DEMONSTRATION OF A FULL-SCALE RETROFIT OF THE ADVANCED HYBRID PARTICULATE COLLECTOR TECHNOLOGY

Final Report

October 2002 – December 2004

Addendum Section added for Period

January 2005 – December 2005

Prepared by:

Tom Hrdlicka
Otter Tail Power Company
Plant Engineer

William Swanson
Otter Tail Power Company
Principal Engineer

Prepared for:

United States Department of Energy
National Energy Technology Laboratory
DOE Award No. DE-FC26-02NT41420

Submitting Organization:

Otter Tail Power Company
Big Stone Plant
PO Box 218
Big Stone City, SD 57216-0218

DISCLAIMER

ABSTRACT

The Advanced Hybrid Particulate Collector (AHPC), developed in cooperation between W.L. Gore & Associates and the Energy & Environmental Research Center (EERC), is an innovative approach to removing particulates from power plant flue gas. The AHPC combines the elements of a traditional baghouse and electrostatic precipitator (ESP) into one device to achieve increased particulate collection efficiency. As part of the Power Plant Improvement Initiative (PPII), this project was demonstrated under joint sponsorship from the U.S. Department of Energy and Otter Tail Power Company. The EERC is the patent holder for the technology, and W.L. Gore & Associates was the exclusive licensee for this project.

The project objective was to demonstrate the improved particulate collection efficiency obtained by a full-scale retrofit of the AHPC to an existing electrostatic precipitator. The full-scale retrofit was installed on an electric power plant burning Powder River Basin (PRB) coal, Otter Tail Power Company's Big Stone Plant, in Big Stone City, South Dakota. The $13.4 million project was installed in October 2002. Project related testing concluded in December 2005.

The following Final Technical Report has been prepared for the project entitled "Demonstration of a Full-Scale Retrofit of the Advanced Hybrid Particulate Collector Technology" as described in DOE Award No. DE-FC26-02NT41420. The report presents the operation and performance results of the system.

POINT OF CONTACT

For further information on the “Demonstration of a Full-Scale Retrofit of the Advanced Hybrid Particulate Collector Technology”, please contact:

William Swanson
Otter Tail Power Company
Big Stone Plant
PO Box 218
Big Stone City, SD 57216-0218

TABLE OF CONTENTS

LIST OF ACRONYMS

A/C	air-to-cloth ratio
AG	(Swiss, translation roughly is Incorporation or consolidation)
AHPC	advanced hybrid particulate collector
APS	aerodynamic particle sizer
COHPAC	compact hybrid particulate collector
CPC	condensation particle counter
DOE	U.S. Department of Energy
EERC	Energy & Environmental Research Center
EPA	U.S. Environmental Protection Agency
ePTFE	expanded polytetrafluoroethylene
ESP	electrostatic precipitator
FF	fabric filter
HEPA	high-efficiency particulate air
HiPPS	high-performance power system
MWh	megawatt hours
µm	micrometer
NSPS	New Source Performance Standards
O&M	operating and maintenance
OEMs	original equipment manufacturers
OTP	Otter Tail Power Company
P&ID	Piping and Intrumentation Diagram
PID	Proportional-Integral-Derivative
PJBH	pulse-jet baghouse
PM	particulate matter
PPS	polyphenylene sulfide
PRB	Powder River Basin
PJFF	pulse-jet fabric filter
P-84	aromatic polyimide fiber
QAPP	quality assurance project plan
RGFF	reverse-gas fabric filter
SCA	specific collection area
SMPS	scanning mobility particle sizer
TR	transformer-rectifier
UND	University of North Dakota
W.C.	water column

EXECUTIVE SUMMARY

This document summarizes the operational results of a project titled "Demonstration of a Full-Scale Retrofit of the Advanced Hybrid Particulate Collector Technology". The Department of Energy's National Energy Technology Laboratory awarded under a program entitled the Power Plant Improvement Initiative Program.

The advanced hybrid particulate collector (AHPC) was developed with funding from the U.S. Department of Energy (DOE). The AHPC combines the best features of electrostatic precipitators (ESPs) and baghouses in novel manner. The AHPC combines fabric filtration and electrostatic precipitation in the same housing, providing major synergism between the two methods, both in particulate collection and in transfer of dust to the hopper. The AHPC provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emissions with conventional ESPs, and solves the problem of reentrainment and recollection of dust in conventional baghouses.

Big Stone Power Plant operated a 2.5 MWe slipstream AHPC (9000 scfm) for 1½ years. The AHPC demonstrated ultrahigh particulate collection efficiency for submicron particles and total particulate mass. Collection efficiency was proven to exceed 99.9% by one to two orders of magnitude over the entire range of particles from 0.01 to 50 µm. This level of control is well below any current particulate emission standards. These results were achieved while operating at significantly higher air-to-cloth ratios (up to 12 ft/min compared to 4 ft/min) than standard pulse-jet baghouses. To achieve 99.99% control of total particulate and meet possible stricter fine-particle standards, the AHPC is being demonstrated as the possible economic choice over either ESPs or baghouses.

Otter Tail Power Company and its partners, Montana-Dakota Utilities and NorthWestern Energy, installed the AHPC technology into an existing ESP structure at the Big Stone Power Plant. The overall goal of the project is to demonstrate the AHPC concept in a full-scale application. Specific objectives are to demonstrate 99.99% collection of all particles in the 0.01 to 50 µm size range, low pressure drop, overall reliability of the technology and long-term bag life.

This is the project final report. It is meant to summarize the operational experience over the last three plus years (October 2002 – December 2005).

Addenda Note:

The final report is now being submitted after the initial draft of this final report was completed. This further information is intended to cover the material changes and information that occurred to the Advanced Hybrid™ system through 2005. The sections described, as "Addendum" will describe the events and conclusions during this period.

PROJECT NOMENCLATURE DISCUSSION

When this technology was originally developed, the device was referred to as the "Advanced Hybrid Particulate Collector". Since the original development, from concept to an attempt at a commercial demonstration, the name of the technology has changed to "Advanced Hybrid™". This name was trademarked by W.L. Gore and Associates, Inc. to aid in the commercialization effort and tries to maintain the continuity of the successful history to date. Either "Advanced Hybrid Particulate Collector" (AHPC) or "Advanced Hybrid™" refers to the same process and equipment.

1.0 INTRODUCTION

The *Advanced Hybrid*™ filter combines the best features of ESPs and baghouses in a unique approach to develop a compact but highly efficient system. Filtration and electrostatics are employed in the same housing, providing major synergism between the two collection methods, both in the particulate collection step and in the transfer of dust to the hopper. The *Advanced Hybrid*™ filter provides ultrahigh collection efficiency, overcoming the problem of excessive fine-particle emissions with conventional ESPs, and solves the problem of reentrainment and re-collection of dust in conventional baghouses.

The goals for the *Advanced Hybrid*™ filter are as follows: > 99.99% particulate collection efficiency for particle sizes ranging from 0.01 to 50 μm, applicable for use with all U.S. coals, and cost savings compared to existing technologies.

The electrostatic and filtration zones are oriented to maximize fine-particle collection and minimize pressure drop. Ultrahigh fine-particle collection is achieved by removing over 90% of the dust before it reaches the fabric and using a GORE-TEX® membrane fabric to collect the particles that reach the filtration surface. Charge on the particles also enhances collection and minimizes pressure drop, since charged particles tend to form a more porous dust cake. The goal is to employ only enough ESP plate area to precollect approximately 90% of the dust. ESP models predict that 90%–95% collection efficiency can be achieved with full-scale precipitators with a specific collection area (SCA) of less than 100 ft^2/kacfm (1, 2). FF models predict that face velocities greater than 12 ft/min are possible if some of the dust is precollected and the bags can be adequately cleaned. The challenge is to operate at high A/C ratios (8–14 ft/min) for economic benefits while achieving ultrahigh collection efficiency and controlling pressure drop. The combination of GORE-TEX® membrane filter media (or similar membrane filters from other manufacturers), small SCA, high A/C ratio, and unique geometry meets this challenge.

Studies have shown that FF collection efficiency is likely to deteriorate significantly when the face velocity is increased (3, 4). For 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 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).

Assuming that low particulate emissions can be maintained through the use of advanced filter materials and that 90% of the dust is precollected, operation at face velocities in the range of 8–14 ft/min should be possible, 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 the transferring of the dislodged dust to the hopper. The *Advanced Hybrid*™ filter achieves enhanced bag cleaning by employing electrostatic effects to precollect a significant portion of the dust and by trapping in the electrostatic zone the redispersed dust that comes off the bags following pulsing.

1.1 History of Development

The *Advanced Hybrid*™ filter concept was first proposed to DOE in September 1994 in response to a major solicitation addressing air toxics. DOE has been the primary funder of the *Advanced Hybrid*™ filter development since that time, along with significant cost-sharing from industrial cosponsors. Details of all of the results have been reported in DOE quarterly technical reports, final technical reports for completed phases, and numerous conference papers. A chronology of the significant development steps for the *Advanced Hybrid*™ filter is shown below.

- September 1994 - *Advanced Hybrid*™ filter concept proposed to DOE
- October 1995 - September 1997 - Phase I - *Advanced Hybrid*™ filter successfully demonstrated at 0.06-MW (200-acfm) scale
- March 1998 - February 2000 - Phase II - *Advanced Hybrid*™ filter successfully demonstrated at 2.5-MW (9000-acfm) scale at Big Stone Plant
- September 1999 - August 2001 - Phase III - *Advanced Hybrid*™ filter commercial components tested and proven at 2.5-MW scale at Big Stone Plant
- Summer 2000 – Minor electrical damage on bags first observed
- January–June 2001 – To prevent electrical damage, the *Advanced Hybrid*™ filter perforated plate configuration was developed, tested, and proven to be superior to the original design
- July 2001 - December 2004 - Mercury Control with the *Advanced Hybrid*™ Filter - Extensive additional testing of the perforated plate concept was conducted with the 2.5-MW pilot unit

1.2 Design of the Perforated Plate *Advanced Hybrid*™ Filter Configuration

After bag damage was observed in summer 2000, extensive experiments were carried out at an Energy & Environmental Research Center (EERC) laboratory to investigate the interactions between electrostatics and bags under different operating conditions. The 200-acfm *Advanced Hybrid*™ filter was first operated without fly ash under cold-flow conditions with air. The effects of electrode type, bag type, plate-to-plate spacing, the relative distance from the electrodes to plates compared to the distance from the electrodes to the bags (spacing ratio), and various grounded grids placed between the electrodes and bags were all evaluated. Several of the conditions from the cold-flow tests were selected and further evaluated in hot-flow coal combustion tests. While all of these tests resulted in very low current to the bags, there appeared to be a compromise in overall *Advanced Hybrid*™ filter performance for some configurations.

