regeneration systems. With the in-line 35- $\mu\text{m}$  fail-safe filter, the peak pressure was maintained at 41.3 kPa (6 psig) by increasing the compressed air tank pressure by 10% to 84.8 kPa (12.3 psig). The pulse duration was essentially the same but the pressure rise during the pulse was not as rapid when the pressurized air was pulsed through the fail-safe filter and then the candle. It was unclear how this would affect candle regeneration. The pulse profile data indicated that the amount of backpulse gas consumed would be the same in both cases but an additional cost would be incurred by higher gas compression costs for the case of candles operating in tandem with fail-safe filters.

Figure 4 shows the pressure drop across the candle filter over many filtration cycles both with and without a 35- $\mu\text{m}$  fail-safe filter in tandem with the candle filter. The backpulse pressure was 41.3 kPa (6 psig) in both cases. The initial forward flow pressure drop at ambient conditions was increased by less than 10% by incorporation of the fail-safe filter. The candle filter pressure drop after cleaning without the fail-safe filter was quite stable. With the fail-safe filter, the candle pressure drop appeared to stabilize after a few cycles indicating that candle filter regeneration was possible. Somewhat more stable clean filter pressure drop was obtained by utilizing 68.9 kPa (10 psig) pulse pressures. Based on this data and the short-term successful testing of the CeraMem 25- $\mu\text{m}$  fail-safe filter at Siemens-Westinghouse (Sanjana et al., 2002), it was decided to start at 35 to 40 kPa ( 5 to 6 psig) pulse pressure and increase as necessary during the hot gas tests at the EERC.

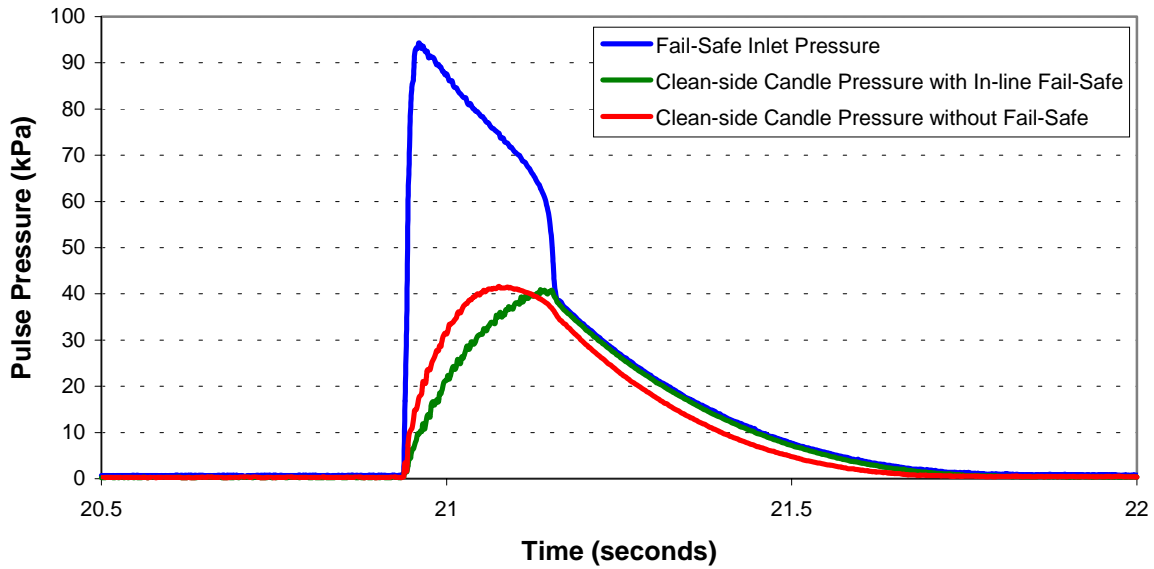


Figure 3. Pulse Pressure Profiles as a Function of Time for the Candle Filter and Candle/Fail-safe Filter Tandem (10 kPa = 1.45 psi)

