ADVANCED HYBRID PARTICULATE COLLECTOR, A NEW CONCEPT FOR AIR TOXICS AND FINE-PARTICLE CONTROL

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Introduction

This project was funded under the U.S. Department of Energy (DOE) Program Research and Development Announcement (PRDA) No. DE-RA22-94PC92291, Advanced Environmental Control Technologies for Coal-Based Power Systems Phases I and II, and addresses Topic 7: Advanced Concepts for Control of Fine Particles and Vapor-Phase Toxic Emissions. In addition to DOE, the project team includes the Energy & Environmental Research Center (EERC) as the primary contractor, Allied Environmental Technologies Company as a subcontractor, and W.L. Gore & Associates, Inc., as a technical and financial partner.

The primary technologies for state-of-the-art particulate control are fabric filters (baghouses) and electrostatic precipitators (ESPs). However, each of these has limitations that prevent it from achieving ultrahigh collection of fine particulate matter. A major limitation of ESPs is that the fractional penetration of 0.1- to 1.0-µm particles is typically at least an order of magnitude greater than for 10-µm particles, so a situation exists where the particles that are of greatest health concern are collected with the lowest efficiency. Fabric filters are currently considered to be the best available control technology for fine particles, but they also have weaknesses that limit their application. Emissions are dependent on ash properties and typically increase if the air-to-cloth (A/C) ratio is increased. In addition, many fabrics cannot withstand the rigors of high-SO_3 flue gases, which are typical for bituminous fuels. Fabric filters may also have problems with bag cleanability and high pressure drop, which has resulted in conservatively designed, large, costly baghouses.

A new concept in particulate control is being developed, called an advanced hybrid particulate collector (AHPC), which combines the best features of ESPs and baghouses in a manner that has not been done before. The AHPC concept consists of a combination of fabric filtration and electrostatic precipitation in the same box, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of the dust to the hopper (see Figure 1).

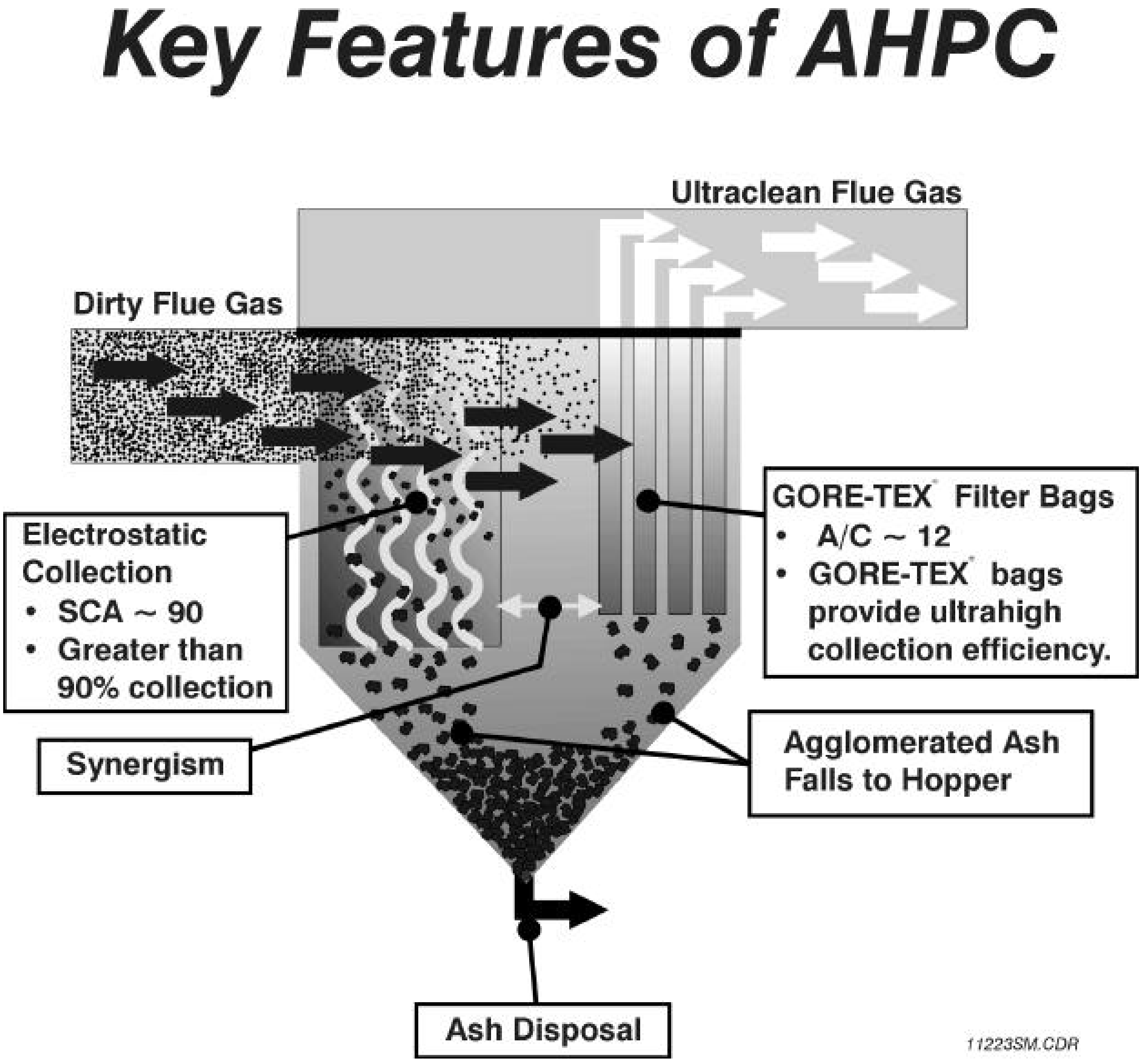

Figure 1. AHPC concept.

Objective

The objective of the project is to develop a highly reliable AHPC that can provide >99.99% particulate collection efficiency for all particle sizes from 0.01 to 50 µm, is applicable for use with all U.S. coals, and is cost-competitive with existing technologies.

Approach

State-of-the-art ESPs can provide 99.9% total mass particulate control, but collection efficiency for 0.1- to 1.0-µm particles is significantly lower. Current fabric filters can achieve 99.9% collection efficiency on large coal-fired boilers, and when advanced fabrics are employed or when flue gas conditioning is used, fabric filters can achieve 99.99% collection efficiency with no significant deterioration in performance for sizes from 0.1 to 1.0 µm. Fabric filters cannot routinely achieve that level of control for all coals within economic constraints, and studies have shown that collection efficiency is likely to deteriorate significantly when the face velocity is increased.[1,2] An approach to make fabric filters more economical is to employ smaller baghouses that operate at much higher A/C ratios. The challenge is to increase the A/C ratio for economic benefits and to achieve ultrahigh collection efficiency at the same time. To achieve high collection efficiency, the pores in the filter media must be effectively bridged (assuming they are larger than the average particle size). With conventional fabrics at low A/C ratios, the residual dust cake serves as part of the collection media, but at high A/C ratios, only a very light residual dust cake is acceptable, so the cake cannot be relied on to help achieve high collection efficiency. The solution is to employ a sophisticated fabric that can ensure ultrahigh collection efficiency and endure frequent high-energy cleaning. In addition, the fabric should be reliable under the most severe chemical environment likely to be encountered (such as high SO_3). Such a fabric is already commercially available but is not widely applied to coal-fired boilers because of its higher cost compared to conventional fabrics. The fabric is GORE-TEX® membrane on GORE-TEX® felt which can achieve very high collection efficiencies at high A/C ratios. GORE-TEX® membrane filter bags consist of a microporous, expanded polytetrafluoroethylene (PTFE) membrane laminated to a felted or fabric backing material. Consequently, even fine, nonagglomerating particles do not penetrate the filter, resulting in significant improvements in filtration efficiency, especially for submicron particles. This fabric is also rugged enough to hold up under rigorous cleaning, and the all-PTFE construction alleviates concern over chemical attack under the most severe chemical environments. Although GORE-TEX® membrane filter media is more expensive than conventional fabrics, the much smaller surface area required for the AHPC will make the use of GORE-TEX® membrane filter media economical.

Successful operation of fabric filters at high A/C ratios is a challenge because of the increasing difficulty in controlling pressure drop. The size of fabric filters and bag-cleaning frequency are determined by pressure drop. If we assume viscous flow, pressure drop across a fabric filter is dependent on three components:

$$\Delta P = K_f V + K_2 W_R V + K_2\, C\, V^2\, t\, /\, 7000 \qquad \text{[Eq. 1]}$$

where:

ΔP = differential pressure across baghouse tube sheet (in. of water)
K_f = fabric resistance coefficient (in. of water-min/ft)
V = face velocity or A/C ratio (ft/min)
K_2 = specific dust cake resistance coefficient (in. of water-ft-min/lb)
W_R = residual dust cake weight (lb/ft^2)
C = dust loading (grains/acf)
t = filtration time between bag cleaning (min)

The first term in Eq. 1 accounts for the pressure drop across the fabric. For conventional fabrics, the pore size is quite large and the corresponding fabric permeability is high, so the pressure drop across the fabric alone is negligible. To achieve better collection efficiency, the pore size can be significantly reduced, without making the fabric resistance a significant contributor to pressure drop. The GORE-TEX® fabric allows for this optimization by providing a microfine pore structure while maintaining a sufficient fabric permeability to permit operation at high A/C ratios. The second term in Eq. 1 accounts for the pressure drop contribution from the permanent residual dust cake that exists on the surface of the fabric. For operation at high A/C ratios, the bag cleaning must be sufficient to maintain a very light residual dust cake and ensure that the pressure drop contribution from this term is not unreasonable (e.g., up to 50% of the total.) The third term in Eq. 1 accounts for the pressure drop contribution from the dust accumulated on the bags since the last bag cleaning. K_2 is determined primarily by the fly ash particle-size distribution and the porosity of the dust cake. Typical K_2 values for pulverized coal (pc)-fired fly ash range from about 3 to 15 in. of water-ft-min/lb, but may, in extreme cases, cover a wider range. Of interest is the maximum A/C ratio at which a baghouse can be expected to operate reliably for the range of K_2 values likely to be encountered. All three terms in Eq. 1 may require increased bag-cleaning frequency with increased A/C ratio, but the third term dictates the minimum bag-cleaning interval. From Eq. 1, with a face velocity of 2 ft/min, a dust loading of 3 grains/acf, and a ΔP increase of 4 in. of water, the required bag-cleaning frequency is greater than 100 min when K_2 is less than 23 in. of water-ft-min/lb. In a reverse-gas utility baghouse, cleaning takes place off-line and may require several minutes per compartment and more than an hour to clean all of the compartments. This is one reason why most reverse-gas baghouses are conservatively designed for a face velocity of 2 ft/min. To ensure that adequate cleaning time is available when K_2 is not known demands a conservative approach. On the other hand, if K_2 were known to be less than 6 in. of water-ft-min/lb, Eq. 1 implies that a face velocity of 4 ft/min could be employed. However, to date, reverse-gas baghouses have not been designed much above face velocities of 2 ft/min because an effective method of controlling K_2 has not existed and excessive residual dust cake weight is frequently encountered.