A configuration that appeared to have promise was a perforated plate design in which a grounded perforated plate was installed between the discharge electrodes and the bags to protect the bags. On the opposite side of the electrodes, another perforated plate was installed to simulate the geometric arrangement where each row of bags would have perforated plates on both sides, and no solid plates were used. The discharge electrodes were then centered between perforated plates located directly in front of the bags. With this arrangement, the perforated plates function both as the primary collection surface and as a protective grid for the bags. With the 200-acfm *Advanced Hybrid*™ filter, the perforated plate configuration produced results far better than in any previous *Advanced Hybrid*™ filter tests and provided adequate protection of the bags.

Based on the 200-acfm results, a perforated plate configuration was designed and installed on the 9000-acfm slipstream pilot unit at the Big Stone Power Plant. The differences between the new perforated plate design and the previous *Advanced Hybrid*™ filter can be seen by comparing Figure 1 with Figure 2. Figure 1 is a simplified top view of the 9000-acfm *Advanced Hybrid*™ filter configuration at the start of Phase III, which had a plate-to-plate spacing of 23.6 in. For the perforated plate configuration (Figure 2), the bag spacing was not changed, allowing use of the same tube sheet as in the previous configuration (Figure 1). However, the distance from the discharge electrodes to the perforated plates as well as the distance from the bags to the perforated plates can be reduced without compromising performance. Therefore, one of the obvious advantages of the perforated plate configuration is the potential to make the *Advanced Hybrid*™ filter significantly more compact than the earlier design.

Another difference is that directional electrodes are not required with the perforated plate design. With the previous design, directional electrodes (toward the plate) were needed to prevent possible sparking to the bags. This means that conventional electrodes can be used with the *Advanced Hybrid*™ filter. Electrode alignment is also less critical because an out-of-alignment electrode would simply result in potential sparking to the nearest grounded perforated plate, whereas with the old design, an out-of-alignment electrode could result in sparking to a bag and possible bag damage.

While the perforated plate configuration did not change the overall *Advanced Hybrid*™ filter concept (precollection of > 90% of the dust and enhanced bag cleaning), the purpose of the plates did change. The perforated plates serve two very important functions: as the primary collection surface and as a protective grid for the bags. With approximately 45% open area, there is adequate collection area on the plates to collect the precipitated dust while not restricting the flow of flue gas toward the bags during normal filtration. During pulse cleaning of the bags, most of the reentrained dust from the bags is forced back through the perforated plates into the ESP zone. The 9000-acfm results as well as the 200-acfm results showed better ESP collection than the previous design while maintaining good bag cleanability. The better ESP collection efficiency is likely the result of forcing all of the flue gas through the perforated plate holes before reaching the bags. This ensures that all of the charged dust particles pass within a maximum of one-half of the hole diameter distance of a grounded surface. In the presence of the electric field, the particles then have a greater chance of being collected. In the old *Advanced Hybrid*™ filter design, once the gas reached the area between the electrodes and bags, it would be driven toward the bags rather than the plates, and a larger fraction of the dust was likely to bypass the ESP zone.

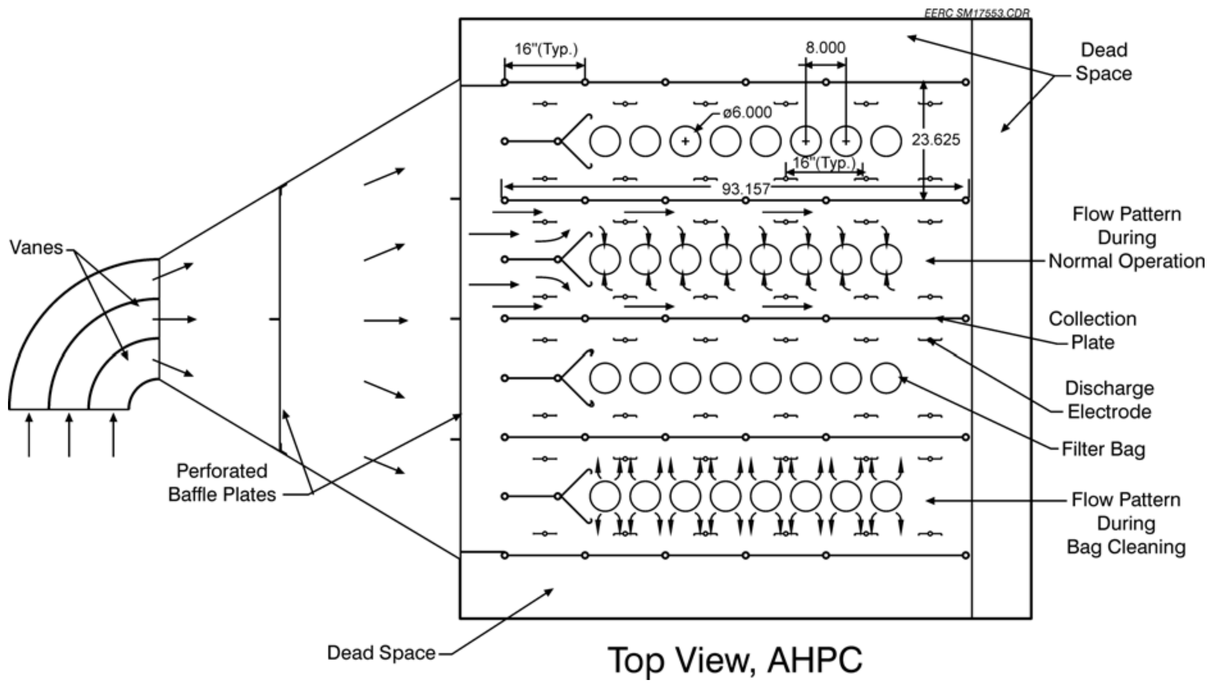


Figure 1. Top view of the old configuration for the 9000-acfm *Advanced Hybrid*™ filter at Big Stone.

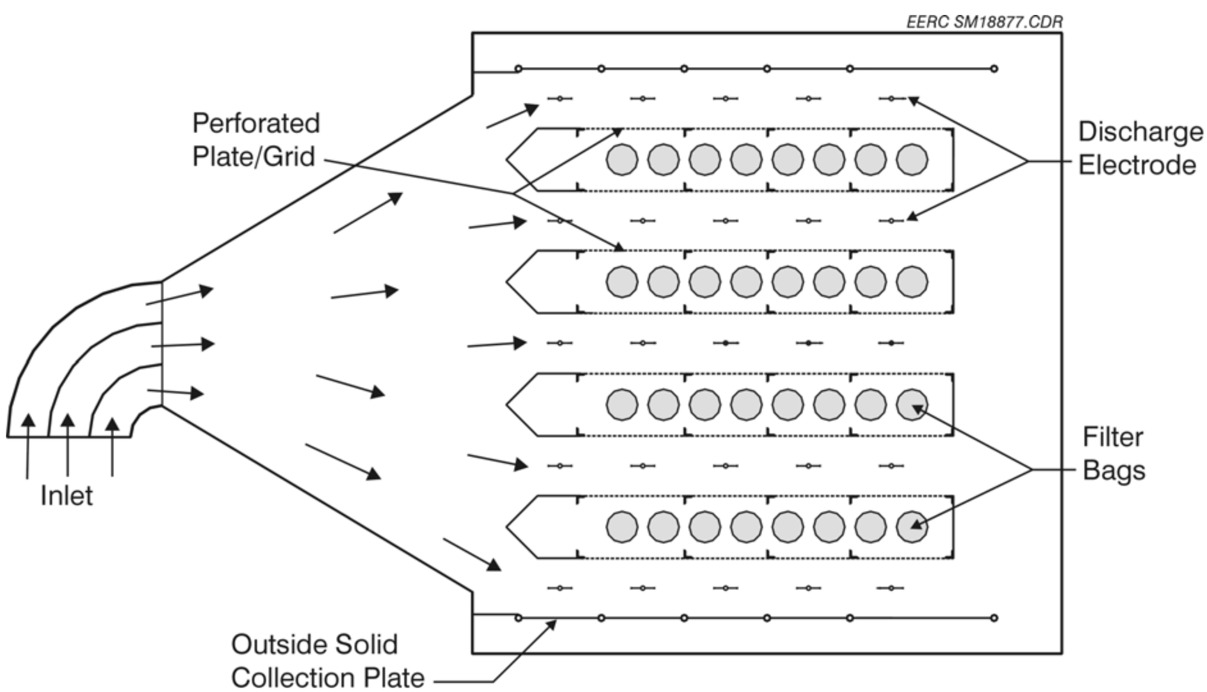


Figure 2. Top view of the perforated plate configuration for the 9000-acfm *Advanced Hybrid*™ filter.

1.3 Pressure Drop Theory and Performance Evaluation Criteria

Pressure drop across the bags is one of the main operational parameters that defines overall performance. It must be within capacity limits of the boiler fans at the maximum system flow rate. Since acceptable pressure drop is so critical to successful operation, a detailed discussion of the theory and factors that control pressure drop follows.

For viscous flow, pressure drop across a FF is dependent on three components:

$$dP = K_f V + K_2 W_R V + \frac{K_2 C_i V^2 t}{7000} \qquad \text{[Eq. 1]}$$

where:

- dP = differential pressure across baghouse tube sheet (in. W.C.)
- K_f = fabric resistance coefficient (in. W.C.-min/ft)
- V = face velocity or A/C ratio (ft/min)
- K_2 = specific dust cake resistance coefficient (in. W.C.-ft-min/lb)
- WR = residual dust cake weight (lb/ft^2)
- C_i = inlet 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 fabric resistance a significant contributor to pressure drop. The GORE-TEX® membrane filter media allows for this optimization by providing a microfine pore structure while maintaining sufficient fabric permeability to permit operation at high A/C ratios. A measure of the new fabric permeability is the Frazier number which is the volume of gas that will pass through a square foot of fabric sample at a pressure drop of 0.5 in. W.C. The Frazier number for new GORE-TEX® bags is in the range from 4 to 8 ft/min. Through the filter, viscous (laminar) flow conditions exist, so the pressure drop varies directly with flow velocity. Assuming a new fabric Frazier number of 6 ft/min, the pressure drop across the fabric alone would be 1.0 in. W.C. at an A/C ratio (filtration velocity) of 12 ft/min.

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 reasonable. The contribution to pressure drop from this term is one of the most important indicators of longer-term bag cleanability.