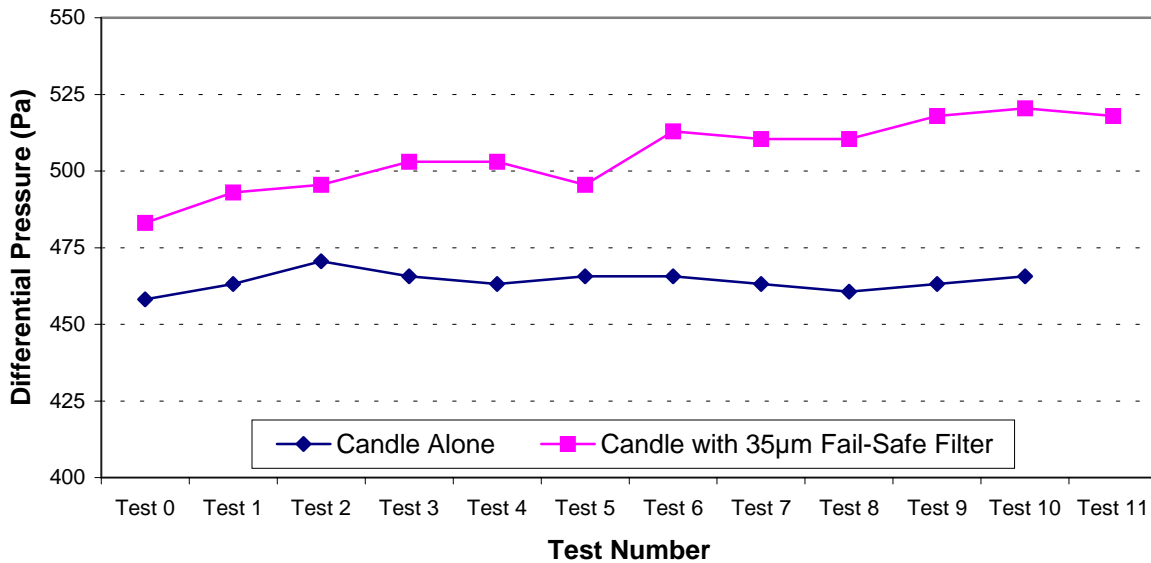


Figure 4. Candle Filter Pressure Drop After Cleaning With and Without the In-line Fail-safe Filter Over Several Filtration Cycles (1" wc = 250 Pa)

Ambient particle challenge tests were conducted at the EERC for each of the fail-safe filter pore sizes. For the three different candle filter scenarios, the particle loadings for each of the fail-safe filter types are listed in Table 1. For the normal candle operation scenario, the average time weighted particle size was less than 4  $\mu\text{m}$  and for the leaking candle condition it was 8  $\mu\text{m}$ . Inlet particle size was not measured for the broken candle scenario. The actual particle loading for the “normal” candle filter operation scenario is higher than expected for well-operating candle filters and was used only for an approximation in these tests.

Table 1. Average Particle Loading for Ambient Particle Challenge Tests at the EERC

Fail-safe Pore Size	Time Weighted Average Particle Loading (ppm)		
	Normal Candle	Leaking Candle	Broken Candle
25 $\mu\text{m}$	6	22	> 500
35 $\mu\text{m}$	7	12	> 500
45 $\mu\text{m}$	3	25	> 500

Figures 5 - 9 depict the performance of the 25- $\mu\text{m}$ , 35- $\mu\text{m}$ , and 45- $\mu\text{m}$  fail-safe filters at ambient conditions. Figures 5, 6, and 7 are plots of pressure drop versus time for the fail-safe filters being operated at normal, leaking, and broken candle conditions, respectively. Figures 7, 8, and 9 are plots of outlet particle concentration versus time for the same conditions.

At all particle load conditions, the 25- $\mu\text{m}$  fail-safe filter increases in pressure drop much more rapidly than either the 35- $\mu\text{m}$  or 45- $\mu\text{m}$  fail-safe filters. At normal candle outlet particle concentration, the 25- $\mu\text{m}$  filter takes over an hour to plug while at broken candle conditions it plugs almost instantaneously. Under leaking candle conditions, the 25- $\mu\text{m}$  filter takes about 15 minutes to plug. The 35- $\mu\text{m}$  and 45- $\mu\text{m}$  fail-safe filters plug much more slowly than the 25- $\mu\text{m}$  fail-safe filter. At normal candle operating conditions, the larger pored materials start to plug after 3-4 hours while at broken candle conditions these same materials take 15 minutes or more to reach the same “plugged” pressure drop as the 25- $\mu\text{m}$  fail-safe filter. At leaking candle conditions, the plugging time was extended to an hour or more. In addition, the pressure drop of the 25- $\mu\text{m}$  fail-safe filter was not recoverable after plugging while the larger pored filters had at least part of their pressure drop recovered by backpulsing at 34.5 kPa (5 psig).

The particle outlet concentrations from the fail-safe filters show similar trends. At normal and leaking candle particle load conditions, the 25- $\mu\text{m}$  fail-safe filter’s outlet concentration is less than 1 ppm except for just after the backpulse. Under broken candle particle load conditions, the 25- $\mu\text{m}$  fail-safe filter emitted between 2.5 and 13.5 ppm of particulate. For the 35- $\mu\text{m}$  and 45- $\mu\text{m}$  fail-safe filters, the filters plugged (i.e., less than 1 ppm outlet particle concentration) in 3-4 hours under normal candle filter conditions and about 30 minutes under leaking candle conditions. The larger pored materials did not completely plug off under broken candle conditions and showed no indication of plugging over the course of the tests.

Based on the ambient conditions tests at the EERC, the 25- $\mu\text{m}$  and 35- $\mu\text{m}$  fail-safe filters were selected for hot gas testing. The 25- $\mu\text{m}$  fail-safe filter was selected because it was the most likely to plug off quickly and stay plugged off during backpulse regeneration of a leaking or broken candle. However, if there were a low but acceptable concentration of particulate that bypassed the candle filters (e.g., much less than 1 ppm) then the 25- $\mu\text{m}$  fail-safe filters may irreversibly increase to an unacceptable level of pressure drop in a period of time shorter than