Pulse-jet baghouses have the potential to operate at much higher face velocities because bags can be cleaned more often and adequate pulse energy can usually prevent excessive residual dust cake buildup. Assuming that bag life is acceptable and that low particulate emissions can be maintained through the use of advanced filter materials, face velocities much greater than 4 ft/min should be possible. Assuming 10 min is the minimum cleaning cycle time for a pulse-jet baghouse, a face velocity of 4 ft/min is adequate to handle a dust with a K_2 greater than 30 in. of water-ft-min/lb (see Figure 2). If K_2 is less than 15 in. of water-ft-min/lb, the face velocity can be

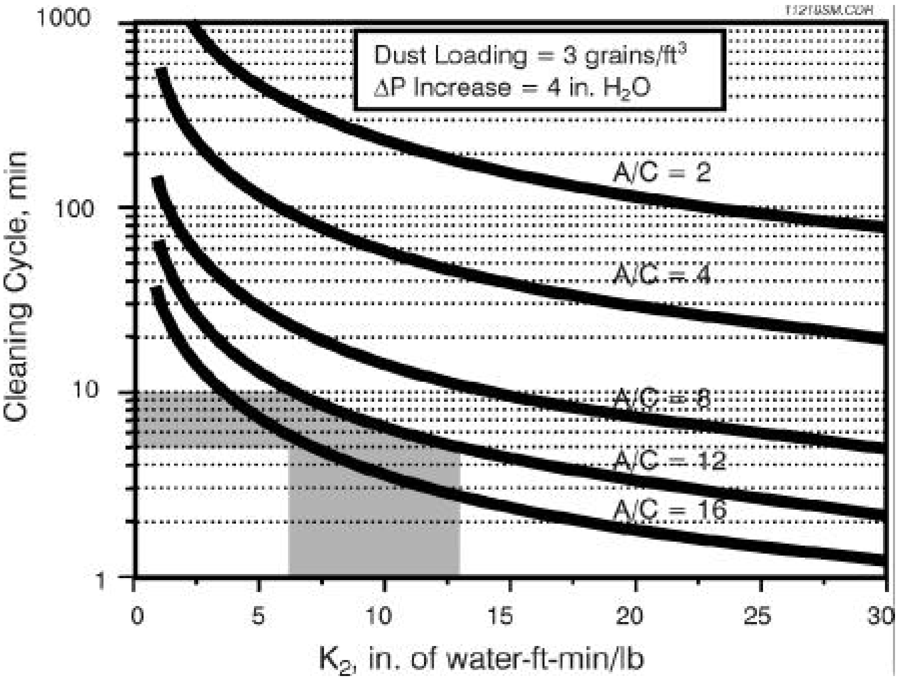

Figure 2. Cleaning cycle requirements for full dust loading.

increased to 8 ft/min. For many dusts, this might be possible with conventional systems. Doubling face velocity again to 16 ft/min implies that K_2 would have to be less than 4 in. of water-ft-min/lb. This is lower than most typical K_2 values; however, through the use of flue gas conditioning, it may be possible. Increasing the face velocity beyond 16 ft/min appears to be stretching the theoretical limit for a full dust loading of 3 grains/scf. However, if the actual dust loading that reached the fabric were reduced by a factor of 10, the allowable K_2 would increase by a factor of 10, while keeping the cleaning interval at 10 min. If a process could collect 90% of the dust before it reached the bags, a K_2 of up to 40 would be allowable at an A/C ratio of 16 ft/min and a 10-min bag-cleaning interval (see Figure 3.) The K_2 for almost all coal fly ash dusts is likely to be less than 40, even allowing for some size fractionating between the precollected dust and the dust that reaches the bags. Therefore, a theoretical basis exists to operate a fabric filter at a reduced dust loading and high A/C ratio with a reasonable bag-cleaning frequency.

The preceding analysis is valid as long as the dust can be effectively removed from the bags and transferred to the hopper without significant redispersion and re-collection. With pulse-jet cleaning, heavy residual dust cakes are not typically a problem because of the fairly high cleaning energy that can be employed. However, the high cleaning energy can lead to significant redispersion of the dust and subsequent re-collection on the bags. The combination of a very high-energy pulse and a very light dust cake tends to make the problem of redispersion much worse. The barrier that limits operation at high A/C ratios is not so much the dislodging of dust from the bags as it is transferring the dislodged dust to the hopper. Therefore, any improvement that facilitates transfer of the dislodged dust to the hopper without re-collection on the bags will greatly enhance operation at higher A/C ratios. The AHPC achieves enhanced bag cleaning by

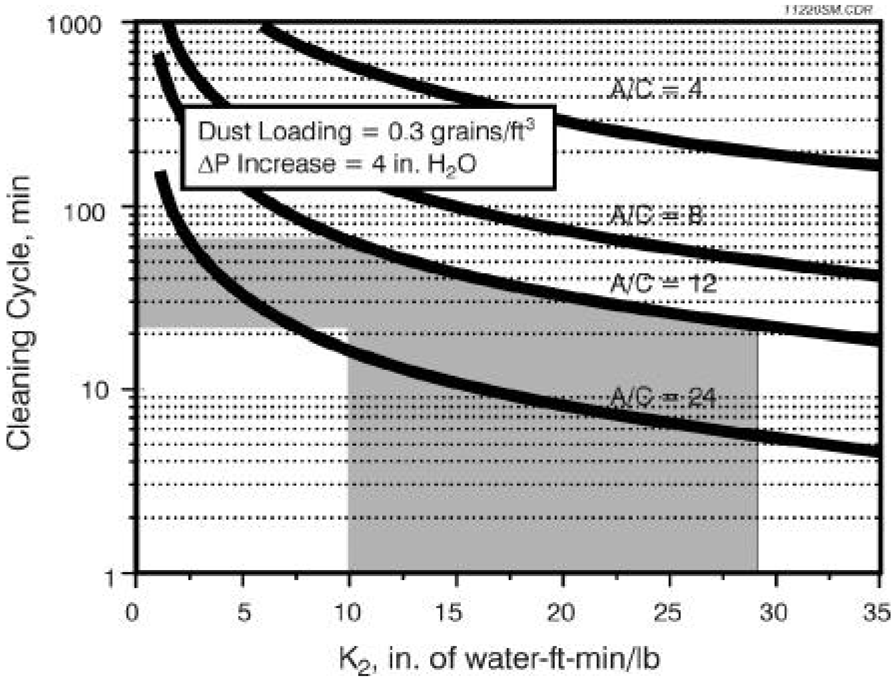

Figure 3. Cleaning cycle requirements for reduced dust loading.

employing electrostatic effects to precollect a significant portion of the dust and to facilitate moving the dust from the bags to the hopper.

While very large ESPs are required to achieve >99% collection of the fine particles, a small ESP can remove 90% to 95% of the dust. Including rapping puffs, 90% to 95% collection efficiency can be achieved with full-scale precipitators with a specific collection area (SCA) of less than 100 ft^2 of collection area/1000 acfm.[3] In the AHPC concept, the goal is to employ only enough ESP plate area to remove approximately 90% of the dust. Similarly, the cloth area should be held to a minimum to keep the cost reasonable. If the fabric is operated at an A/C ratio of 12 ft/min and the SCA of the ESP is 83, the filtration collection area will be the same as the plate collection area. A SCA of 83 should be sufficient to easily remove at least 90% of the dust. (Note that an alternative definition of SCA is simply the inverse of A/C ratio multiplied by 1000.) A baghouse operating at an A/C ratio of 2 ft/min has the same collection area as an ESP with a SCA of 500. Both of these are typical of the size of collectors employed for new power plants. Therefore, an AHPC operating at an A/C ratio of 12 ft/min and a SCA of 83 would offer an 83% reduction in fabric area over a conventional baghouse operating at 2 ft/min and an 83% reduction in plate area over a conventional ESP with a SCA of 500. The combined collection area in the AHPC would be 67% lower than either the conventional baghouse or the ESP.

Project Description

The work was organized into three tasks for Phase I and three additional tasks for Phase II. Task 1 was for the purpose of project management and reporting for Phase I. Task 2 was for the purpose of design, construction, and installation of a 200-acfm working AHPC model. Task 3 consisted of the experimental work completed under Phase I. Phase II is structured similarly to Phase I, in that Task 1 includes project management activities; Task 2 includes design, construction, and installation of a 9000-acfm pilot AHPC, and Task 3 will include field-testing with the pilot AHPC.

The experimental work for Phase I was divided into three subtasks that followed a logical sequence from initial shakedown of the AHPC model through 100-hr proof-of-concept tests. The first formal tests were cold-flow tests with air for the purpose of adjusting the bag-cleaning parameters to achieve the best interaction between the ESP and filtration zones. Reentrained dust (fly ash) was injected into the carrier air upstream of the AHPC, operating at an A/C ratio of 12 ft/min. The cold-flow tests were completed in September 1996.

The 8-hour verification tests with real flue gas produced from coal combustion were completed in December of 1996. The fractional collection efficiency and system pressure drop were determined as a function of the main independent variables, coal type and A/C ratio. The 100-hr tests were conducted to evaluate the longer-term operability of the AHPC over multiple cleaning cycles. Extensive inlet and outlet particulate measurements were completed to thoroughly document the performance of the AHPC as a function of time. These tests were completed in April 1997.

Phase II of the project has now begun, with a primary objective of demonstrating the AHPC at a much larger scale. A 9000-acfm field demonstration AHPC will be designed and constructed at the EERC and then installed on a slipstream of a full-scale power plant. Some additional 200-acfm optimization tests are planned during the summer of 1998 to aid in the design of the field unit. Design and construction of the field unit is scheduled for the period of September 1998 through March 1999, followed by field tests beginning in the spring of 1999 and running for at least a 6-month period.

8-hour Test Results Firing Absaloka Subbituminous Coal

The objectives of the 8-hr tests on coal were to evaluate:

- The AHPC under real flue gas conditions firing Absaloka subbituminous coal.
- AHPC operability with the ESP alone and all bags removed.
- AHPC operability with ESP off and all bags removed.
- On-line versus off-line cleaning.
- A/C, 3.66 and 4.8 m/min (12 and 16 ft/min).

Operational variables for the Absaloka-fired tests are found in Table 1, and average concentrations for flue gas constituents are found in Table 2.

With the ESP on and bags removed, the particulate emissions ranged between 0.2840 to 0.3728 g/m^3 (0.1240 to 0.1628 gr/scf). Efficiency was calculated using the average of the inlet dust loading of previous 8-hr tests and the outlet dust loadings of Test PTC-AB-574. The AHPC efficiency with the ESP on without bags was about 95%. This result was encouraging because 90%–95% efficiency for the ESP was the basis for the original concept.

TABLE 1

Test Parameters for Absaloka Coal

Date	10-17-96	11-5-96	11-6-96	11-7-96	11-7-96
PTC[1] Test	PTC-AB-574	PTC-AB-575	PTC-AB-576	PTC-AB-577	PTC-AB-578
Air/Cloth, m/min	NA	3.7	3.7	4.8	4.8
Inlet Temp., °F	149	149	149	149	149
On-Line and Off-Line Cleaning	NA	Off	On	Off	On
Type of Bag	NA	PTFE Set #6	PTFE Set #6	PTFE Set #6	PTFE Set #6
No. of Bags in Use	0	4	4	3	3

[1] Particulate test combustor.

TABLE 2

Average Flue Gas Analysis for Tests PTC-AB-572 to PTC-AB-578*

O_2, % by volume	CO_2, % by volume	H_2O, % by volume	SO_2, ppm	NO_x, ppm
4.0–4.5	14–16	9.5–10.0	720	700

* Dry basis except for H_2O.