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 a full dust loading of pulverized coal (pc)-fired fly ash range from about 4 to 20 in. W.C.-ft-min/lb but may, in extreme cases, cover a wider range. Within this term, the bag-cleaning interval, t, is the key performance indicator. The goal is to operate with as long of a bag-cleaning interval as possible, since more frequent bag pulsing can lead to premature bag failure and require more energy consumption from compressed air usage. An earlier goal for the pilot-scale tests was to operate with a pulse interval of at least 10 min while operating at an A/C ratio of 12 ft/min. While this goal was exceeded in the pilot-scale tests, a pulse interval of only 10 min is now considered too short to demonstrate good *Advanced Hybrid*™ filter performance over a longer period. With a shorter pulse interval, the *Advanced Hybrid*™ filter does not appear to make the best use of the electric field, because of the reentrainment that occurs just after pulsing. Current thought is that a pulse interval of at least 60 min is needed to demonstrate the best long-term performance.

Total tube sheet pressure drop is another key indicator of overall performance of the *Advanced Hybrid*™ filter. Here, the goal was to operate with a tube sheet pressure drop of 8 in. W.C. at an A/C ratio of 12 ft/min. Note that the average pressure drop is not the same as the pulse-cleaning trigger point. For many of the previous and current tests, the pulse trigger point was set at 8 in. W.C., but the average pressure drop was significantly lower.

To help analyze filter performance, the terms in Eq. 1 can be normalized to the more general case by dividing by velocity. The dP/V term is commonly referred to as drag or total tube sheet drag, D_T:

$$\frac{dP}{V} = D_T = K_f + K_2 W_R + \frac{K_2 C_i Vt}{7000} \quad \text{[Eq. 2]}$$

The new fabric drag and the residual dust cake drag are typically combined into a single term called residual drag, D_R:

$$D_T = D_R + \frac{K_2 C_i Vt}{7000} \quad \text{[Eq. 3]}$$

The residual drag term then is the key indicator of how well the bags are cleaning over a range of A/C ratios, but may still be somewhat dependent on A/C ratio. For example, it may be more difficult to overcome a dP of 10 in. W.C. to clean the bags than cleaning at a dP of 5 in. W.C. For most baghouses, the residual drag typically climbs somewhat over time and must be monitored carefully to evaluate the longer-term performance. Current thought is that excellent *Advanced Hybrid*™ filter performance can be demonstrated with a residual drag value of 0.6 or lower.

Between bag cleanings, from the second term in Eq. 3, the drag increases linearly with K_2 (dust cake resistance coefficient), C_i (inlet dust concentration), V (filtration velocity), and t (filtration time). For conventional baghouses, the C_i term is easily determined from an inlet dust loading measurement, and approximate K_2 values can be determined from the literature or by direct measurement. However, for the *Advanced Hybrid*™ filter, the concentration of the dust that reaches the bags is generally not known and would be very difficult to measure experimentally. From the Phase I laboratory tests, results indicated approximately 90% of the dust was precollected and did not reach the fabric. However, this amount is likely to fluctuate significantly with changes to the electrical field and with the dust resistivity. Since C_i is not known, for evaluation of *Advanced Hybrid*™ filter performance, the K_2 and C_i can be considered together:

$$K_2 C_i = \frac{(D_T - D_R)7000}{Vt} \qquad \text{[Eq. 4]}$$

Evaluation of K_2C_i can help in assessing how well the ESP portion of the *Advanced Hybrid*™ filter is functioning, especially by comparing with the K_2C_i during short test periods in which the ESP power was shut off. For the Big Stone ash, the K_2C_i value has typically been about 20 without the ESP field. For the 9000-acfm pilot *Advanced Hybrid*™ filter, longer-term K_2C_i values of 1.0 have been demonstrated with the ESP field on, which is equivalent to 95% precollection of the dust by the ESP. Again, the goal is to achieve as low of a K_2C_i value as possible; however, good *Advanced Hybrid*™ filter performance can be demonstrated with K_2C_i values up to 4, but this is interdependent on the residual drag and filtration velocity.

Eq. 4 can be solved for the bag-cleaning interval, t, as shown in Eq. 5. The bag-cleaning interval is inversely proportional to the face velocity, V, and the K_2C_i term and directly proportional to the change in drag before and after cleaning (delta drag). The delta drag term is dependent on the cleaning set point or maximum pressure drop as well as the residual drag. The face velocity, delta drag, and K_2C_i terms are relatively independent of each other and should all be considered when the bag-cleaning interval is evaluated. However, as mentioned above, the drag may be somewhat dependent on velocity if the dust does not clean off the bags as well at high velocity as at low velocity. Similarly, the K_2C_i is somewhat dependent on velocity for a constant plate collection area. At the greater flow rates, the SCA of the precipitator is reduced, which will result in a greater dust concentration, C_i, reaching the bags.

$$t = \frac{(D_T - D_R)7000}{VK_2C_i} \quad \text{[Eq. 5]}$$

By evaluating these performance indicators, the range in possible A/C ratios can be calculated by using Eq. 1. For example, using the acceptable performance values of a 60-min pulse interval and a residual drag of 0.6, Eq. 1 predicts that a K_2C_i value of 2.33 would be needed when operating at an A/C ratio of 10 ft/min and a pulse trigger of 8 in. W.C. Obviously, deterioration in the performance of one indicator can be offset by improvement in another. Results to date show that performance is highly sensitive to the A/C ratio and that excellent *Advanced Hybrid*™ filter performance can be achieved as long as a critical A/C ratio is not exceeded. If the A/C ratio is pushed too high, system response is to more rapidly pulse the bags. However, too rapid of pulsing tends to make the residual drag increase faster and causes the K_2C_i to also increase, both of which lead to poorer performance. The design challenge is to operate the *Advanced Hybrid*™ filter at the appropriate A/C ratio for a given set of conditions.

1.4 9000-acfm Pilot-Scale Results

During the summer of 2002 the 9000-acfm *Advanced Hybrid*™ filter was operated from June 28 through early September with minimal changes to the operating parameters. This is the longest time the pilot unit was operated without interruption and is the best example of the excellent performance demonstrated with the 9000-acfm *Advanced Hybrid*™ filter. One of the main objectives of the summer 2002 tests was to assess the effect of carbon injection for mercury control on longer-term *Advanced Hybrid*™ filter performance. In order to achieve steady-state *Advanced Hybrid*™ filter operation prior to starting carbon injection, the *Advanced Hybrid*™ filter was started with new bags on June 28 and operated continuously until the start of the carbon injection for mercury control in August. Operational parameters are given in Table 1, and the bag-cleaning interval, pressure drop, and K_2C_i data from June 28 to September 3 are shown in Figures 3-5. The daily average pressure drop data increased slightly with time as would be expected after starting with new bags. When the carbon was started on August 7, there was no perceptible change in pressure drop. The bag-cleaning interval was somewhat variable as a result of temperature and load swings, but, again there was no increase when the carbon feed was started. The K_2C_i values are an indication of the amount of dust that reaches the bags and subsequently relate to how well the ESP portion of the *Advanced Hybrid*™ filter is working. Again, there was no perceptible change when the carbon was started. These data show that the *Advanced Hybrid*™ filter can be expected to provide good mercury removal with upstream injection of carbon without any adverse effect on performance.

From August 21 to August 26, the *Advanced Hybrid*™ filter current was deliberately reduced to 25 mA compared to the normal 55 mA setting (see Figures 3-5) to see if good mercury removal could be maintained. The bag-cleaning interval dropped to about one-half, and the K_2C_i value approximately doubled, which would be expected. Both of these indicate that about twice as much dust reached the bags at 25 mA compared to 55 mA. However, almost no effect on pressure drop was seen. This implies that it should be possible to optimize *Advanced Hybrid*™ filter operational parameters to get the best overall mercury removal while maintaining good *Advanced Hybrid*™ filter performance.

Table 1. 2.5-MW *Advanced Hybrid*™ Filter Test Parameters and Operational Summary, June 28 - September 2, 2002

A/C Ratio	10 ft/min
Pulse Pressure	70 psi
Pulse Duration	200 ms
Pulse Sequence	87654321 (multibank)
Pulse Trigger	8.0 in. W.C.
Pulse Interval	260 - 400 min
Temperature	260° - 320°F
Rapping Interval	15 - 20 min
Voltage	58 - 62 kV
Current	55 mA

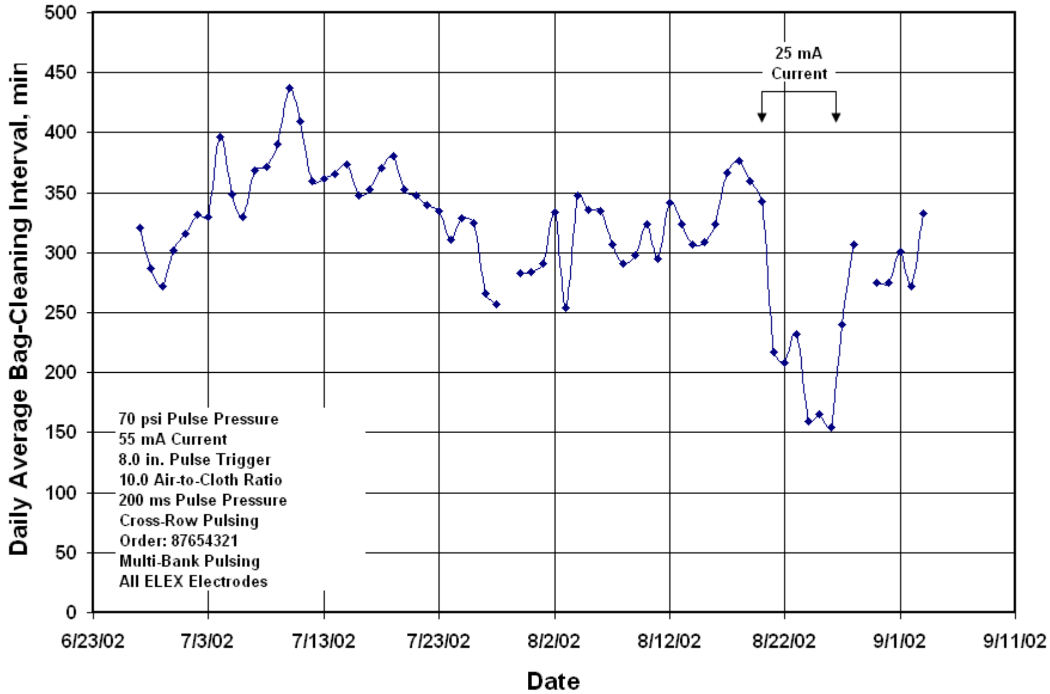


Figure 3. Daily average bag-cleaning interval for summer 2002 tests with the 9000-acfm *Advanced Hybrid*™ filter.