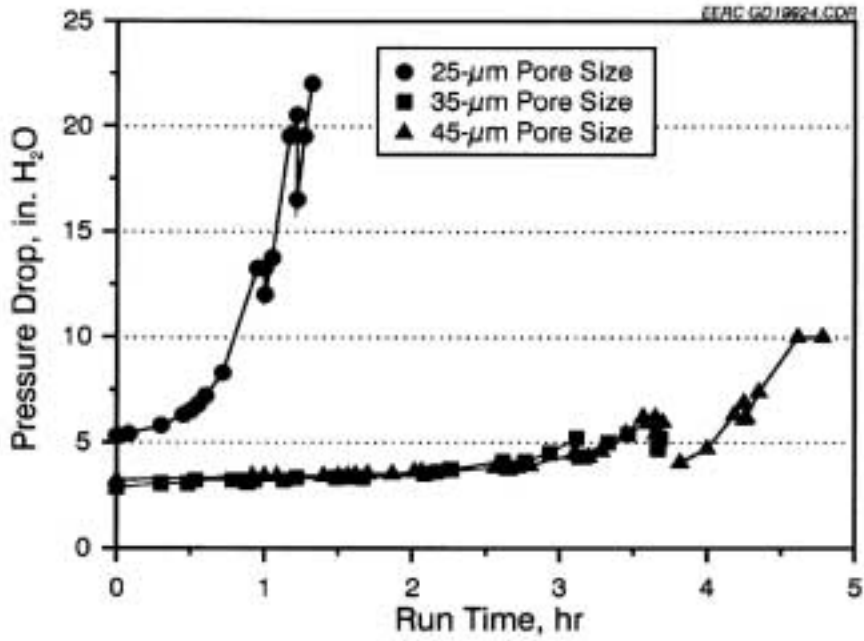


Figure 5. Pressure Drop Across the Fail-safe Filters as a Function of Time for Tests Simulating a Normally Operating Candle Filter (1" wc = 0.25 kPa)

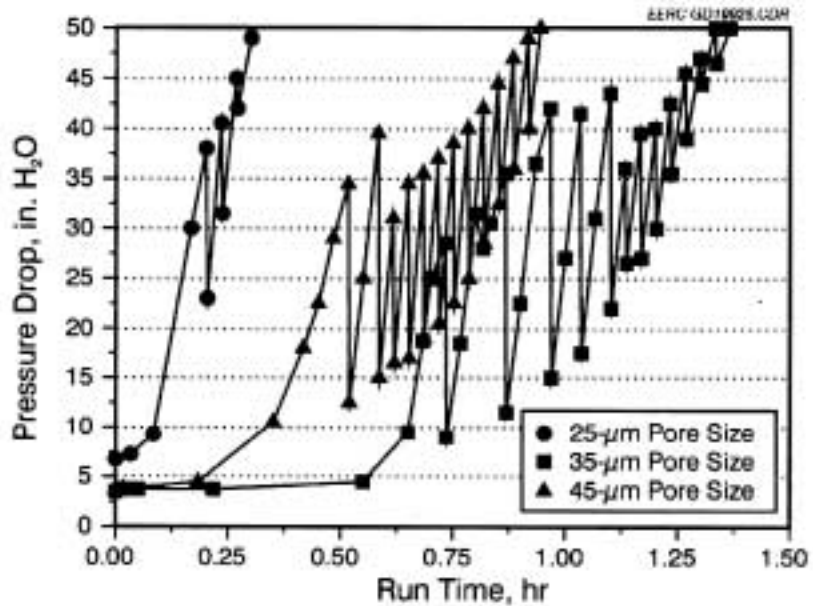


Figure 6. Pressure Drop Across the Fail-safe Filters as a Function of Time for the Tests Simulating a Leaking Candle Filter (1" wc = 0.25 kPa)



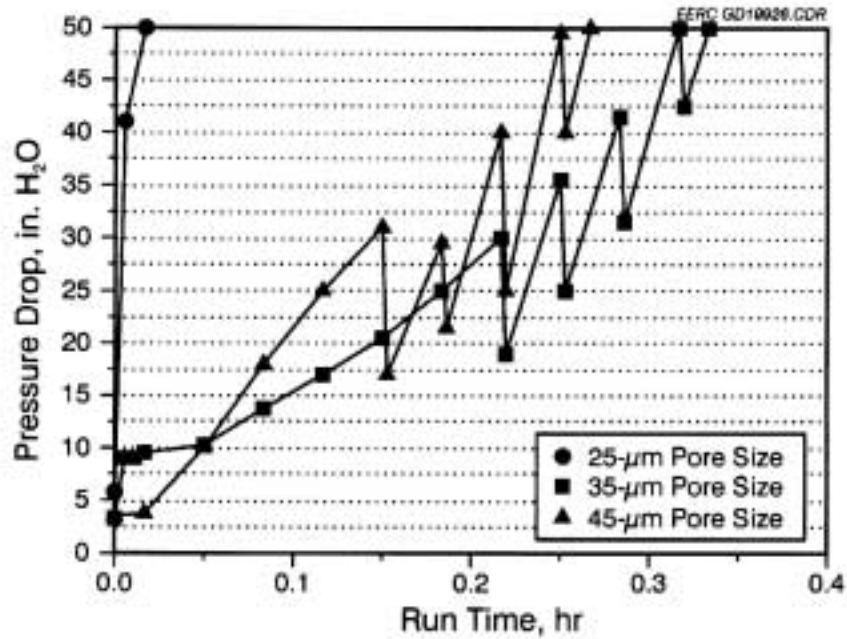


Figure 7. Pressure Drop Across Fail-safe Filters as a Function of Time for Tests Simulating Operation Downstream of a Broken Candle Filter (1" wc = 0.25 kPa)