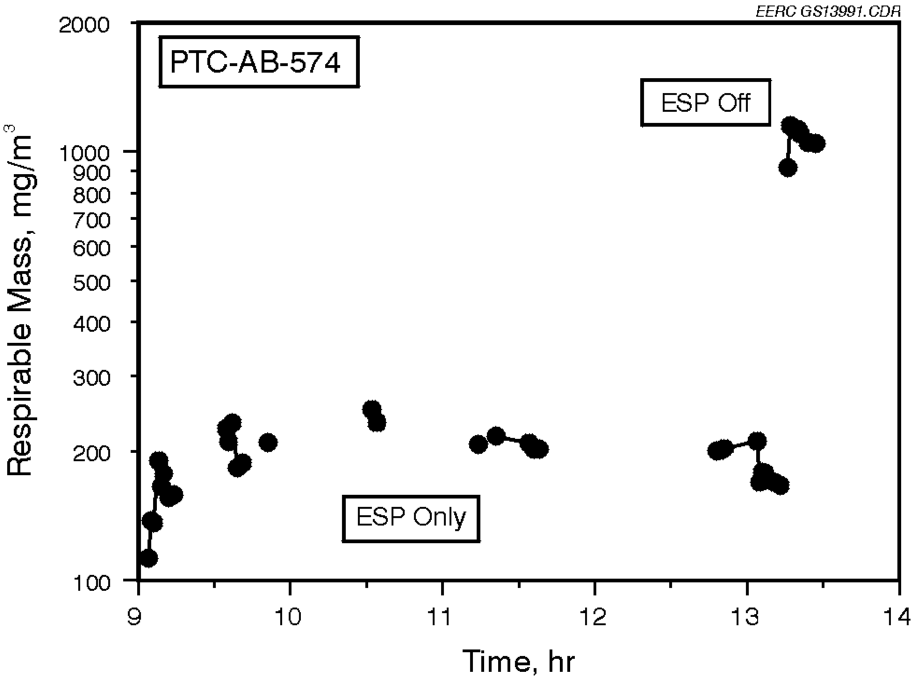

Figure 4. APS data for Test PTC-AB-574.

APS respirable mass data, presented in Figure 4, show the AHPC outlet particulate emission when the ESP was on and when the ESP was off. With the ESP on, the APS showed an average outlet emission of about 220 mg/m^3. The average respirable mass emission when the ESP was off was approximately 1300 mg/m^3. The ESP by itself achieved 83% collection efficiency of respirable mass compared to 95% total mass. However, this result is encouraging because it shows that the ESP removes a substantial portion (83%) of the fine-particle mass.

The dP versus time graph for Test PTC-AB-575 is presented in Figure 5. The change in dP before and after cleaning was 1.2 to 1.4 kPa (5.0 to 5.5 in. W.C.) through 8 hr of testing. Figure 6 shows the pulse interval steadying out at about 70 min.

In Test PTC-AB-576, the cleaning mode of the AHPC was set in the on-line mode. The dP versus time graph is shown in Figure 7. The change in dP before and after cleaning was at 1.1 to 1.2 kPa (4.5 to 5.0 in. W.C.), with pulse intervals averaging around 70 min (see Figure 8).

Since Runs 575 and 576 both demonstrated excellent pressure drop control and at least a 70-min bag-cleaning interval, the decision was made to increase the A/C ratio from 3.7 m/min (12 ft/min) to 4.9 m/min (16 ft/min). For the first test (AB-577) at 4.9 m/min (16 ft/min), cleaning was off-line. Changes in the dP before and after the cleaning cycle ranged from 0.6 to 0.5 kPa (2.5 to 2.0 in. W.C.) at steady state, as shown in Figure 9. Pulse intervals decreased from 20 min at the beginning of the test to around 10 min at steady state, as shown in Figure 10.

In Test PTC-AB-578, the AHPC was cleaned in the on-line cleaning mode at an A/C of 4.8 m/min (16 ft/min). Similar to the off-line cleaning mode, changes in the dP before and after the cleaning cycle ranged from 0.6 to 0.5 kPa (2.5 to 2.0 in. W.C.) at steady state. The dP information for the test is shown in Figure 11. Pulse intervals ranged slightly higher at 10–12 min between cleaning cycles. Figure 12 presents the pulse interval versus time graph.

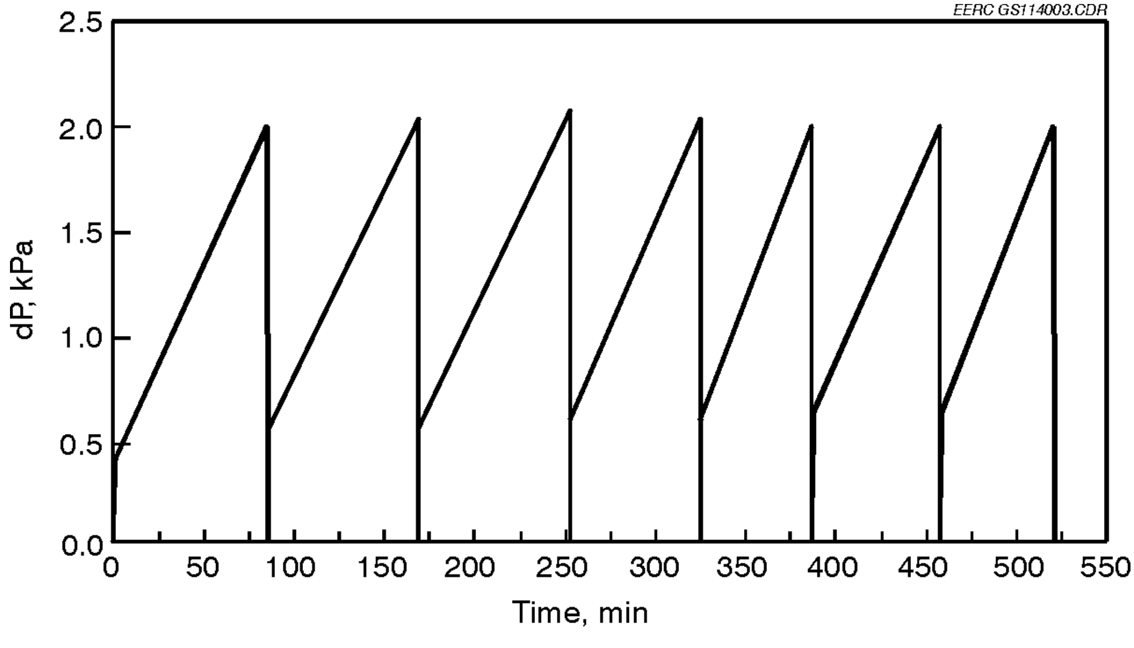

Figure 5. Pressure drop as a function of time for Test PTC-AB-575 with off-line cleaning.

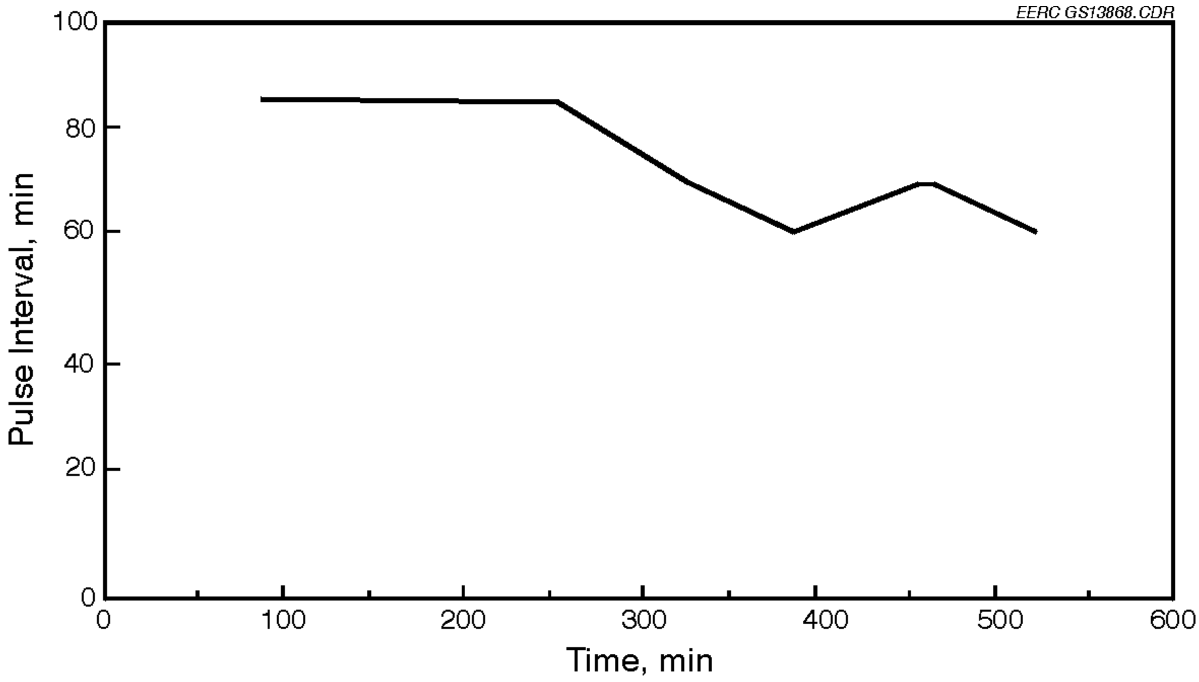

Figure 6. Pulse interval as a function of time for Test PTC-AB-575 with off-line cleaning.

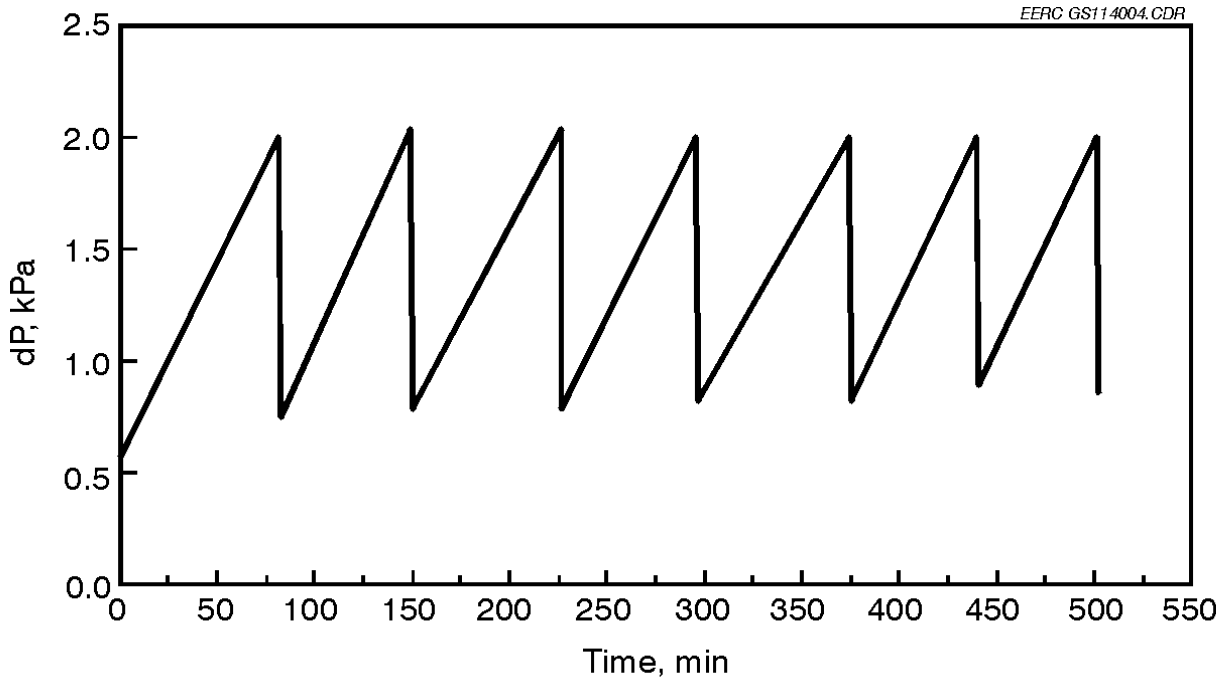

Figure 7. Pressure drop as a function of time for Test PTV-AB-576 with on-line cleaning.