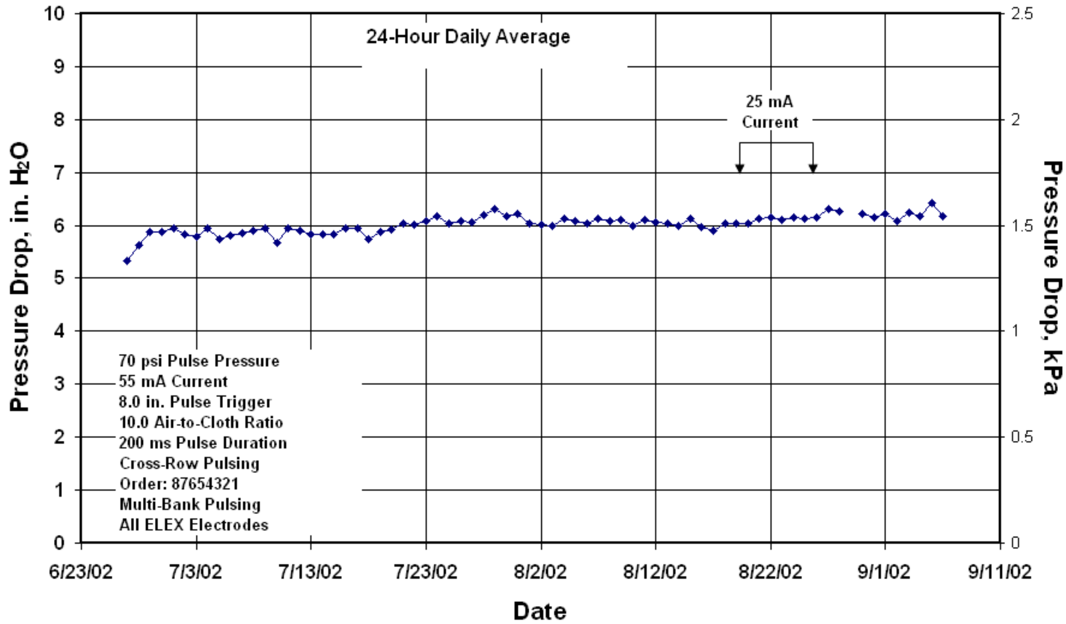


Figure 4. Daily average pressure drop for summer 2002 tests with the 9000-acfm *Advanced Hybrid*™ filter.

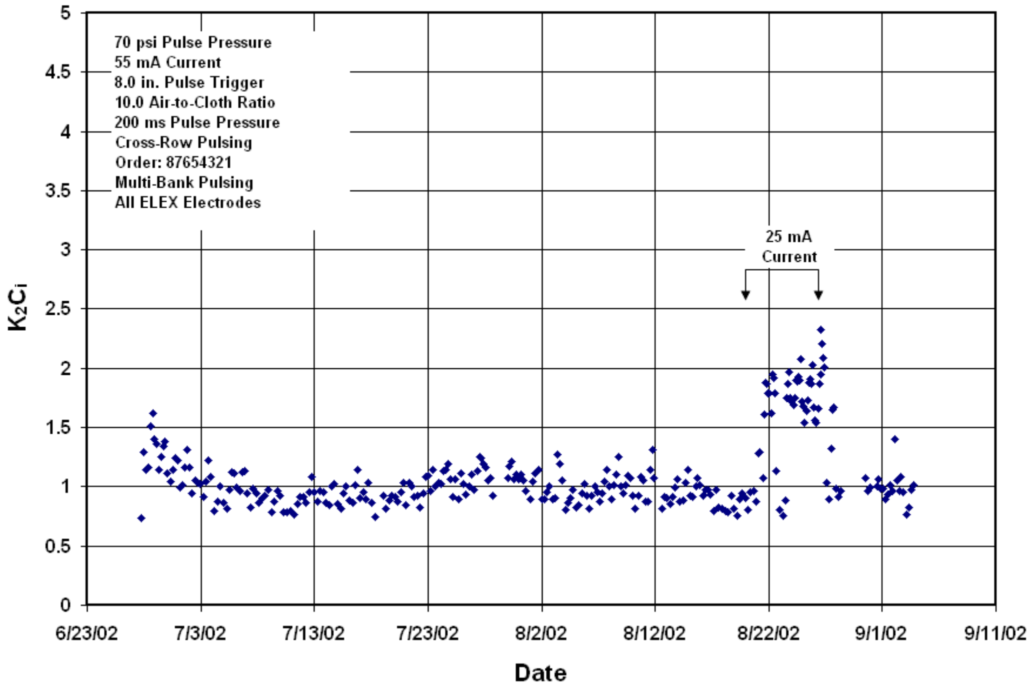


Figure 5. K_2C_i for summer 2002 tests with the 9000-acfm *Advanced Hybrid*™ filter.

A summary of the results in Table 2 shows the excellent operational performance achieved with the 9000-acfm at an A/C ratio of 10 ft/min.

Table 2. Summary of 9000-acfm Pilot-Scale Results from Summer 2002

A/C Ratio	10 ft/min
Average dP	~6 in. W.C.
Bag-Cleaning Interval	2–5 hr
Residual Drag	0.4–0.5
K_2C_i	0.9–1.5

The 9000-acfm pilot *Advanced Hybrid*™ filter was also used to vary the operational parameters to assess the most critical effects. One of the most important findings was the observed significant effect of the pulse interval on the K_2C_i value, as shown in Figure 6. The large increase in K_2C_i at the lowest pulse intervals indicates that the benefit of the electric field is diminished at lower pulse intervals. This indicates that for good *Advanced Hybrid*™ filter performance, a minimum allowable pulse interval should be established. Based on Figure 6, a 60 min pulse interval would be a good minimum performance goal.

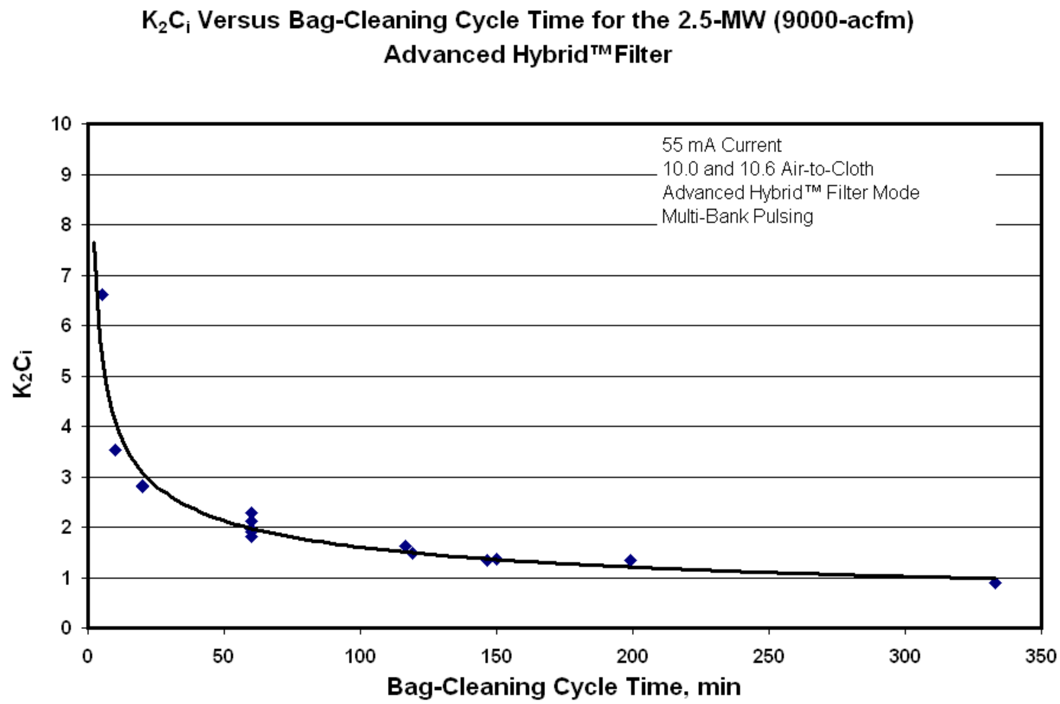


Figure 6. Effect of pulse interval on K_2C_i for 9000-acfm pilot *Advanced Hybrid*™ filter.

1.5 Full-Scale Design and Differences Between Full and Pilot Scale

The original ESP at Big Stone consisted of a Lurgi-Wheelabrator design with four main chambers and four collecting fields in series within each chamber. Only the last three fields in each chamber were converted into an *Advanced Hybrid*™ filter while the first field was unchanged (Figure 7). Since the ESP plates are 40 ft high, but the *Advanced Hybrid*™ filter bags are only 23 ft long, there is a large open space between the bottom of the bags and the hoppers (Figure 8). The outer six compartments (Figure 7) are arranged with 20 rows and 21 bags per row, while the six inner compartments have 19 rows with 21 bags per row. The total number of planned bags for the 12 compartments was 4914. However, because of a spacing limitation from the electrode rapping mechanism, a total of 81 bags had to be removed, so the total number of bags in service is 4834.

The main differences between the 2.5-MW pilot *Advanced Hybrid*™ filter and the full-scale Big Stone *Advanced Hybrid*™ filter are as follows:

- The pilot unit has a small precollection zone consisting of one discharge electrode, while the full-scale unit has no precollection zone (without the first field on). The effect would be better ESP collection (lower K_2C_i) in the pilot unit. The pilot unit has shorter bags, 15 ft versus 23 ft for the full-scale *Advanced Hybrid*™ filter. The expected result would be better bag cleaning with the pilot unit (lower residual drag).

- The full-scale *Advanced Hybrid*™ filter has an ESP plate spacing of 12 in. compared to 13.5 in. for the pilot-scale unit. The expected result is somewhat better ESP collection efficiency.

- The entrance velocity of the flue gas is 4–8 ft/s for the full-scale unit versus 2 ft/s in the pilot-scale unit. The expected effect is better ESP collection efficiency with the pilot unit.

- The pilot unit has very uniform side inlet flow distribution while the full-scale *Advanced Hybrid*™ filter has flow from the side for the first *Advanced Hybrid*™ filter compartment and from the bottom in the back 2 compartments.

In the pilot unit all of the flow is uniformly distributed from the side and none of the flow comes from the bottom. In the full-scale *Advanced Hybrid*™ filter, flow entering the first *Advanced Hybrid*™ filter chamber comes from the side (similar to the pilot unit). The flow to the back two compartments must first travel below the first *Advanced Hybrid*™ filter compartment and then either directly up from the bottom into the compartment or up from the bottom into the areas between compartments and then horizontally into the compartments (Figure 8).