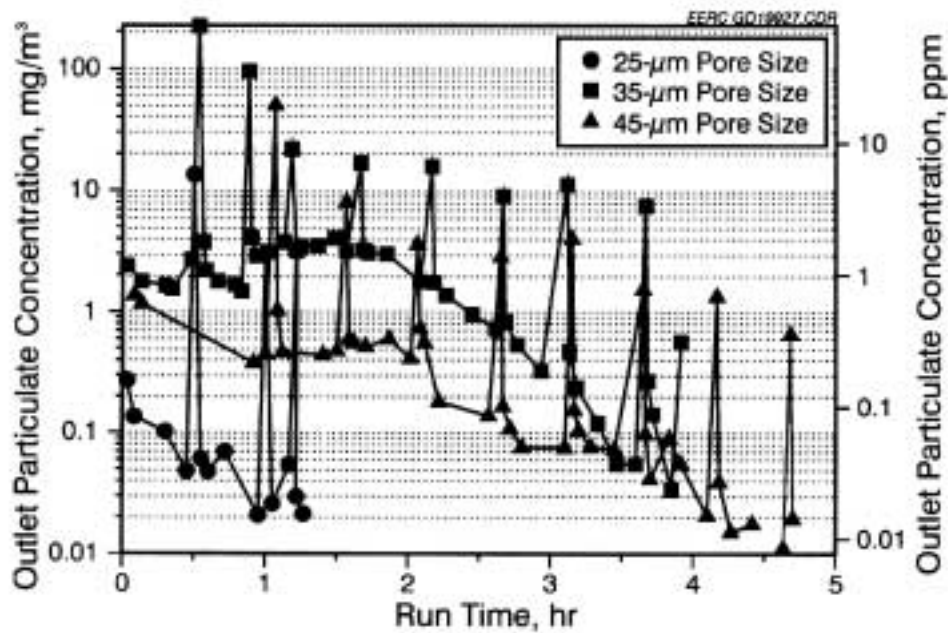


Figure 8. Outlet Particulate Concentrations as a Function of Time for the Fail-safe Filters During Tests Simulating a Normally Working Candle Filter

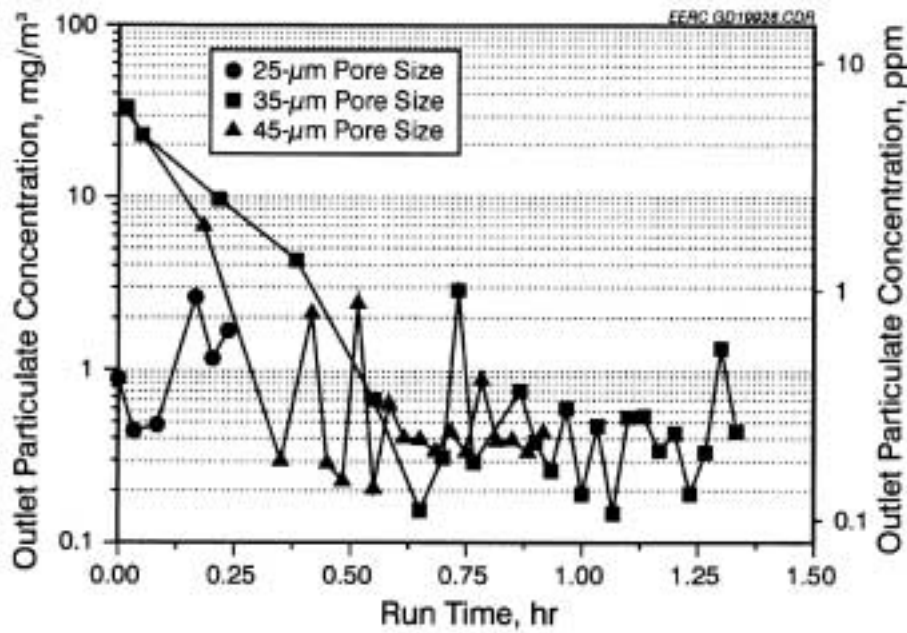


Figure 9. Outlet Particulate Concentrations as a Function of Time for the Fail-safe Filters During Tests Simulating a Leaking Candle Filter