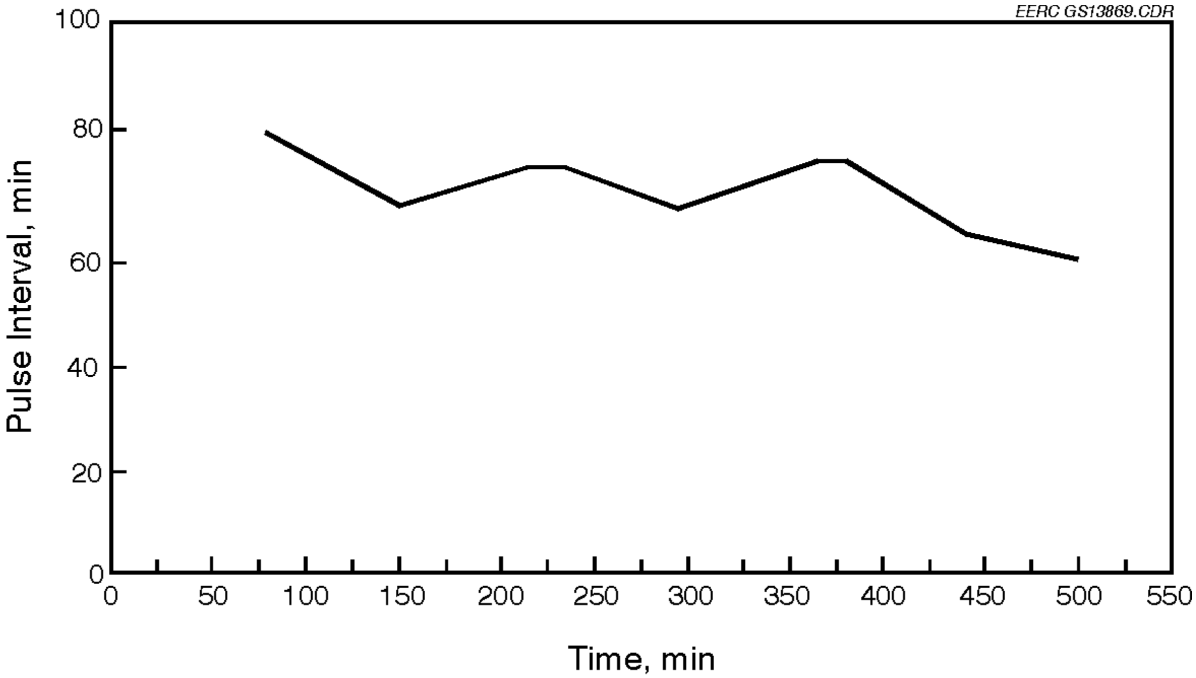

Figure 8. Pulse interval as a function of time for Test PTC-AB-576 with on-line cleaning.

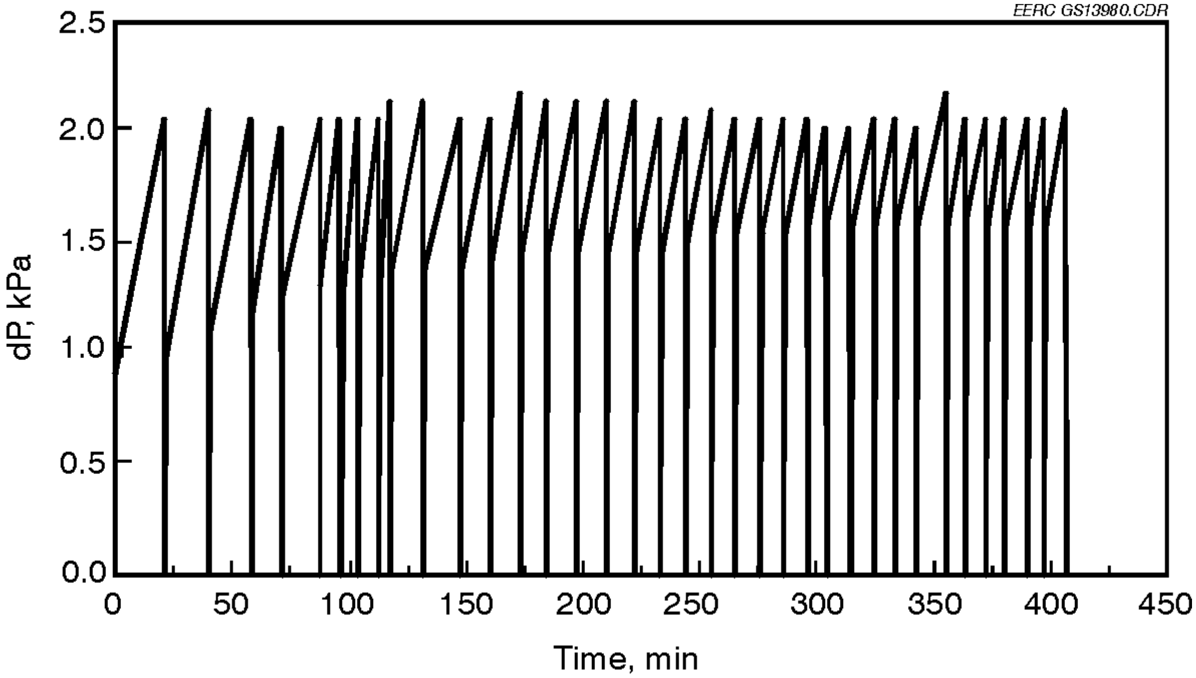

Figure 9. Pressure drop as a function of time for Test PTC-AB-577 with off-line cleaning at 16 ft/min.

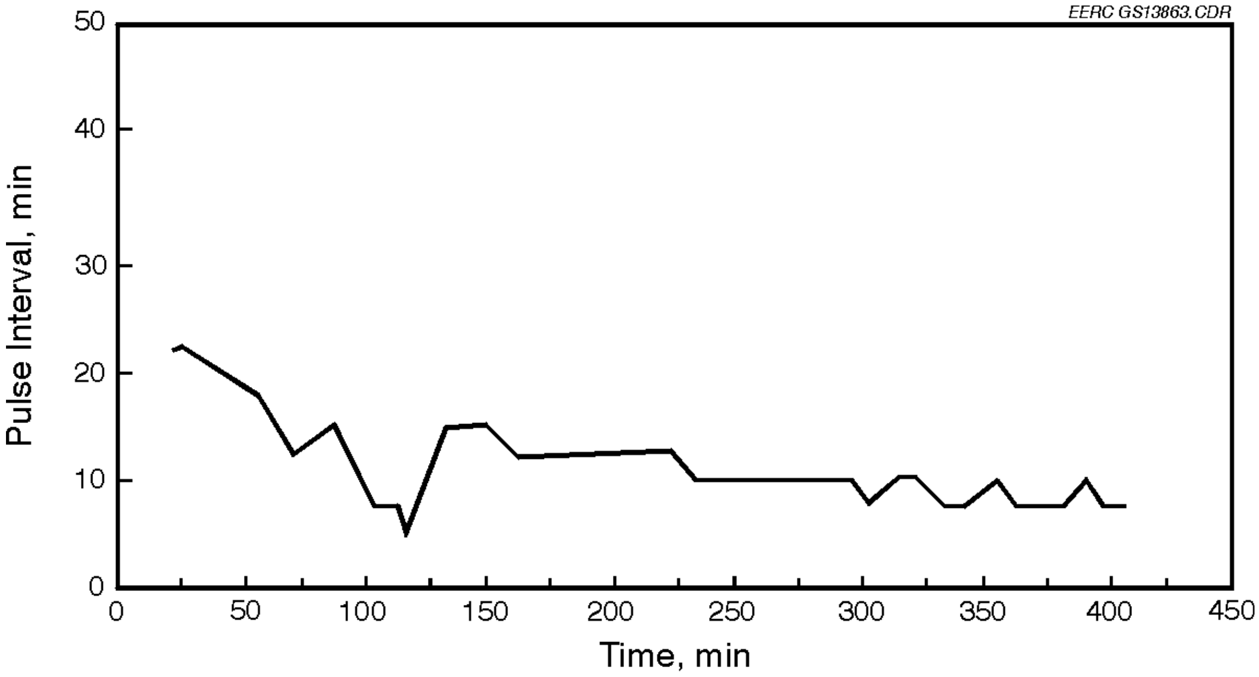

Figure 10. Pulse interval as a function of time for Test PTC-AB-577 with on-line cleaning at 16 ft/min.

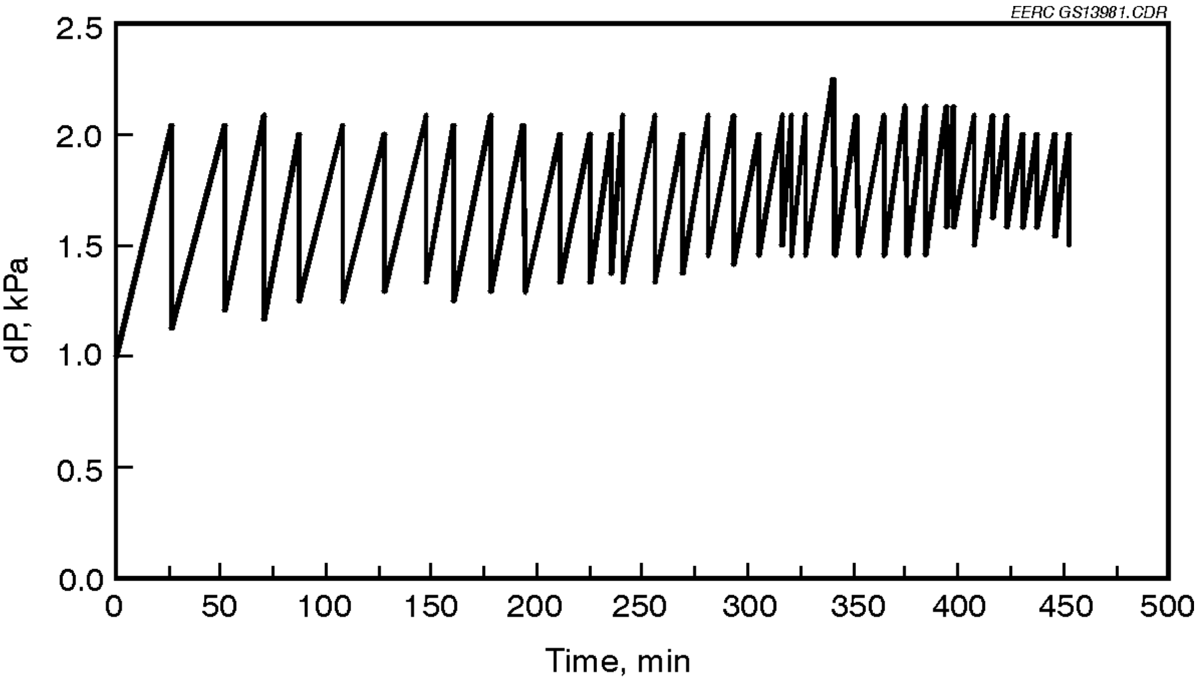

Figure 11. Pressure drop as a function of time for Test PTC-AB-578 with on-line cleaning at 16 ft/min.