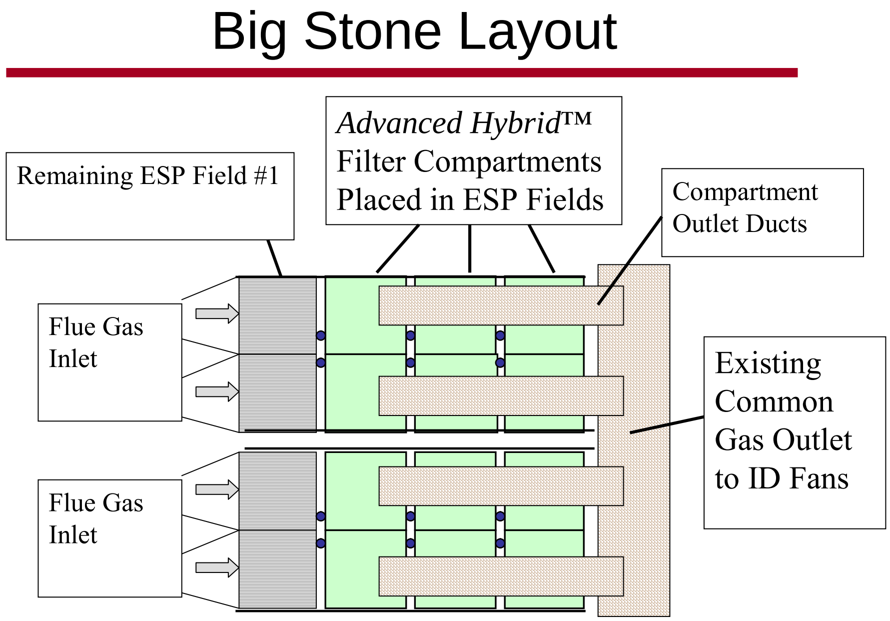


Figure 7. Top view of the *Advanced Hybrid*™ filter full-scale retrofit configuration at Big Stone.

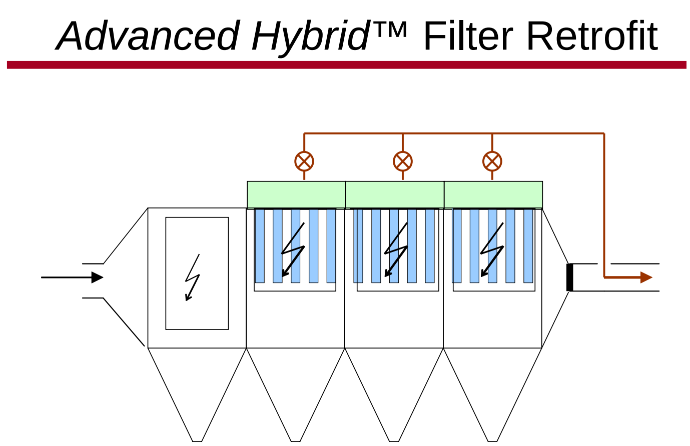


Figure 8. Side view of the *Advanced Hybrid*™ filter full-scale retrofit configuration at Big Stone.

2.0 EXPERIMENTAL

2.1 Independent Characteristics

2.1.1 Independent Characteristic Chart

The following chart lists the specific independent characteristics of the Advanced Hybrid System. If changes are made to the independent data, they will be described in the section listed under the "Notes" column.

Table 3.

Data	Status	Notes
ESP Collecting Surface	170,500 ft^2	Unchanged
# of Discharge Electrodes	2,706	Unchanged
# of Filter Bags	4833	Unchanged
Filter Bag Dimensions	7 Meters Long, 6 Inches Diameter	Unchanged
Filter Bag Surface Area	36.07 ft^2	Unchanged
Filter Bag Material	See 2.1.2	Unchanged
Pulse Pressure	80 psi	Unchanged
Cleaning Mode	Threshhold Cleaning	Unchanged
TR Rating of AH Field	1500 ma, 55 kV	Unchanged
TR Rating of Inlet ESP Field	2000 ma, 55 kV	Unchanged
Inlet ESP Field Data		
Inlet Field Dimensions[1]	45 gas passages, 40 feet high, 14 feet deep/chamber	Unchanged
Inlet Field Plate Area[1]	50,400 ft^2	Unchanged
Inlet Field Electrodes[1]	Wheelabrator bed frame "Star" Electrodes	Unchanged

[1]The inlet ESP field was left in place. The design is the original configuration as installed in 1975. It is not the intention to operate the inlet field, however it was left in place as an added benefit of the system.

2.1.2 Bag Layout

For specific bag layout and description over the life of the project, refer to Appendix B23.

2.2 Dependent Characteristics

2.2.1 Dependent Data

The dependent data is largely presented in graphical format in the Appendix. The specific data points that are instrumented and presented are as follows;

Plant Gross Load: Continuously monitored TDC-3000 calculated value based on the generator output voltage and current. When the plant trips offline or shuts down for maintenance, the plant gross load will be zero.

Total Flue Gas Flow: Continuously monitored using United Science Inc.'s Ultra Flow 100 ultrasonic flow monitor. The flow monitor is located at the stack midlevel (see position #6 on the figure in 2.2.2). The readout of the flow monitor is in kscfm using 68^{o}F and 29.92 in HG as standard conditions. The flow is converted to kacfm using the following equation:

$$\text{Gas Flow (kacfm)} = \frac{\text{(Gas Flow(kscfm)*(460 + Inlet Gas Temp}^o\text{ F)}}{(460+68^o\text{ F})} * \frac{29.92\text{ in HG}}{\text{(28.56 in HG + AHPC outlet Pressure)}}$$

Inlet Flue Gas Temperature: Continuously monitored using a grid of Type E thermocouples. The thermocouples are located at the AHPC inlet (see position #1 on the figure in 2.2.2). There are eight thermocouples at the inlet of each of the four AHPC chambers for a total of 32 thermocouples.

Tubesheet Differential Pressure: Continuously monitored on two of the twelve compartments. Pressure taps above and below the tubesheet (see positions #3 and #4 on the figure in 2.2.2) are equipped with Honeywell 3000 Smart DP Transmitters.

Flange–Flange Differential Pressure: Continuously monitored using two Honeywell 3000 Smart DP Transmitters at the AHPC inlet (see position # 2 in the figure in 2.2.2) and two Honeywell 3000 Smart DP Transmitters at the AHPC outlet (see position #5 on Diagram 1). Continuously calculated by the TDC- 3000 by taking the difference between the flue gas pressure at the AHPC inlet and outlet.

Air-to-Cloth Ratio: Calculated by dividing the Gas Flow (acfm) by the total surface area of the bags.

Opacity: Continuously measured by the plant opacity monitor, Monitor Labs Model #LS541. Opacity is measured in the Plant Stack, position 6 on the figure in 2.2.2. Position 6 is approximately at the 300 ft. level from grade.

Flue Gas Outlet Pressure: Continuously monitored using two Honeywell 3000 Smart DP Transmitters at the AHPC outlet (see position #5 in the figure in 2.2.2). The inlet pressure can be determined by the difference between the outlet pressure, and the flange-to-flange pressure drop.

Temperature per Chamber: See Inlet Temperature above.

ESP Power Consumption: Continuously monitored with a watt-hour meter to each chamber.

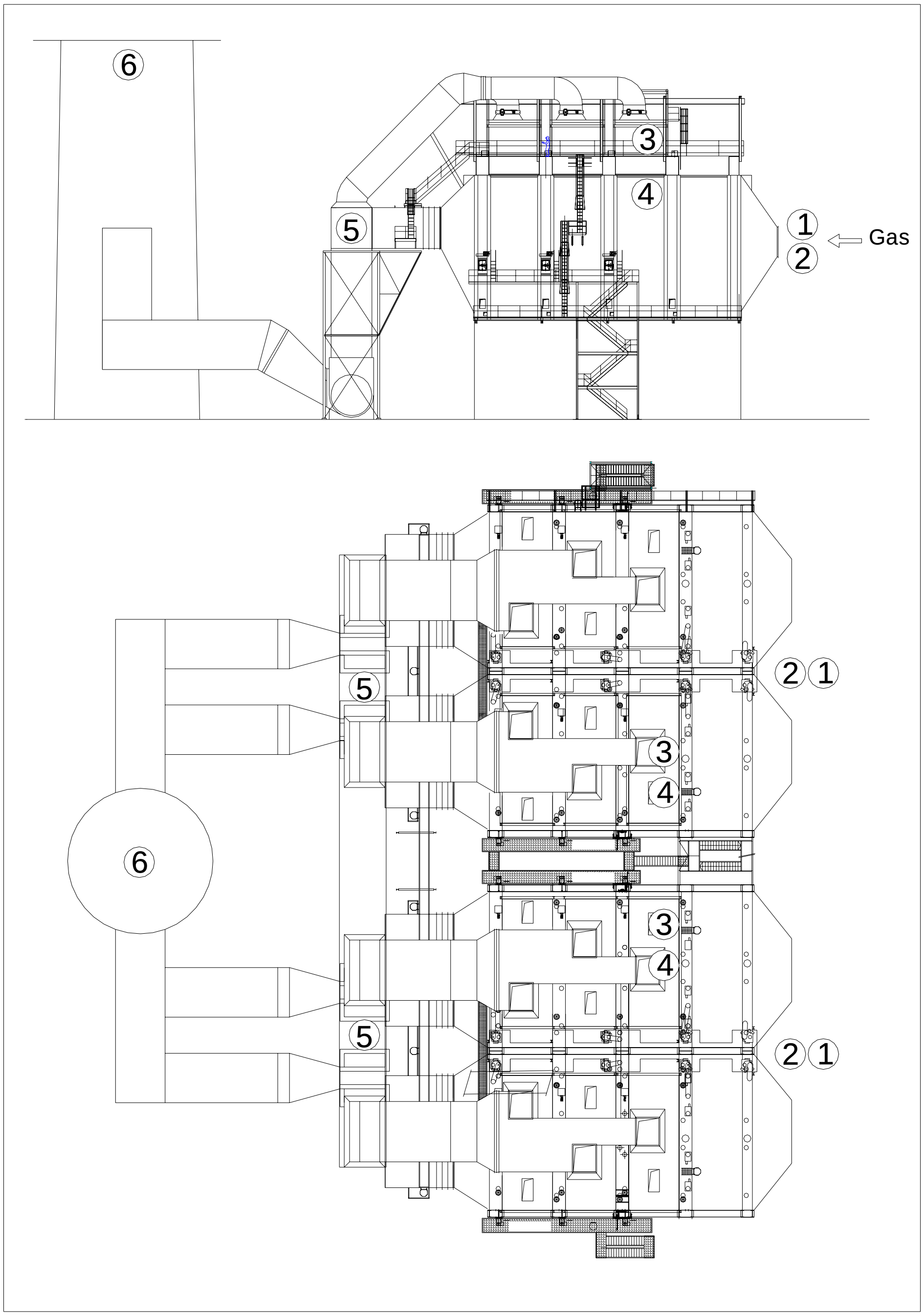
Compressed Air Flow: Continuously monitored using a Diamond II Annubar flow sensor equipped with a Honeywell 3000 Smart DP Transmitter. This ANNUBAR instrument is in the compressed air supply line after the compressors but before the desiccant dryer.