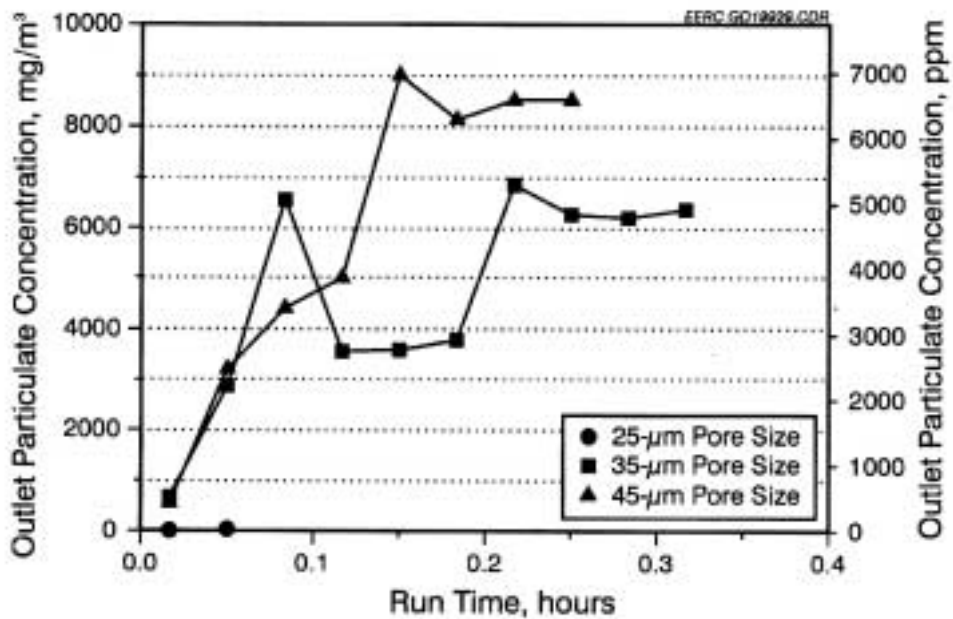


Figure 10. Outlet Particulate Concentrations as a Function of Time for the Fail-safe Filters During Tests Simulating a Broken Candle Filter

desired for commercial filtration system operation. For this reason, the 35- $\mu\text{m}$  fail-safe filter was also selected for hot gas testing. This material will plug off much more slowly than the 25- $\mu\text{m}$  fail-safe but very low levels of particulate will be less likely to cause fail-safe pressure drop increase in short periods of time. The hot gas tests were designed to determine which pore size material would be the lead candidate for long-term testing at the Power Systems Development Facility in Wilsonville, AL.

Some of the results of the particulate-laden hot gas tests on the 25- $\mu\text{m}$  fail-safe filters are included in Figures 11 and 12 and Table 2. Figure 11 is a plot of vessel pressure drop as a function of test time. Figure 12 is a plot of outlet particle concentration versus time before and after one of the candle filters was broken. Table 2 shows the pressure drop of each fail-safe over the first 130 hours of the hot gas test.

Figure 11 shows how the filtration vessel performed throughout the test. Each of the three candle/fail-safe tandems were backpulsed in rapid succession at a pressure drop of 6.2 kPa (25" wc) every 3-4 hours. After each round of backpulses, the pressure drop returned to approximately 4.0 kPa (16" wc). The system lined out at these conditions, and there did not appear to be any increase in the required regeneration frequency. This strongly indicates that the candle filters were being cleaned well over the course of this test.

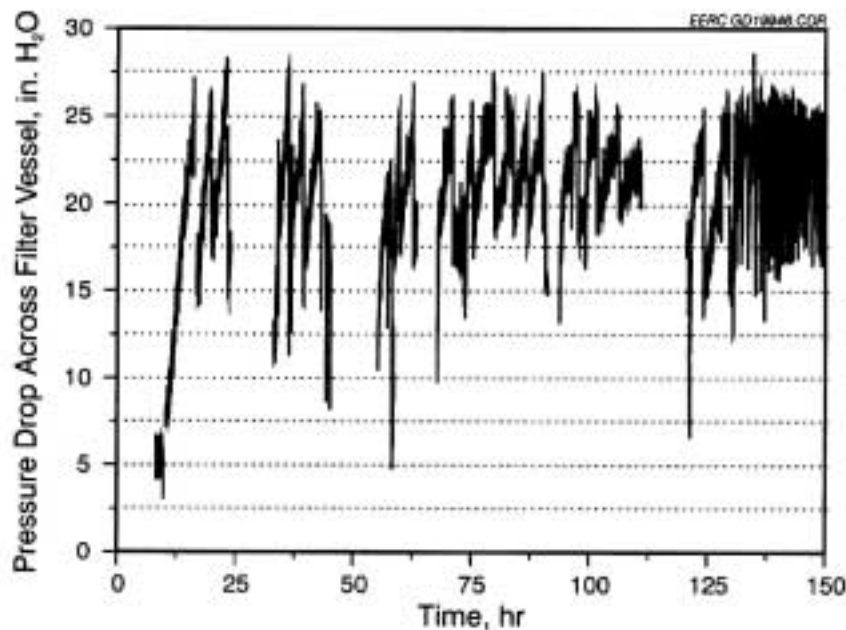


Figure 11. Pressure Drop Across the Filter Vessel Tube Sheet as a Function of Time for the 25- $\mu\text{m}$  Fail-safe Filter Hot Gas Test (1" wc = 0.25 kPa)

Figure 12 indicates that there is no change in particle outlet concentration from the filter vessel after the candle was broken. Prior to breaking the candle, the particle outlet concentration was between 0.01 and 0.1 ppm during normal operation and spiked up to almost 1 ppm during regeneration. After the filter was broken, the outlet concentration spiked up to about 1 ppm but then came back down, essentially the same as when the candle was regenerated. These results were relatively constant for each of the pulse cycles after the candle was broken and show that the 25- $\mu$ m filter operates successfully as a fail-safe device.