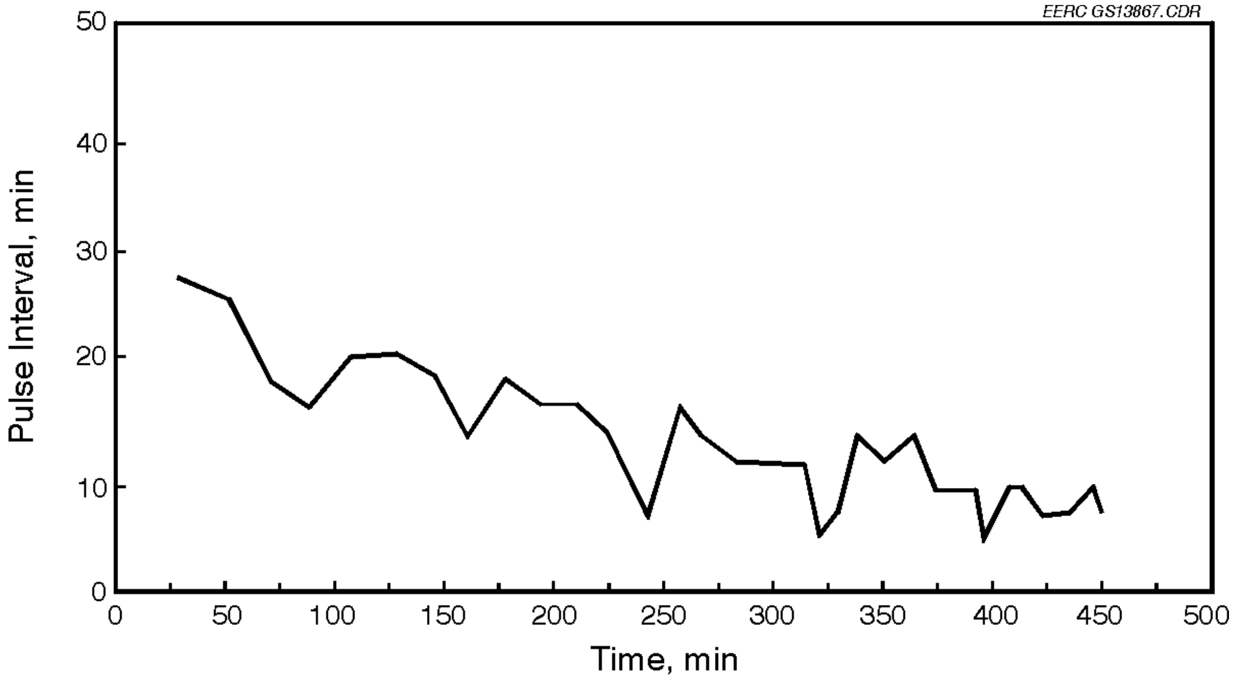

Figure 12. Pulse interval as a function of time for Test PTC-AB-578 with on-line cleaning at 16 ft/min.

The 4.8 m/min (16 ft/min) tests were successful because the pressure drop was readily controlled with a pulse-cleaning intensity of 10–15 min. However, this is a smaller interval than would be anticipated based on the sole effect of increasing A/C ratio. The theoretical increase in dP as a function of time is proportional to the square of the face velocity, so at 4.8 m/min (16 ft/min), the theoretical cleaning interval should be 0.56 times the interval at 3.7 m/min (12 ft/min). Based on the 60–70-min pulse interval observed at 3.7 m/min (12 ft/min), the theoretical interval is about 35 min compared to the 10–15-min interval observed. This indicates additional nonideal effects occurred, which may be the result of a nonideal geometry of the AHPC for the higher A/C ratio tests.

Particle-Size Distributions and Fractional Efficiency. Figure 13 plots the combined inlet particulate concentration and the combined outlet particulate concentration for Test PTC-AB-573. The inlet concentration is a combination of data from the scanning mobility particle sizer (SMPS), multicyclone sampling, and Coulter counter analysis of the first cyclone catch.

While the multicyclone collects all of the inlet ash, it divides it into only six fractions: the five cyclones and a backup filter. The cut point of the first cyclone is typically about 7 μm (depending on temperature and sampling flow rate), and the cut point of the last cyclone is typically about 0.7 μm. To obtain more information about the entire particle-size distribution requires further resolution of the first cyclone catch (which usually contains about 80% of the total mass) and the particles collected on the backup filter. A convenient method to expand the resolution of the first cyclone catch is to perform a Coulter counter analysis on it and to combine the data. Since no

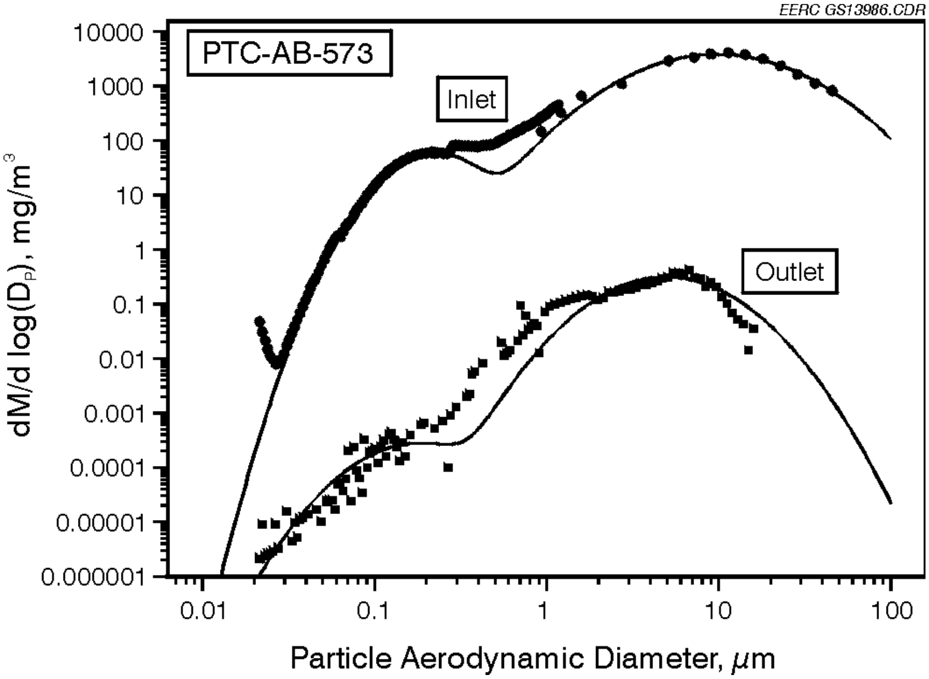

Figure 13. Inlet and outlet particle-size distributions particulate for Test PTC-AB-573.

instrument is available to accurately determine the distribution of the multicyclone filter catch, the submicron distribution is most conveniently determined by direct sampling of the flue gas with the SMPS. At the outlet, the dust concentration is too low to use mutlicyclones or the Coulter counter, so the distribution is obtained by combining data from the SMPS and the aerodynamic particle sizer (APS).

A number of assumptions and conversions were made to combine the data into single particle-size distributions. First, the particle sizes for the SMPS and Coulter data were converted to aerodynamic diameters, which is a function of the geometric particle diameter and the particle density. It was assumed that the SMPS diameter was roughly equal to the geometric diameter, and the density for all particles was 2.5 g/cm^3. Once the particle size was represented in terms of aerodynamic diameter, the mass concentration (mg/m^3) for each channel (size) was calculated. The Coulter counter data represent the first cyclone catch of the multicyclone, which is the upper end of the particle-size distribution. The Coulter counter data are provided in two forms: number of particles counted in each channel and percent of total mass in each channel. The mass concentration was calculated based on the percentage of total mass in each channel, the total mass in the cyclone catch, and the volume of gas sampled. The results are in mg/m^3. The SMPS mass concentration is calculated from the particle geometric diameter, assumed density, and the dilution-corrected-number concentration for each channel. The mass distribution for the multicyclone sample is calculated directly from the data. Once the mass concentration was calculated, it was plotted (on a dM/d log [Dp] basis) as a function of particle size.

The outlet concentration is a combination of the SMPS and APS data collected at the outlet of the AHPC under various operating conditions. The outlet SMPS data are processed the same as the inlet data. The APS mass concentration can be downloaded as a function of aerodynamic diameter. The APS software automatically corrects for dilution and requires an input value for density which is measured with a helium-air pycnometer. The APS samples represent the particulate emissions for an entire cleaning cycle or multiple cycles. This gives a representation of the true collection efficiency for the AHPC.

8-hour Test Results Firing Blacksville Bituminous

The objectives of these tests were to evaluate:

- Operability with real flue gas firing a bituminous coal.
- On-line versus off-line cleaning.
- The effects of NH_3/SO_3 conditioning.

Operating the AHPC using Blacksville bituminous was somewhat more difficult because of the higher carbon content of the ash. The loss-on-ignition (LOI) value for the ash was 2.3% by weight. The unburned carbon in the ash tended to accumulate on the surface of electrical insulators, forming a conductive path which led to arcing between the high-voltage electrode and ground. Flue gas concentrations are given in Table 3.

TABLE 3

Average Flue Gas Analysis* for Tests PTC-BV-579 to PTC-BV-584

O_2, % by volume	CO_2, % by volume	H_2O, % by volume	SO_2, ppm	SO_3, ppm	NO_x, ppm
4–4.5	13–14.5	8	1650–1800	11.1	525–600

* Dry basis except for H_2O.

For Run 581, the bag-cleaning mode was set for off-line. Figure 14 shows dP versus time for the test. During the first cleaning cycle, the dP jumped from 1.2 to 72.5 kPa (5 to >10 in. W.C.) This was due to a slug of ash and unburned carbon flooding the AHPC compartment. Visual inspection revealed arcing occurring across various places. At that point, it was determined that the fuel gun supplying the mix of air and coal into the combustor was obstructed. The gun was cleaned, and the dP-versus-time graph shows more consistent steady-state performance. The before and after changes in dP were about 0.8 to 0.9 kPa (3.0–3.5 in. W.C.) The pulse interval- versus-time information is found in Figure 15. During the steady-state period, the pulse interval ranged from 20 to 25 min.