The non-instrumented data that can be found in the appendix is as follows

- Coal Analysis
- Flyash Analysis
- Coal and Alternative fuel Burned

2.2.2 Instrument Location Diagram

1 & 2: Advanced Hybrid Inlet
3 & 4: Above and Below Tubesheet
5: Advanced Hybrid Outlet
6: Plant Stack



2.2.3 Data Retrieval

Big Stone Plant's Honeywell TDC-3000 process control system monitors and controls a large number of actuators, sensors, and processes using PID controllers, programmable logic controllers, and special-purpose programs. Data gathered by the TDC-3000 is retrieved using an existing plant historian database. The dependent characteristic data presented in this report is calculated using 60-minute averages of the TDC-3000 readings, which are recorded every minute.

2.2.4 Data Reduction

Reported NO_X and SO_2 emissions have had 5% of data removed due to erroneous spikes occurring during daily calibration of CEMS instrumentation. No other assumptions or restrictions were used to transform the raw measured data into a form usable for interpretation.

3.0 RESULTS AND DISCUSSION

3.1 General Results and Discussion

3.1.1 Chronological History of Significant Accomplishments

<u>Quarter 1 (October 2002 – December 2002)</u>	
System Startup	October 2002
Rapper Problems Realized	November 2002
Pulse Valve Problems Realized	November 2002
EERC Testing (99.99% particulate capture goal met)	November 2002
Inlet Field Energized	December 2002
<u>Quarter 2 (January 2003 – March 2003)</u>	
Soybeans burned at Big Stone as Alternative Fuels	January 2003
Derates due to high dP across the AH system begin	January 2003
Comparative Testing of Pilot unit to full-scale unit	February 2003
Plant shut down to wash boiler	February 2003
<u>Quarter 3 (April 2003 – June 2003)</u>	
Meeting to discuss improvement options	April 2003
Bags washed in two chambers	April/May 2003
Pitot data used for evaluation and decision	May 2003
Decision to replace filter bags	May 2003
Complete bag changeout	June 2003
Inlet field evaluated	June 2003
Plant restored to full load	June 2003
<u>Quarter 4 (July 2003 – September 2003)</u>	
Big Stone limited to 440 – 445 MW not due to AH	July/Sept 2003
Performance Tests	July/Sept 2003
Fluent Analysis Plan	Sept 2003
Preliminary baffle design submitted	Sept 2003
<u>Quarter 5 (October 2003 – December 2003)</u>	
Opacity rise attributed to initiation of bag failures	October 2003
Competitive bidding of replacement bags	November 2003
Fluent modeling results for flow baffles	November 2003
Test flow baffles installed	December 2003
Four compartments of bags replaced	December 2003
<u>Quarter 6 (January 2004 – March 2004)</u>	
Stable system operation	Jan/March 2004
Fluent modeling work continues	February 2004
Technology goals reviewed	February 2004
Next phase of project reviewed & proposed by OTP	March 2004

Quarter 7 (April 2004 – June 2004)	
PPS Bags Failing and Opacity Rising	April/June 2004
Inlet Field AH Proposal	May 2004
All PPS Bags replaced with P-84 Bags	June 2004
Chamber 2B baffles installed	June 2004
One compartment of blowpipes modified	June 2004
Opacity returned to low levels	June 2004
Bag analysis performed	June 2004
Additional 8 bags removed for testing	June 2004
Quarter 8 (July 2004 – September 2004)	
Independent Lab Analysis of Bags Completed	July 2004
Evidence of NOMEX Bag failure	August 2004
Future project reviewed	July/Sept 2004
Failed P-84 bags discovered	September 2004
Quarter 9 (October 2004 – December 2004)	
NOMEX Bags replaced with fiberglass	October 2004
1/2 compartment of P-84 bags replaced	October 2004
High dP through the end of the year	Oct/Dec 2004
Independent Lab Analysis of P-84 Bags	December 2004
Quarter 10 (January 2005 – March 2005)	
Design for inlet field modifications finalized	January 2005
Fabrication of inlet field equipment	February 2005
Construction plans finalized	March 2005
Quarter 11 (April 2005 – June 2005)	
Modification of Inlet field	April/May 2005
Startup of lower A:C Ratio Advanced Hybrid	June 2005
Shakeout of new installation	July 2005
Quarter 12 (July 2005 – September 2005)	
Investigation of performance issues	July 2005
Corrected known ESP clearance problems	July 2005
Investigated TR Set issues	September 2005
Quarter 13 (October 2005 – December 2005)	
Replaced failed pulse header joints	December 2005
Corrected additional ESP clearance problems	December 2005
Final determination of technology (OTP)	December 2005

3.1.2 Discussion of Results of Significant Accomplishments

General Discussion (First Quarter 10/2002 – 12/2002)

Initial Startup Problems

The Plant was put on-line (after the scheduled maintenance outage) on October 25 at 17:37, which is the official beginning of commercial operation of the Advanced Hybrid system. Startup and checkout of the system went fairly smoothly. There were few significant issues that came up during system startup, as described below.

First, there appeared to be a problem with damper operability as the dampers were commanded to open and close to check functionability. The indication for opened and closed did not come in to the plant control room. This was a simple limit switch setting in the controller. Specific training needed to take place between the ELEX startup engineers and Big Stone Plant personnel, as setting the limit switches required knowledge of procedures that, if not followed correctly, would result in the unintended dismantling of the controller body. The manual wheel on the actuator would unscrew from the controller body allowing the oil to leak out, thus rendering the actuator inoperable. This occurred 3 or 4 times before startup personnel familiarized themselves and from that point it proceeded well.

Second, ice had formed in the pressure sensing lines after the advanced hybrid system (just prior to the ID fans). At startup, the pulse controller used the flange-to-flange pressure drop as the input for pulse frequency. If a high enough differential had been realized, the system would not have started pulsing because there would have been no pressure measurement. This could have delayed startup. The sensing lines were about 70 feet long and run 50 feet overhead. However, the ice buildup was not significant and was cleared using torches and poke rods.

Third, pre-coating the bags was a new experience and the procedure was not well developed. The bag manufacturer deemed pre-coating the bags necessary. A supplier delivered crushed limestone via truck and had to wait until the system was ready to be pre-coated. Pre-coating was a manual operation, as Big Stone Plant operators moved a four inch flexible line from duct to duct to inject the crushed limestone into the appropriate chambers. This process directly added to the critical path of the outage, and therefore the time that it takes to pre-coat the bags is directly related to delays in starting up the unit. If this must continue in the future, it would be necessary to install a silo and automatic feed system so the process could be completed in minutes rather than hours. This was an oversight in the project design and plans should be taken into account for future installations if bag pre-coating is necessary.

Fourth, the pulse system was not tested with compressed air until the system was started up. The system worked to pulse the bags, however it required the ELEX startup engineers several days to work the bugs out of the pulsing program to consider it functional for normal operation.

Overall system startup went well and fairly trouble free. The operational issues listed above are only the points of interest, and in general, the system components fit and worked together.

Operational Experience

The operational experience was mixed during the initial phases of operation. W.L. Gore and Associates produced the graph in Figure 9. The graph shows that the drag on the system was running between 0.9 and 1.0 INH2O/ft/min during the first few days of startup. However, the whole story includes the bag pulse

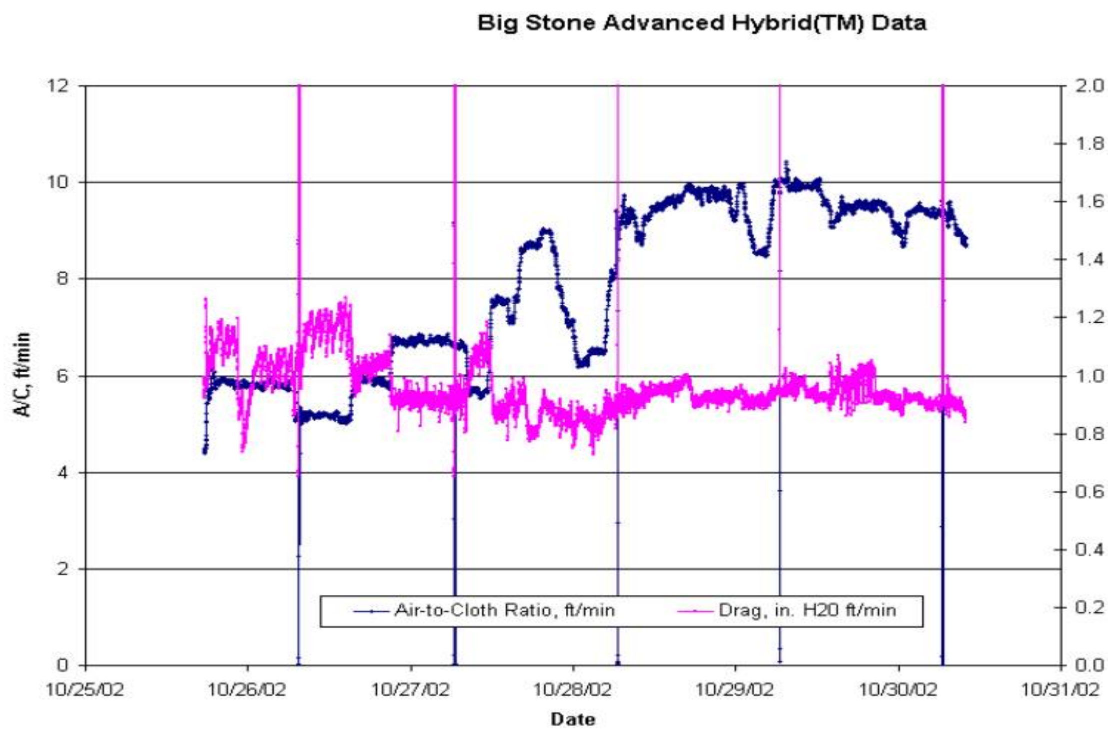


Figure 9 - A/C Ratio and drag during the first week of operation

frequency. The system is attempting to run at a flange-to-flange pressure drop at 9.0 INH2O. It is accomplishing this by changing the rate at which the 504 pulse valves are firing. That rate is not currently being recorded so there is no history. In Figure 1, we do not know if the pulse valves are running continuously (about 1.2 seconds between pulses), or one tenth of that (about 12 seconds between pulses), or any amount between. As a result, it is very difficult to put a meaningful analysis together on how the system was operating. The system was pulsing very quickly (about 1.2 – 2.4 seconds between pulses), within days of initial operation. During the first month of operation, it was deemed necessary to get some type of pulse signal into history. Eventually (around December 5, 2002) a system was installed to measure and record the pulse frequency. By that time the system was in constant pulsing while at full load, and the recorded history was not very useful.