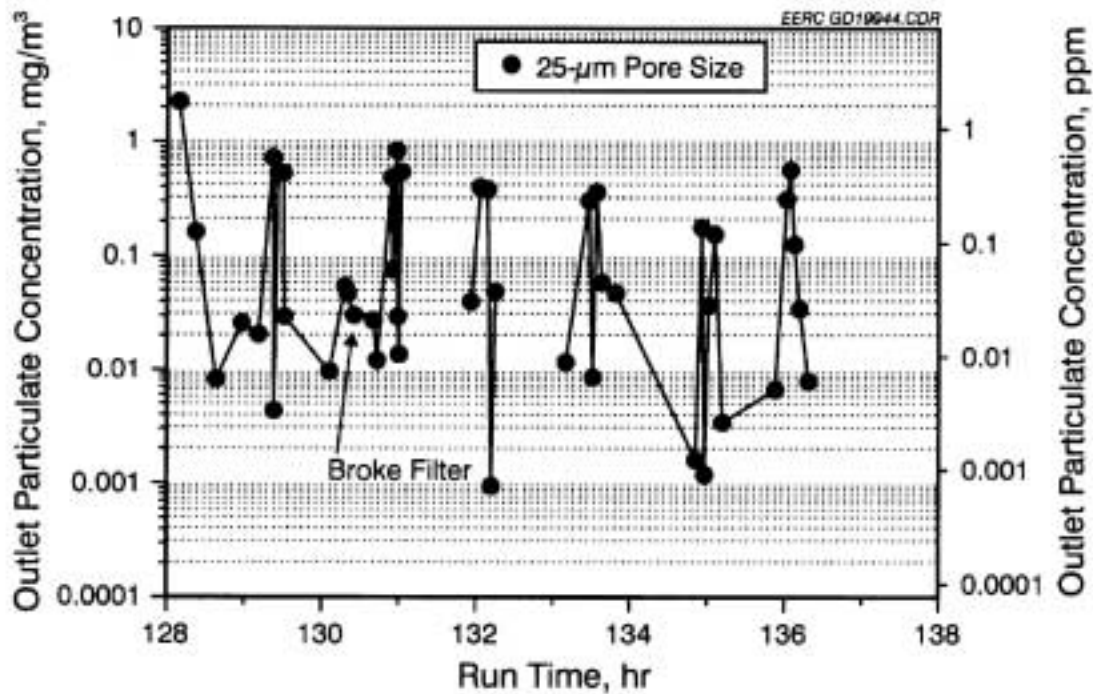


Figure 12. 25- $\mu$ m Fail-safe Filter Outlet Particulate Concentration Before and After the Candle Filter was Broken

Table 2 shows the pressure drop of each of the fail-safe filters over the course of the test. There was variation in the pressure drops across the fail-safes presumably due to differences in flow across each of the candle/fail-safe tandems. The fail-safe filter pressure drops were about 25% to 40% of the total vessel pressure drop at the time of backpulse regeneration. This was higher than desired but may be acceptable if other fail-safe benefits outweigh the cost of lower downstream process pressure. However, it is not clear whether the 25- $\mu$ m fail-safe filters will plug during long-term normal candle filter operation since two of the fail-safe filters had increased pressure drops and the other had decreased pressure drop over the course of the test. Additional testing will be needed to show if long-term plugging of these fail-safe filters is a problem.

Table 2. Pressure Drops of 25- $\mu$ m Fail-Safe Filters Tested at Hot Gas Conditions

Fail-safe Number	Pressure Drop at Start of Test kPa (" wc)	Pressure Drop After 130 Hours kPa (" wc)
1	2.2 (9)	2.7 (11)
2	1.4 (5.5)	1.7 (7)
3	1.7 (7)	1.6 (6.5)

Figures 13-15 plot some of the results from the hot gas test with the 35- $\mu\text{m}$  fail-safe filters. Figure 13 is a plot of filter vessel pressure drop and fail-safe pressure drop as a function of time for the entire test. The lower line is the plot of the fail-safe pressure drop. Figure 14 is a plot of the pressure drop across the filter vessel and the failsafe as a function of time for the period prior to and just after the filter was broken. Figure 15 is a plot the outlet particulate mass concentration as a function of time before and after the candle filter was broken.

Figure 13 shows the performance of the filter vessel and the fail-safe for the entire test. During the first week of testing there were problems with the coal feed system and the backpressure control valve. These problems were fixed before the second week of testing. A Pittsburgh #8 coal was also used for the last two weeks to increase the ash through put to the filter vessel. At one point during the first week the filters were pulsed as the filter vessel static pressure was being dropped for maintenance. It appeared this caused a candle filter failure because when the system was brought back on-line the fail-safe pressure drop increased from 1.2 kPa (5" wc) to over 2.2 kPa (9" wc). At the end of the first week, the filters were inspected with a boroscope and looked undamaged. For the next two weeks of testing, the pressure drop across the fail-safe lined out at 1.7 kPa (7" wc). For the first week the filters were backpulsed approximately every 3 to 4 hours, the backpulse sequence triggered at 6.2 kPa (25" wc). The filters cleaned down to approximately 3.7 kPa (15" wc). During the second and third weeks the filters were pulsed approximately every 90 minutes and cleaned down to approximately 3.2 kPa (13" wc). The operating pressure drop over the last two weeks was very stable indicating that the filters were being adequately cleaned. The pressure drop across the fail-safes was also very stable for the last two weeks. A linear regression was run on the data for each week, and the data were inconclusive as to whether the pressure drops across the fail-safes were increasing with time.