Run BV-582 was performed using the same bags, but bag cleaning was on-line. The change in dP before and after a cleaning cycle ranged from 0.5 to 0.6 kPa (2.0 to 2.5 in. W.C.) A graph

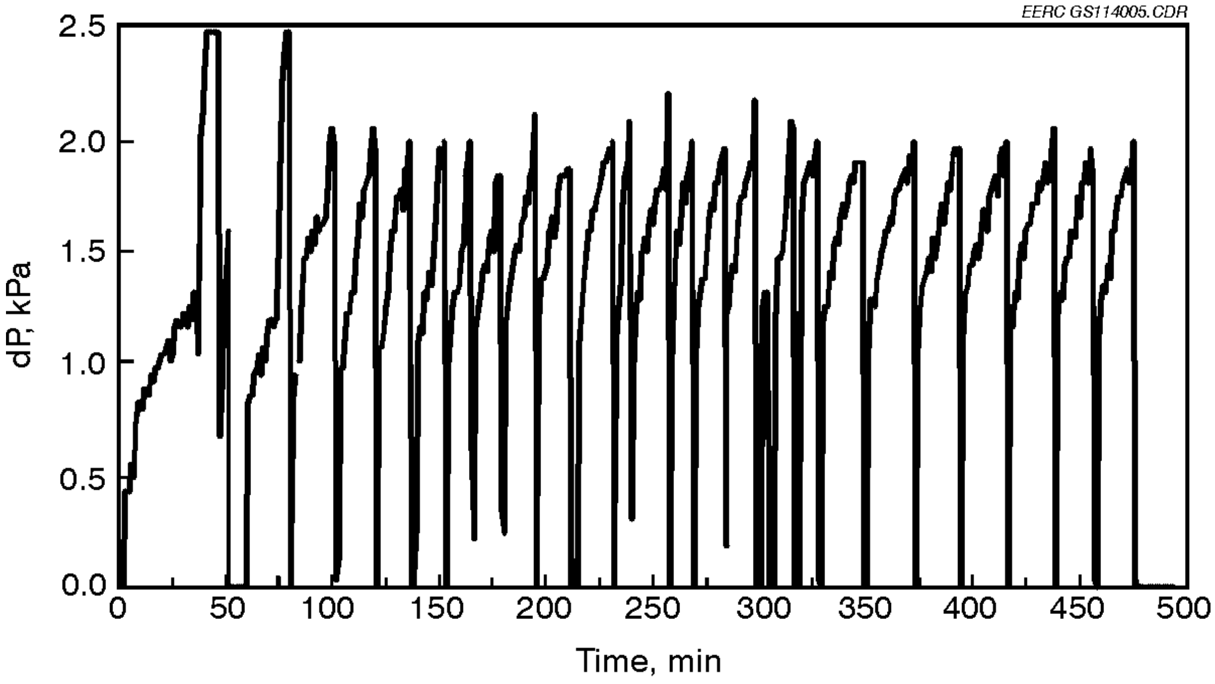

Figure 14. Pressure drop as a function of time for Test PTC-BV-581 with on-line cleaning.

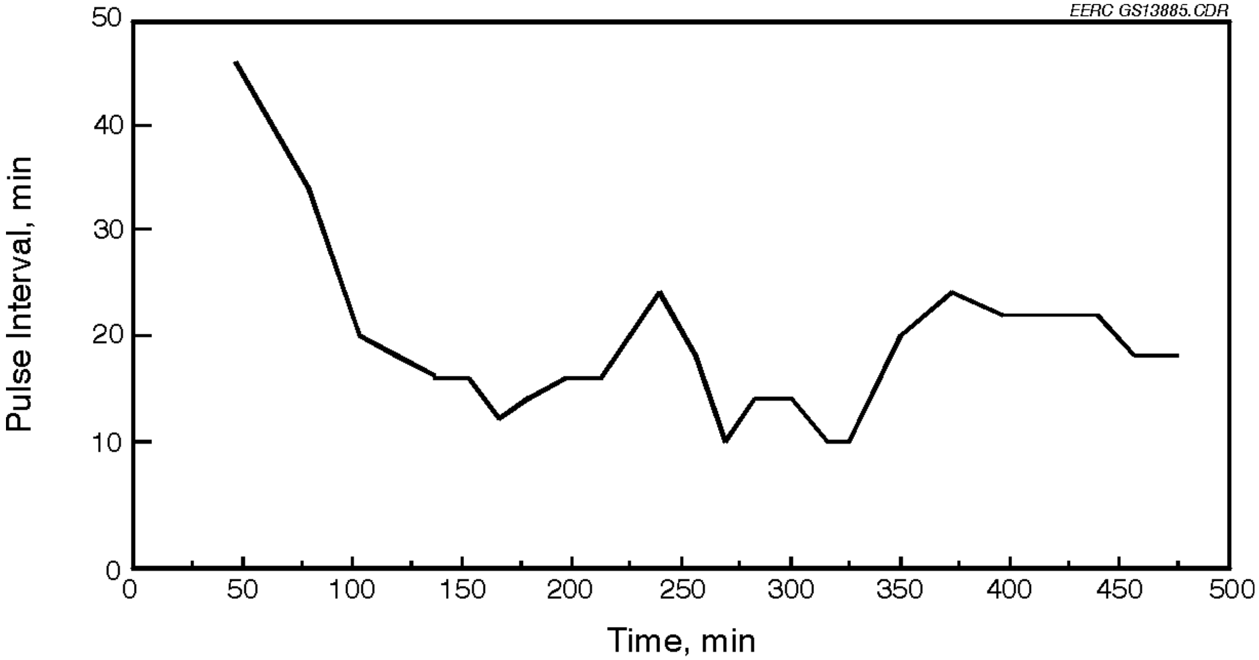

Figure 15. Pulse interval as a function of time for Test PTC-BV-581 with on-line cleaning using PTFE bags and 50-kV applied voltage.

showing dP versus time is found in Figure 16. The pulse interval averaged about 15–20 min. Figure 17 presents the pulse interval-versus-time graph. The APS data (integrated averages of 0.030, 0.032, and 0.030 mg/m^3) show that respirable mass collection efficiency was >99.99% (see Figure 18).

The purpose of the next test, BV-583, was to evaluate the effect of NH_3/SO_3 conditioning on AHPC performance. A new set of GORE-TEX® PTFE bags was installed. Flue gas-conditioning agents of NH_3/SO_3 were added to the inlet gas stream of the AHPC. A concentration ratio of NH_3/SO_3 was set at 24 ppm/12 ppm, respectively, and injected upstream of the AHPC. The dramatic effect of conditioning is shown in Figure 19. The pulse interval was 200 min compared to 20 min without conditioning in Run 581. The graph of pulse cycles versus time is shown in Figure 20.

Summary of the 8-Hour Tests. The 8-hr tests provided the following observations:

- The AHPC achieved particulate collection efficiencies of 99.99% for particle sizes from 0.01 to 50 µm.
- Excellent AHPC performance was achieved for both the subbituminous and bituminous coals, with reasonable bag-cleaning intervals.
- No significant difference in time intervals between bag-cleaning cycles with on-line and off-line cleaning.

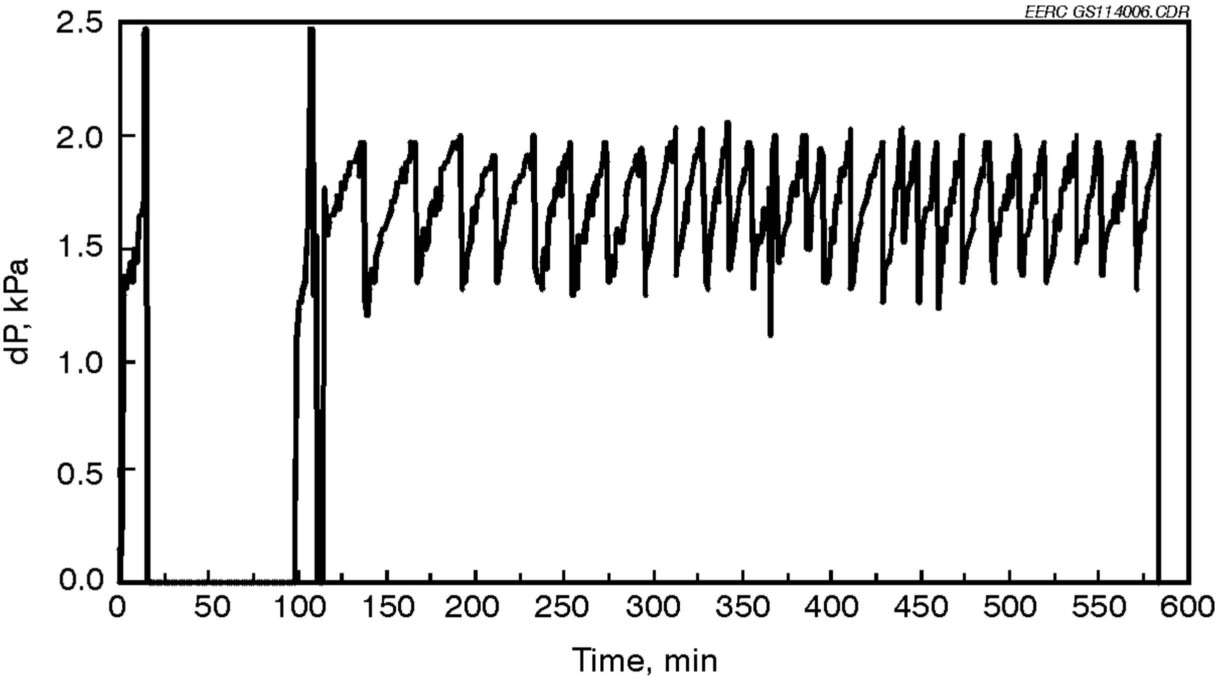

Figure 16. Pressure drop as a function of time for Test PTC-BV-582 with on-line cleaning.

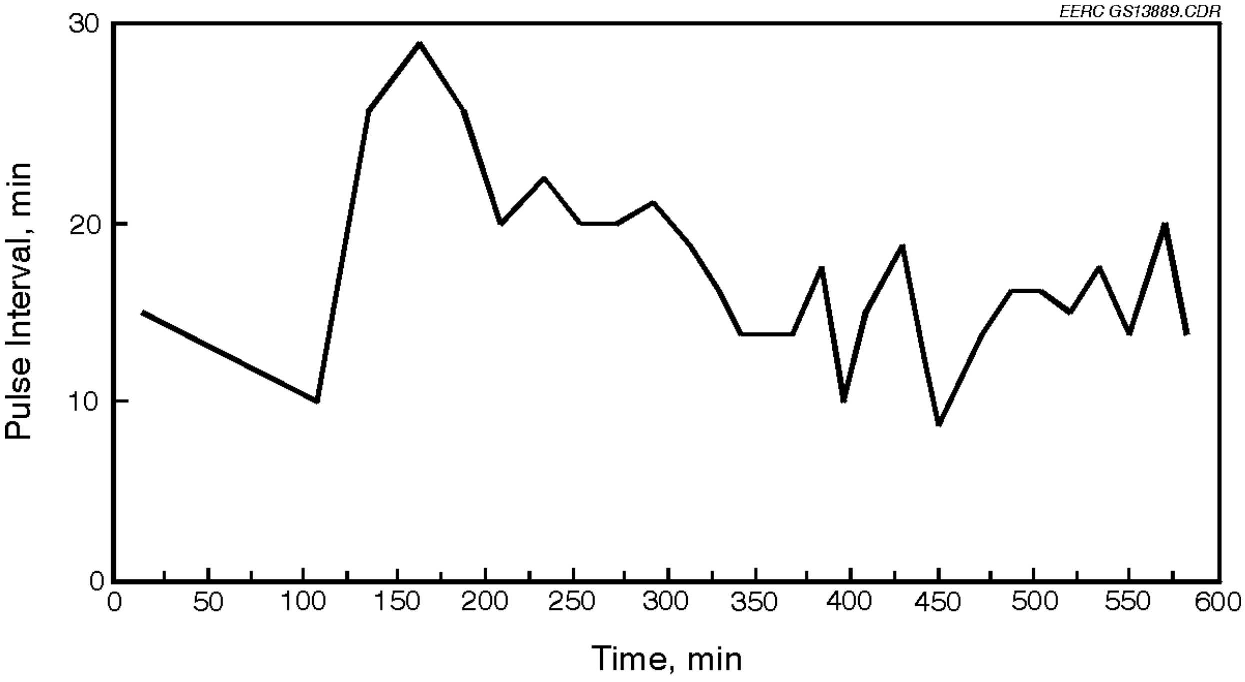

Figure 17. Pulse interval as a function of time for Test PVC-BV-582 with on-line cleaning.