One of the first mechanical issues seen after startup was sticking solenoid valves. On October 28, the Monday after startup, it was noticed that a fair number of solenoid valves were not operational. This was traced to the compressed air supply lines that were not blown clear prior to being connected. The cutting oil and debris in the lines contaminated the solenoid valves. The Big Stone Plant technicians disassembled and cleaned a portion of the solenoid valves to alleviate this problem. After the initial rash of sticking valves, the problem disappeared.

One of the first tests run was the off -line bag cleaning function of the Hesch pulse valve controller. This function intended to enable one compartment (1/12 of the total) to be isolated from gas flow, and pulsed without gas going through the bags. This should have resulted in improved cleaning and a lower differential pressure. This feature was tested on October 29, but did not work as the pulse valves did not activate when the damper was closed to the compartment. This was a software problem and a software update was shipped from Hesch and installed on November 12. The software fix did allow the functionality of off-line cleaning, but through intermittent tests, it was not clearly defined as a benefit to the normal cleaning modes and was not implemented as the normal mode. The differential was too high with 12 compartments in service, and taking one of the compartments out of service raised the overall differential pressure to intolerable levels.

On October 31, forced cleaning mode was also tested. This mode continuously pulsed the cleaning valves. This also did not work correctly, but the software fix mentioned in the paragraph above resolved this issue.

During the first week of operation, two filter bags were found in the ash hoppers below the Advanced Hybrid system. This was a strong concern at the time, as we were not sure if all of the bags were prone to being dislodged from the cage and tubesheet fit. It appears there were only a few ill-fitting or mis-installed bags which came loose and fell. Two bags represents 0.04% of the total bags installed.

The Big Stone Plant was derated on November 9 to replace these two bags, and inspect that portion of the AHPC. One bag was removed for examination by W.L. Gore personnel. During startup and limited first data, from the first two weeks, the bags were in good shape and there were no adverse effects from startup or short-term operation.

Alternative fuels burned at Big Stone were started back up on November 1. The specific amounts can be seen in Appendix B14.

On November 18, the Energy and Environmental Research Center (EERC) performed the first stack test to evaluate the particulate capture of the system. The full report can be found in the Appendix, but the summary chart in Figure 10 shows that the particulate capture of the system was very high as expected.

Table 6. Advanced Hybrid™ Particulate Collection Efficiency (From Appendix)

Date	Sample Method	Advanced Hybrid™ Inlet Dust Loading, grains/scf	Advanced Hybrid™ Inlet[1] Dust Loading, lb/10^6 Btu	Stack Dust Loading, grains/scf	Stack[1] Dust Loading, lb/10^6 Btu	Particulate Collection Efficiency, %
11/18/2002	EPA Method 17			0.00002	0.00003	99.998
11/19/2002	EPA Method 29	1.02092	1.38378			
	Multicyclones	0.64099	0.86882			
11/20/2002	EPA Method 17			0.00006	0.00008	99.994
	EPA Method 29	0.85856	1.16372			
	EPA Method 29	0.92151	1.24904			
11/21/2002	EPA Method 17			0.00003	0.00004	99.997
	Multicyclones	0.66113	0.89611			
	Multicyclones	0.70044	0.94940			

[1] Values were calculated based on the Fd factors shown in Table 3 for 100% PRB.

Figure 10 - Results of Stack Testing by the EERC

During the month of November, two more bags were found in the hoppers. On November 23, three fourths of the system was removed from service to complete an inspection of the system. Two more bags that had fallen from the tubesheet were located and replaced. There was significant ash buildup on the perforated plates and the rapping schedule was adjusted for a higher frequency of rapping.

The Big Stone Plant electricians completed routine external inspections of the plate rapper system by manual operation of the rapper system and observation from the exterior. During one of these inspections in later November, it was found that one of the rappers in Chamber 2B was not turning. Electricians disconnected the motor and verified that rapper shaft was jammed internal to the system. On the 17th of December, the system was removed from service and inspected. At the time, the rapper shaft was found to need repairs; there was a broken hammer, bent rollers, and hammer to anvil alignment problems. The collar that grips the rapper shaft appeared loose. There were two fundamental issues with the reliability of the plate rappers. First, the rapper shafts were the wrong diameter. The collars that grip these shafts to keep them from floating laterally could not effectively maintain the shaft alignment. Second, the internal walkways were mounted fixed at the opposite wall as the fixed point of the rapper shafts. As the system heats up when flue gas is put through it, the walkways and the rapper shafts expand in opposite directions and misalignment between the rapper hammers and the anvils occurs. The system was also taken down on December 31, with misalignment of the rapper shaft to the walkway components the cause of another frozen rapper.

The Goyen pulse valves appeared to have an operational problem during the month of November as observed by listening to the valves operating. Occasionally a valve would not pulse with as much energy as the adjacent valve. This indication was a loud squeak or a muffled noise as opposed to a strong pulse. A Goyen representative was dispatched to the site on December 18 to review the operation of the valves. He recommended removal of the silencers on each valve to reduce the noise. It is possible that these silencers might have been plugged during startup or normal operation. All 504 silencers were removed from the pulse valves and it seemed to take care of the problem. No significant improvement in overall differential pressure was realized, so it is doubtful if more than 5 – 10% of the valves had problems with these silencers.

As the differential pressure had risen in the first couple of months of operation, it was decided to energize the unmodified inlet ESP fields to reduce the ash loading to the Advanced Hybrid system. This was planned as an only-in-an-emergency contingency, but was implemented so a performance and improvement plan could be evaluated. There is one inlet field of original Wheelabrator ESP in each chamber. These fields were energized on December 12 and have remained in service.

There appears to be a discrepancy in the gas flow and sizing of the system. It is our understanding that the system was sized on a stoichiometric flow value based on fuel flow into the boiler, the measured oxygen level after the economizer and the air heater leakage as has been measured at the plant. The flow value was 1,824,000 acfm. However, the stack flow monitor is reading 5 – 15% more flow than is predicted by the stoichiometric balance. Using the 1,824,000 acfm value and dividing by the installed cloth surface area would result in an air-to-cloth ratio of 10.5 fpm. The goal of the technology was demonstration of acceptable performance at an air-to-cloth ratio of 12 fpm so that it would be the clear economic choice when compared to other retrofit technologies. The gas flow through the system presented in Appendices B2, B3, & B7 are based on the stack flow monitor, which reads 5 – 15% more than the stoichiometric balance predicts.

General Discussion (Second Quarter 1/2003 – 3/2003)

The system to date has experienced significant operational problems. The focus is the high differential pressure across the bags. Some of the mechanical issues have been resolved, but the primary performance concerns appear to be design and/or process related. Very significant derates of power plant output have occurred as a result of ID fan limitations, caused by the high differential pressure across the bags of the Advanced Hybrid system. The factors that appear to be contributing to this are described below.

The first regular full-load plant derate due to the high differential pressure across the Advanced Hybrid system occurred on January 8, 2003. Since that date, the plant has experienced derates as high as 55 MW. This is a significant detriment to the plant and the company's portfolio of available energy. As a result, an aggressive stance to improve AHPC performance has been taken. The performance of the system still boils down to two factors, mechanical reliability and process performance.

<u>Mechanical Issues</u>

Two issues remain with the mechanical operation of the system, plate rapper alignment and compressed air supply pressure to the headers of the pulse valves.

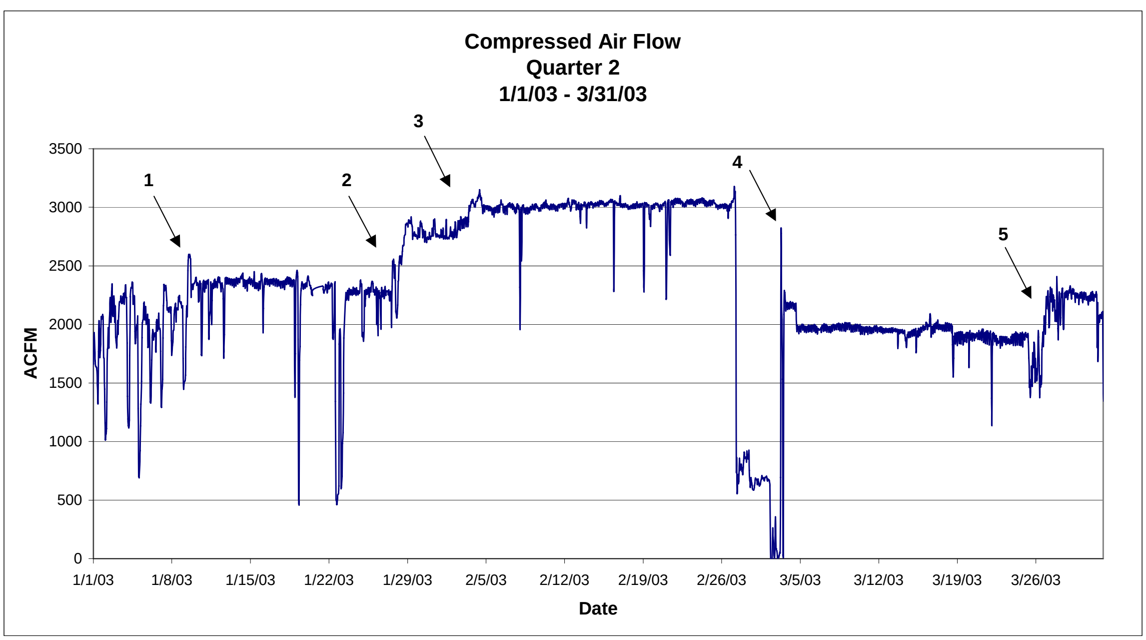
Two of the plate rappers remain a problem with regards to internal clearances and binding of the rapper shafts while in operation. A derate was taken on January 19th to inspect the system, evaluate the cause, and develop possible solutions. The problem with the rapper shafts binding due to internal obstructions as the system heats up is related to two problems. First, the rapper shafts being too small for the retaining collars at the wall. The second issue is, the opposite expansion of the rapper shafts and walkways due to opposite fixed points. This problem is described in the first quarterly report from the period of October 2002 – December 2002. Several pictures can be found in Appendix B18. The most likely fix is the replacement of the section of the rapper shafts extending through the fixed bearing so the retaining equipment can prevent the shaft from sliding laterally. This would most likely occur during the outage in June, 2003.