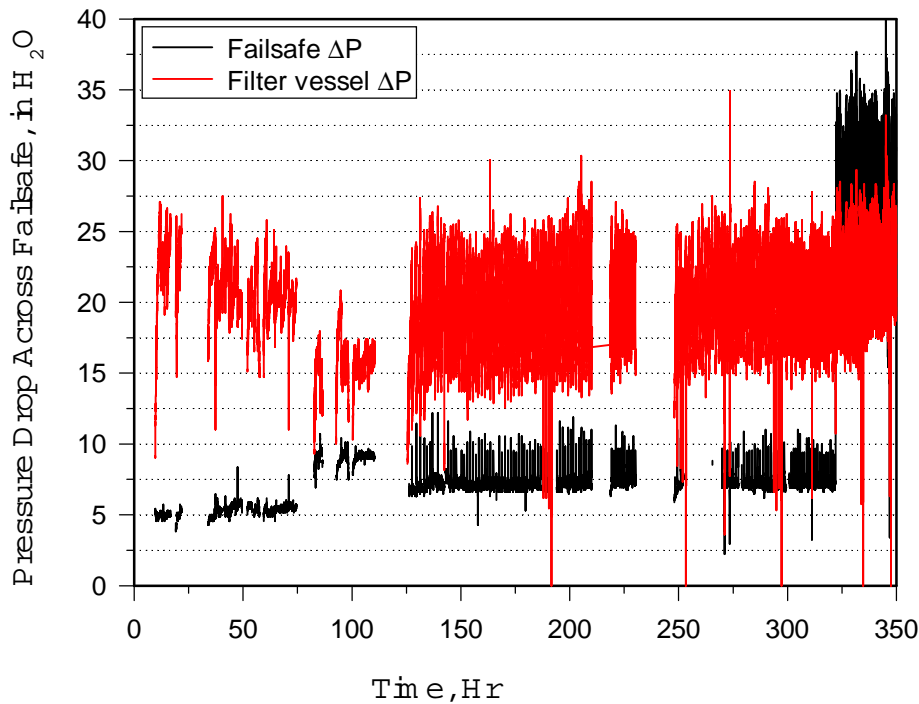


Figure 13. Filter Vessel and 35- $\mu\text{m}$  Fail-safe Filter Pressure Drop Over Duration of Hot Gas Test (1" wc = 0.25 kPa)

Figure 14 shows that the fail-safe plugged off very quickly after the candle filter was broken. There was a difference between the filter vessel and fail-safe pressure transducer readings. When the system was depressurized the fail-safe pressure drop was 0.1 kPa (0.4" wc) and the filter vessel was 0.0 Pa. The pressure transducers do not give negative readings, so it appears the filter vessel pressure transducer was reading about 1.5 kPa (6" wc) low. If this was the case, the fail-safe pressure drop was about 22% of the total vessel pressure drop at the time of backpulse regeneration, which is slightly higher than desired.

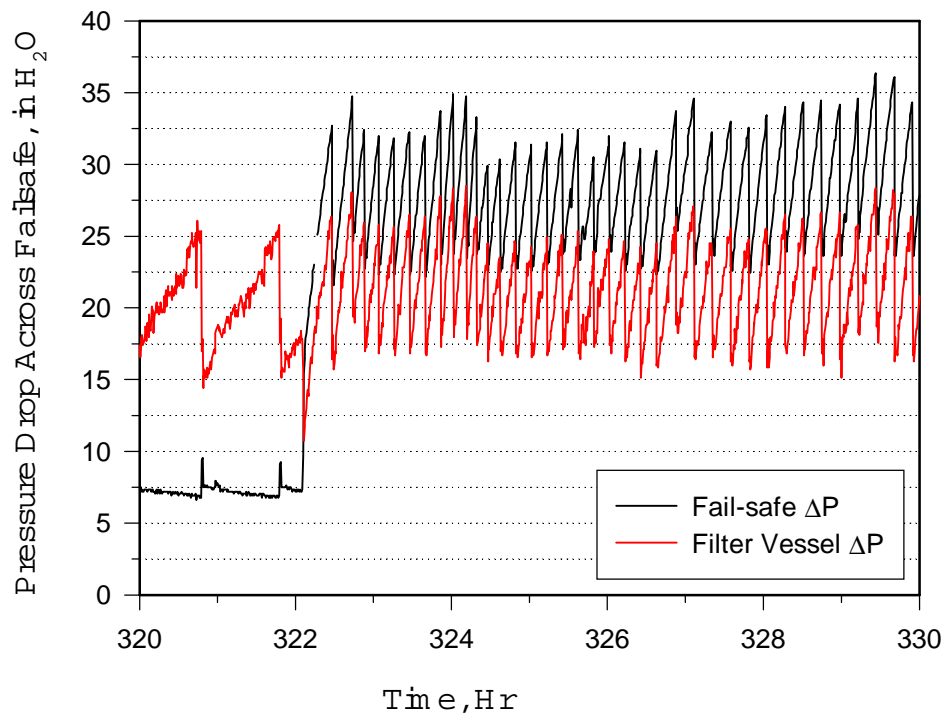


Figure 14. Filter Vessel and 35- $\mu$ m Fail-safe Filter Pressure Drop Before and After Breaking the Candle Filter (1" wc = 0.25 kPa)