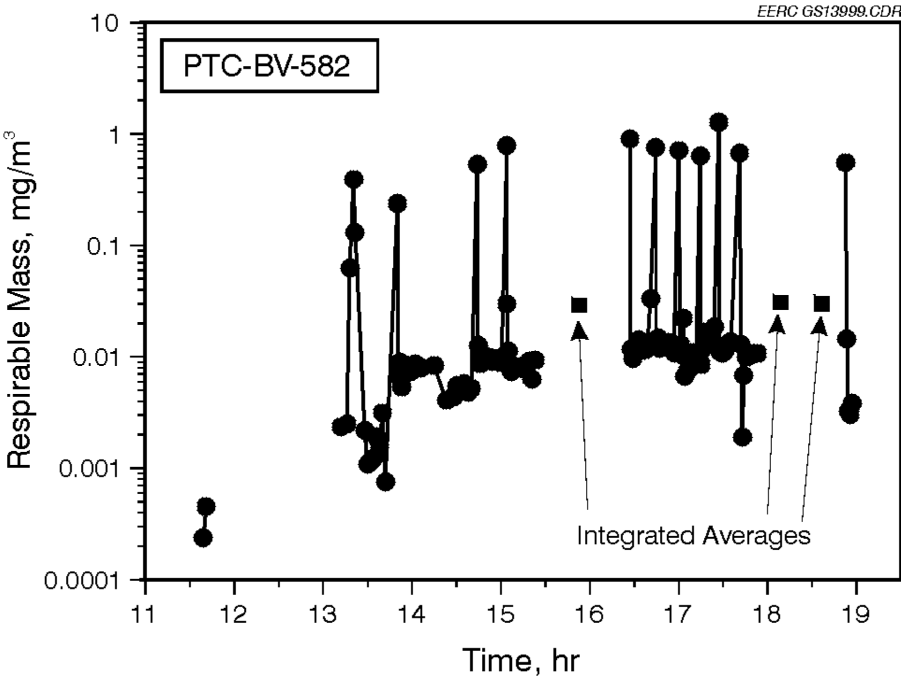

Figure 18. APS data for Test PTC-BV-582.

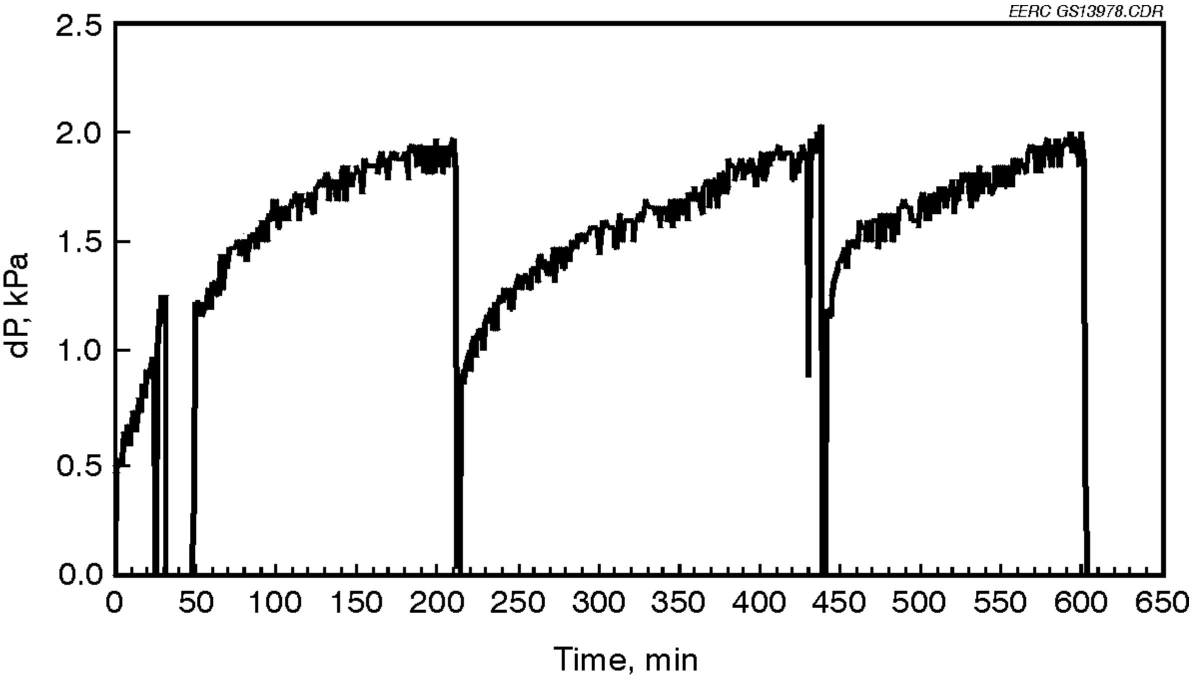

Figure 19. Pressure drop as a function of time for Test PTC-BV-583 with off-line cleaning using NH_3/SO_3 conditioning.

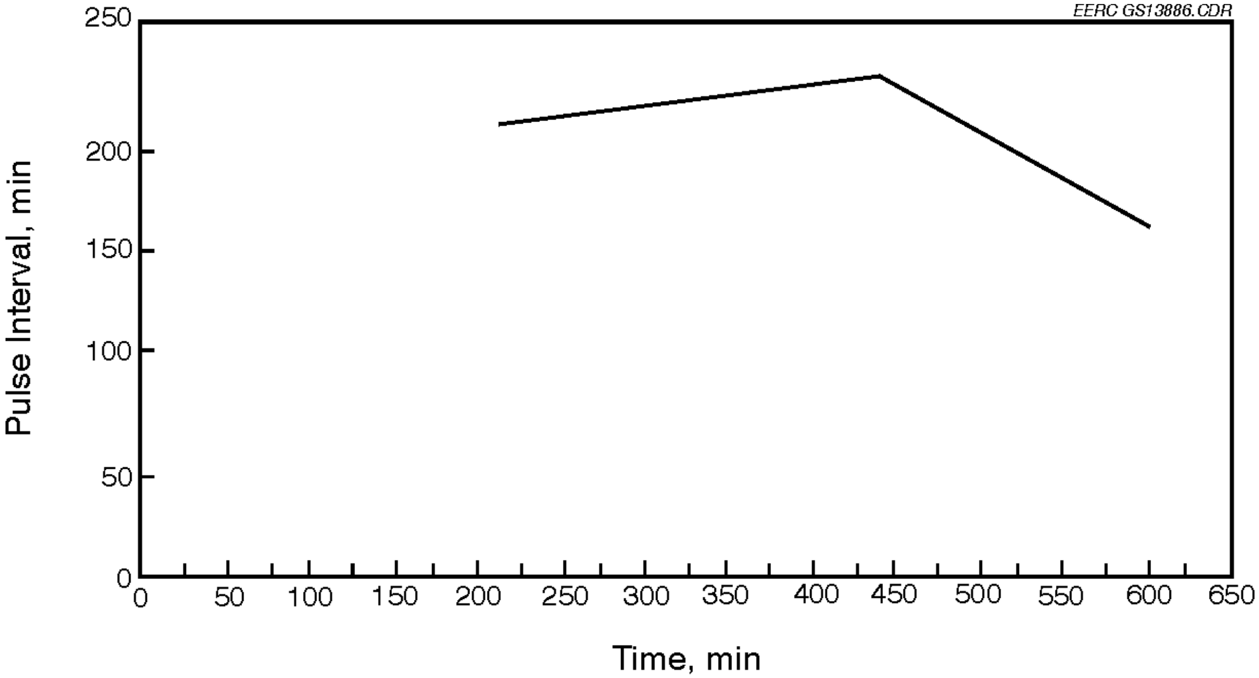

Figure 20. Pulse interval as a function of time for Test PTC-BV-583 with off-line cleaning using NH_3/SO_3 conditioning.

- Flue gas conditioning, using NH_3/SO_3, greatly enhanced AHPC performance by increasing the time interval between cleaning cycles from 20 to 100 min or more while maintaining a 99.99% dust collection efficiency.

100-hour Tests Firing Absaloka Subbituminous Coal

The objectives of the 100-hr tests on coal were to:

- Determine operability of AHPC for an extended period at steady-state conditions.
- Determine baseline information of the fate of seven trace metals using the AHPC system.
- Evaluate the effect of carbon injection on trace elements and system operability.

The AHPC was operated at an A/C of 3.7 m/min (12 ft/min) with on-line cleaning. The temperature of the AHPC was maintained at 147°C (300°F) throughout the baseline test. EPA Method 29 multimetals sampling train was used to determine trace metal concentrations for As, Cd, Cr, Hg, Ni, Pb, and Se as well as the particulate loading of the gas stream. Sampling of the inlet and outlet flue gas from the AHPC was performed simultaneously. Time duration for Method 29 inlet sampling was 1 hour while the time duration for the outlet sampling was 4 hr. In addition, 24-hr outlet dust-loading samples were taken.

The purpose of the sorbent injection test was to evaluate the AHPC performance while injecting activated carbons for mercury control. The AHPC operating temperature was lowered from 149°C (300°F) to 135°C (275°F) to improve the absorption characteristics of the sorbents. Two sorbents were used for this test. A lignite activated carbon (LAC) and an iodine-impregnated activated carbon (IAC) were mixed in a ratio of 4:1 LAC to IAC, respectively. The sorbent addition rate was adjusted to achieve a sorbent-to-Hg ratio of 3000:1.

Figures 21 and 22 show the pulse interval for the last day of the 100-hr tests. The interval was quite steady at about 25 to 35 min at the end of the tests. This shows that in extended operation, the AHPC pressure drop was well controlled and that the injection of a carbon-based sorbent did not adversely affect the pressure drop.

The 24-hr dust-loading results showed that the total mass collection efficiency was greater than 99.999%. Even after sampling for 24 hr, the dust-loading filters looked clean. Respirable mass data also show that an ultrahigh collection efficiency was achieved. Figure 23 is an example of the data showing slight spikes that occur after bag cleaning, but most of the data are around 0.001 mg/m^3. When the sampling included the short-term cleaning spikes (see Figure 23), the integrated average values were still all below 0.01 mg/m^3. Since the inlet respirable mass was typically about 1000 mg/m^3, this corresponds to a fine-particle collection efficiency greater than 99.999%. The different particulate measurements all confirm the ultrahigh collection efficiency, summarized in Table 4.