The particulate mass concentration at the outlet of the filter vessel varied between 0.002 ppm and 12 ppm prior to breaking the candle filter. The variability during a given day was due to pulse regeneration and there may also have been a slight increase after switching from the subbituminous to the bituminous coal. The subbituminous coal was roughly 5% ash and the bituminous coal was 12% ash on a mass basis. Figure 15 shows that after the filter was broken the outlet mass loading increased to approximately 20 ppm with spikes as high as 45 ppm. This indicates that although the 35- $\mu$ m fail-safe plugged off with regard to pressure, it leaked particulate after the candle filter was broken.

### Future Activities

Activities are planned on two separate fronts. First, CeraMem plans on supplying candle filter fail-safe devices to the Power Systems Development Facility (PSDF) in Wilsonville, AL for long-term evaluation at conditions of interest to DOE. This will occur through Siemens Westinghouse and/or directly from CeraMem to the PSDF. Second, CeraMem will further explore approaches to lower the pressure drop of the 25- $\mu$ m fail-safe filters and develop procedures that can be scaled up for production of these devices.

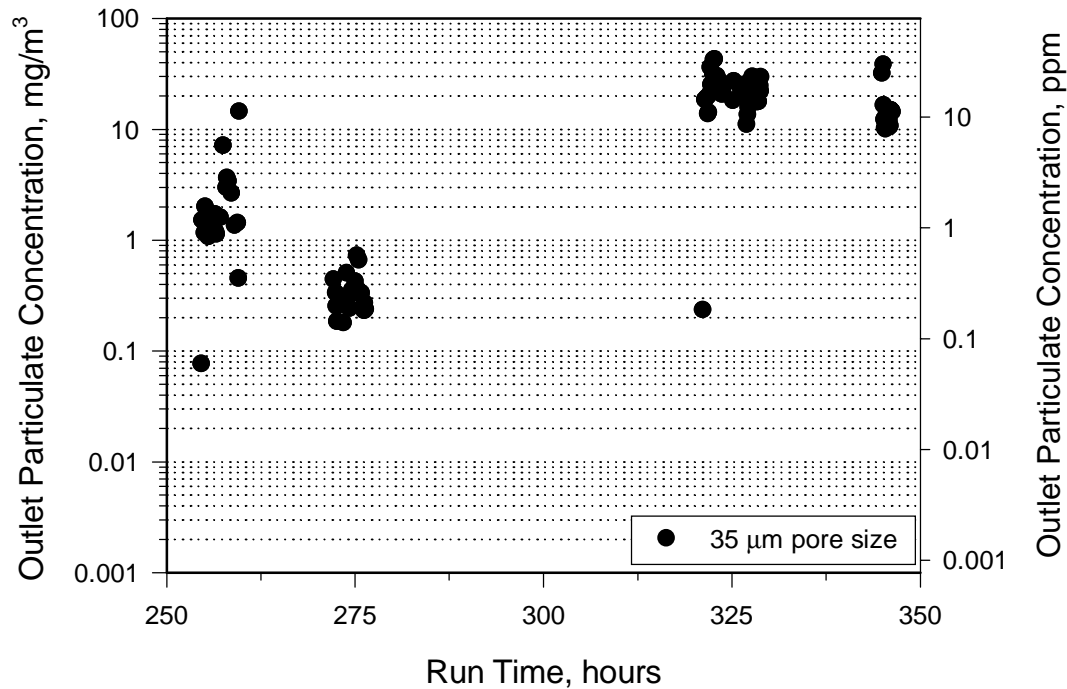


Figure 15. 35-µm Fail-safe Filter Outlet Particulate Concentration Before and After Breaking the Candle Filter

## Conclusions

The CeraMem fail-safe filter device was evaluated and successfully tested at both the EERC at the University of North Dakota and Siemens Westinghouse Power Company. Data from the EERC indicate that the 25-µm (nominal pore size) fail-safe filter operates well as a candle filter protection device over the time period tested. The candle filters were regenerable when operated in tandem with the fail-safe filters and when one candle filter was broken, the fail-safe irreversibly captured the particulate leaking through the damaged candle. Pressure drop across the 25-µm fail-safe filter was higher than targeted but the effect has to be evaluated relative to the benefits of protecting other candle filters in the system and other downstream equipment. The 35-µm and 45-µm (nominal pore size) fail-safe filters leaked too much particulate to operate as fail-safe devices. Based on this work, Siemens Westinghouse has supplied a 67-mm-diameter, 25-µm fail-safe filter from CeraMem to the Power Systems Development Facility in Wilsonville, AL, for tests with a full-size candle filter starting in June 2002.

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