The trace element measurement results are shown in Table 5. At the outlet, only mercury, chromium, and selenium were above detection limits. The chromium, possibly, was the result of contamination, since stainless steel components were used in the construction of the AHPC. The

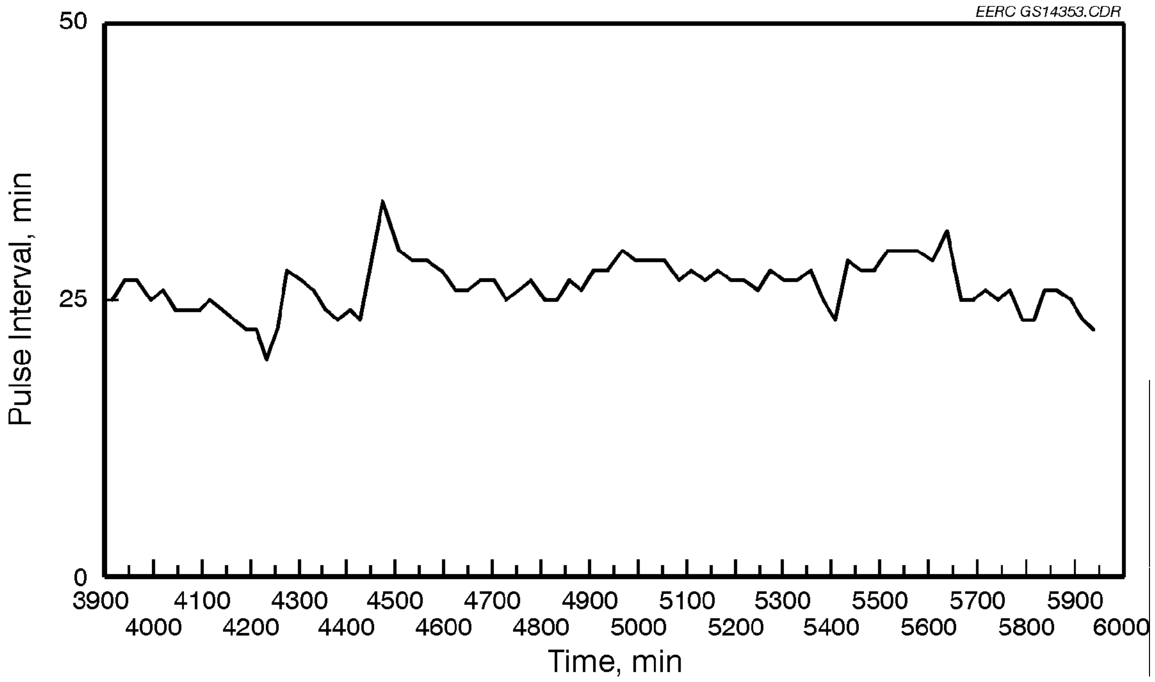

Figure 21. Pulse interval for last day of 100-hr baseline Test PTC-AB-585.

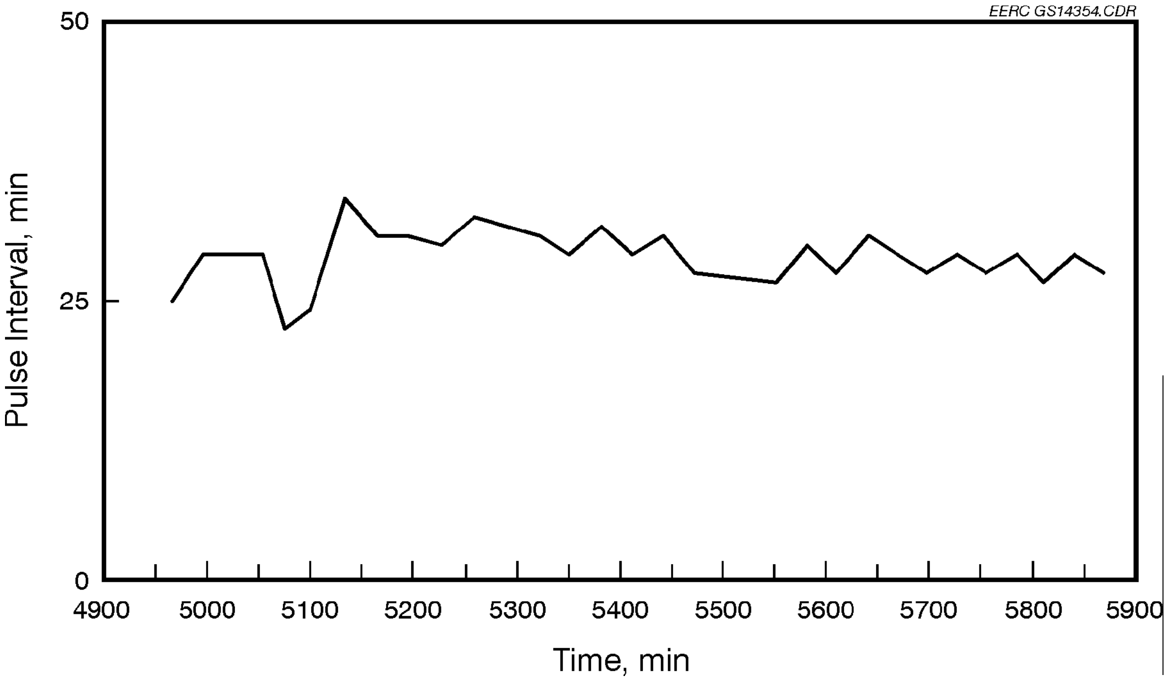

Figure 22. Pulse interval for last day of 100-hr sorbent injection Test PTC-AB-586.

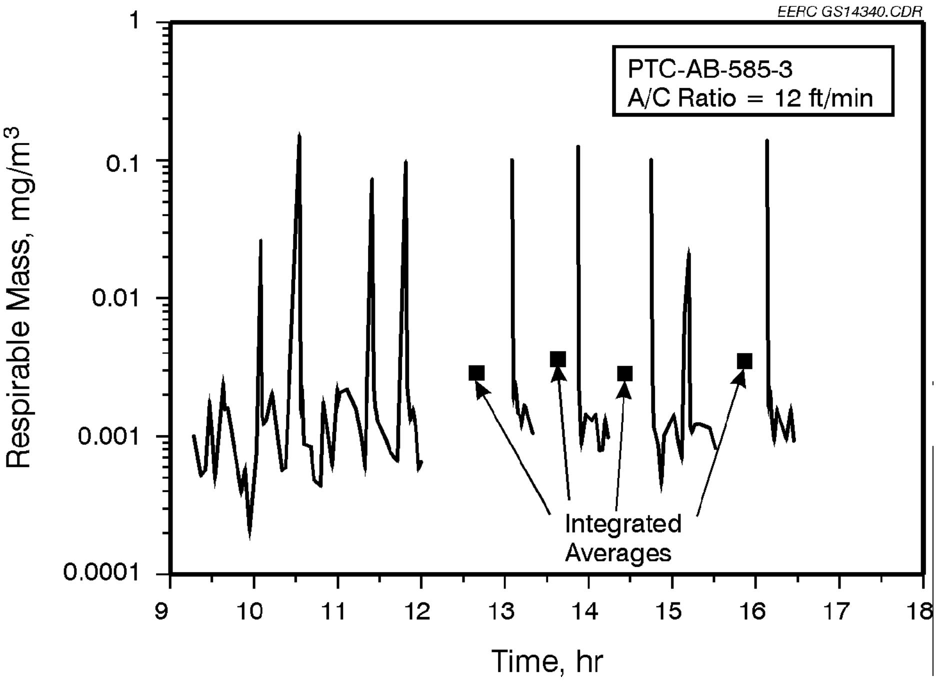

Figure 23. Respirable mass emission for 100-hr test.

TABLE 4

Particulate Collection Efficiency
Run AB-585 (100-hr test)

Method	Particle Size, µm	Outlet Concentration	Collection Efficiency
EPA-5 (24 hr)	0.01–50	3 µg/m^3	>99.9999%
APS (30-min avg.)	0.5–5	2.5 µg/m^3	>99.999%
CPC (real-time)	0.01–1	500 particles/cm^3	>99.999%

TABLE 5

Trace Element Data

		Hg, µg/m^3	As, µg/m^3	Cd, µg/m^3	Cr, µg/m^3	Pb, µg/m^3	Ni, µg/m^3	Se, µg/m^3
PTC-AB-585	Avg. Inlet	5.50	83.08	1.67	462.97	318.70	223.44	31.99
Baseline	Avg. Outlet	3.56	<0.29	<0.021	0.57	<0.16	<0.63	15.68
	% Removal	35.27	>99.65	>98.74	99.88	>99.95	>99.72	50.98
PTC-AB-586	Avg. Inlet	6.84	49.56	0.91	266.90	145.35	114.64	24.59
Sorbent Injection	Avg. Outlet	2.66	<0.63	<0.10	3.29	<0.80	<1.72	7.35
	% Removal	61.18	>98.73	>89.01	98.77	>99.45	>98.50	70.11

injection of sorbent resulted in a modest increase in mercury collection efficiency from 35% for the baseline case to 61% with sorbent. The Absaloka coal is known to produce primarily elemental mercury, which has proven in other work to be more difficult to capture with sorbents. The fine-particle data indicate a collection efficiency greater than 99.999%, but the individual trace element data for the nonvolatile elements indicate collection efficiencies primarily in the range from 99% to 99.9%. Even though the actual efficiency may have been orders of magnitude higher, the detection limits with Method 29 do not allow accurate measurement beyond about 99.9% collection efficiency.

Conclusions from the 100-hr Tests. The 100-hr tests provided the following observations:

- Particulate collection efficiencies greater than 99.99% for all particle sizes from 0.01 to 50 µm were achieved.

- Pressure drop was well controlled and steady. Injection of carbon did not adversely affect pressure drop. Time interval between bag-cleaning cycles ranged from 25 to 35 min.

- Emissions of seven trace elements—arsenic, cadmium, chromium, lead, mercury, nickel, and selenium—were measured. Only two elements, mercury and selenium, were detected in measurable quantities in vapor form at the outlet.

- With sorbent injection, total mercury removal efficiency ranged between 50% and 75%.

- No increased particulate emissions were noted during mercury sorbent injection.

In summary, the performance of the AHPC met all the program objectives in Phase I. Greater than 99.99% particulate collection efficiency for all particle sizes from 0.01 to 50 µm was achieved with both subbituminous and bituminous coals. Excellent operability was observed, and pressure drop was easily controlled at a filtration velocity of 3.7 m/min (12 ft/min). Plans for Phase II are to scale up the AHPC to the 9000-acfm pilot size and test on a slipstream of a full-scale boiler.

Benefits

Specific anticipated benefits of this approach are as follows:

- Solves the problem of excessive fine-particle emissions with conventional ESPs.

- Provides ultrahigh collection efficiency, even at high A/C ratios.

- Solves the problem of reentrainment and re-collection of dust in conventional pulse-jet baghouses caused by the close bag spacing and the effect of cleaning one row of bags at a time.

- Solves the problem of chemical attack on bags, allowing application to all U.S. coals.

- Requires significantly less total collection area than conventional ESPs or baghouses.

- Is suitable for new installations or as a retrofit replacement technology.

References

1. Dennis, R. et al. “Filtration Model for Coal Fly Ash with Glass Fabrics,” EPA-600/7-77-084; Aug. 1977.

2. Leith, D.; Rudnick, S.N.; First, M.W. “High-Velocity, High Efficiency Aerosol Filtration,” EPA-600/2-76-020; Jan. 1976.

3. Oglesby, S.; Nichols, G.B. *Electrostatic Precipitation;* Marcel Dekker, Inc.: New York, 1978.