The other likely fix is to modify the existing equipment binding due to thermal expansion differences. There are five collars per rapper shaft that have clearance issues. The collar bolting is the problem. The collars, bolts, and visual evidence of the damage that occurs are shown in the pictures in Appendix B18 titled "Missing Roller" and "Damaged Bolt & Nut". Modifications to this system will take place during the scheduled wash outage in June. Other damage that occurred can be seen in the pictures titled "Anvil - Front View" and "Anvil – Angle View". Since there is poor hot alignment, a portion of the hammers are not striking the anvils squarely, damaging the anvils.

The other mechanical concern is the flow limitation from the pressure regulators in the compressed air system. As the system was installed, there were six regulators installed as described in the following table (location diagram of chambers and fields is included in multiple areas in the appendix). The AHPC system is capable of faster, more aggressive pulsing, but the regulators are limiting how much

Regulator #	Size	Compartment Supply
1	1.5”	Chamber 1A, Fields 2, 3, & 4
2	1.5”	Chamber 1B, Fields 3 & 4
3	1.5”	Chamber 2A, Fields 3 & 4
4	1.5”	Chamber 2B, Fields 2, 3, & 4
5	1.0”	Chamber 1B, Field 2
6	1.0”	Chamber 2A, Field 2

compressed air flow they allow through. During periods of off-line cleaning, we need to be able to pulse through all of the valves as quickly as possible to bring the off-line compartment back on-line. The following description of the efforts to resolve this issue can best be broken down by describing the “Compressed Air Flow” graph in Appendix B22.



Period 1. During this period, we removed regulators 2 and 3 from service and allowed full plant air system pressure to reach the headers, approximately 100 psig. Just prior to this date, the plant began

derating due to high differential across the bags. A slight increase in compressed air usage is seen on the graph. This made only slight improvements to lower the differential pressure (Appendix B5).

Period 2. We changed regulators 1 and 4 to 2" regulators and set the pulse cleaning cycle pause time to 0.1 seconds. We have been limited to 0.4 seconds of pause time between pulses due to the time required to refill the headers. A noticeable step change from 2250 acfm to 2800 acfm is seen on the trend. We were greatly exceeding the desiccant dryer capacity at this time, as this is rated for approximately 2000 acfm.

Period 3. We removed regulators 1 and 4 from service. This is the highest period of compressed air usage and we had great difficulty maintaining the compressed air system pressure in the plant.

Period 4. The plant was off-line to wash the steam heat transfer surfaces of the boiler. During this outage, we noticed the bags experiencing the highest pulse pressures were forming small concentric wear areas approximately 1 inch in diameter at the very bottom of the bags. This was likely due to the aggressive pulse energy and a poor bag-to-cage fit causing the bag to flex and rebound into the bottom of the cage. At that time we were exceeding the rating of the dessicant dryer. The plant compressed air system was not capable of supplying that continuous volume of compressed air. We put all regulators back in service and increased the pause time to 0.4 seconds.

Period 5. Twelve individual regulators were installed (one per compartment) and the cycle pause time was decreased from 0.4 seconds to 0.3 seconds. This has been the normal state since that time. Graphical data indicates constant pulsing with the pause time at 0.4 seconds results in compressed air usage of approximately 1900 acfm, and a pause time of 0.3 seconds results in a compressed air usage of approximately 2250 acfm.

With all twelve compartments having a dedicated pressure regulator, we have resolved the problem of not maintaining the pressure in the header during pulsing. After regulator installation, the headers have been maintaining a pulse pressure of approximately 80 psig.

<u>System Performance</u>

A great deal of effort has been put forth to both establish where we are at with the existing performance, and what can be done to improve performance. The very high differential pressure is significantly different than the previously reported results of the Pilot Unit operation. The first step in evaluating the performance was to attempt baseline testing with the pilot unit in place. The pilot unit was started up on February 3, and testing took place on February 8. There were two parameters, K2Ci and Residual Drag, which needed to be evaluated to compare performance of the two units. A short explanation of these terms and how they are calculated follows.

K2Ci

K2Ci a measure of the loading rate of dust to the filter bags. The measurement was completed by stopping the bag pulsing and measuring the rate of the rise in differential pressure. A slower rate of differential pressure rise would mean that the ESP portion of the Advanced Hybrid was taking out more dust prior to it reaching the bags. A faster differential pressure rise would mean that the ESP portion is not removing as much dust prior to it reaching the filter bags. Various tests were completed the night of February 8. A trend of the differential pressure of both the full-scale unit and the pilot unit is included below. A description of the individual tests follows.

Residual Drag

Residual Drag is the minimum resistance possible after pulse cleaning, or the resistance of the system with just the bags and whatever dust cake cannot be removed from the bags from pulsing. It is calculated by taking the differential pressure immediately after cleaning and dividing by the air-to-cloth ratio. The units for this measurement are INH2O/ft/min. Although the test was not set up to measure the residual drag of the pilot plant, previously reported results are in the 0.5 – 0.6 range.

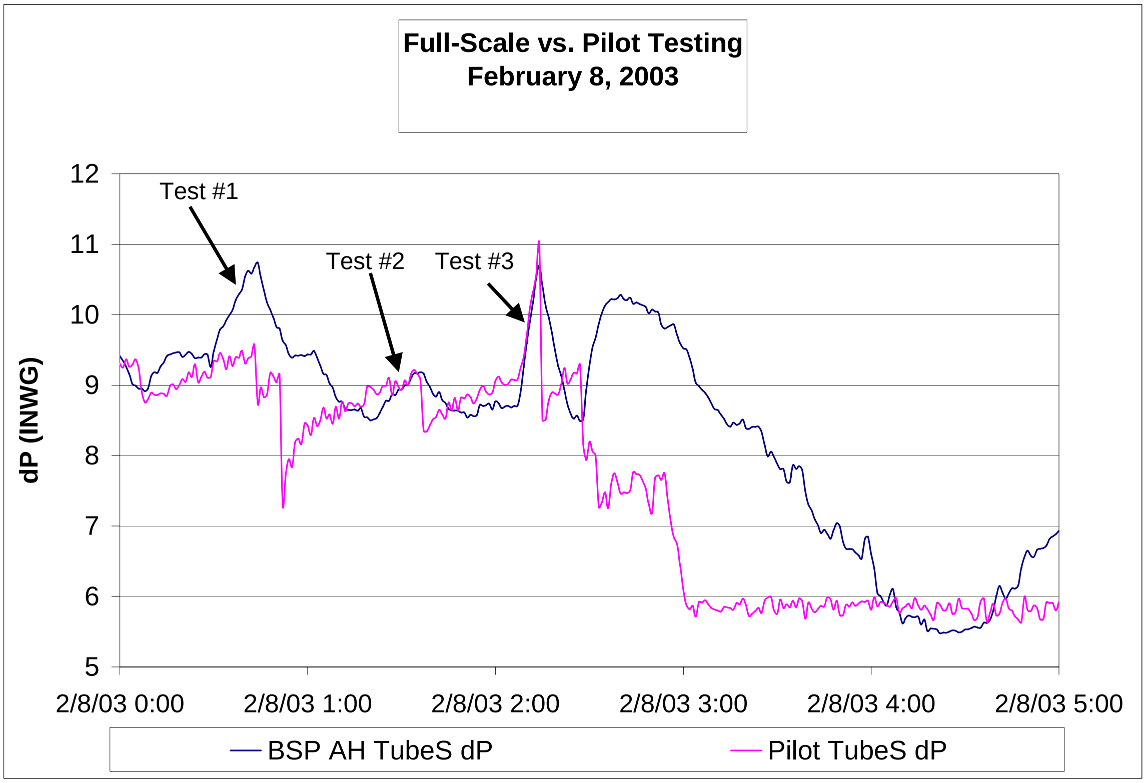
ESP Efficiency

For our test, ESP efficiency was calculated by a rule of thumb method. The loading rate with no ESP section in service was taken as the 0% ESP efficiency state. A 100% efficient ESP would have a 0 loading rate. Therefore, if the K2Ci value was found to be 5.0 IN H2O/HR, and the no ESP loading rate was found to be 19.0, the efficiency value was calculated by the following equation;

$$\text{ESP Efficiency} = (19.0 - 5.0) / 19.0 * 100 = 73.7\%$$

This is an unconventional method of calculating ESP efficiency but works well for our comparison testing.

Test #1. The TRs to only the Advanced Hybrid fields were energized. Both the full-scale system and the pilot unit were operating at 10.4 fpm according to flow instrumentation. The pulsing of the full-scale system was halted until the differential pressure reached unacceptable levels. Then the pulse system was started, but the rate of differential pressure increase was measured, and the differential pressure after one



cycle of cleaning was measured.

Test #2. The first test was repeated with all of the TRs, including the full-scale inlet field, energized.

Test#3. The same test was repeated with all of the TRs for both the pilot unit and the full-scale unit shut off. This test should be a good comparison of the overall ash loading rate to the bags without any electrostatic cleaning of the flue gas.

The following table is the summary of the test results.

	Air-to-cloth Ratio	K2Ci		ESP Efficiency		Residual Drag
		Full-Scale	Pilot	Full-Scale	Pilot	Full-Scale
Test #1	10.4	5.17	0.91	72.5 %	95.4 %	0.91
Test #2	10.4	3.02	1.5	83.9 %	92.5 %	0.83

Test #3	10.4	19.94	18.77	0 %	0 %	NA

Very significant conclusions can be made by analyzing the results of this testing. The loading rate of ash to the bags is 3 – 5 times higher in the full-scale unit when compared to the pilot unit. This means that the amount of dust that is being removed by the ESP portion of the systems is significantly different.

The residual drag is significantly higher in the full-scale unit as noticed during the first few days of startup (see Quarter 1 report).

Running the inlet field of the full-scale system reduces the ash loading to the bags by about 40% ((5.17-3.02)/5.17*100). Improving the ESP portion of the system also has a significant effect by reducing the residual drag. By doing nothing more than improving the overall collection of the ESP sections (inlet field and Advanced Hybrid fields) from 72.5% to 83.9%, the residual drag has been reduced from 9.1 to 8.3, approximately 9%

The comparison results from Test 3 show a very good correlation to the full-scale unit and the pilot unit. This tells us that the inlet dust loading to both systems is about equal.

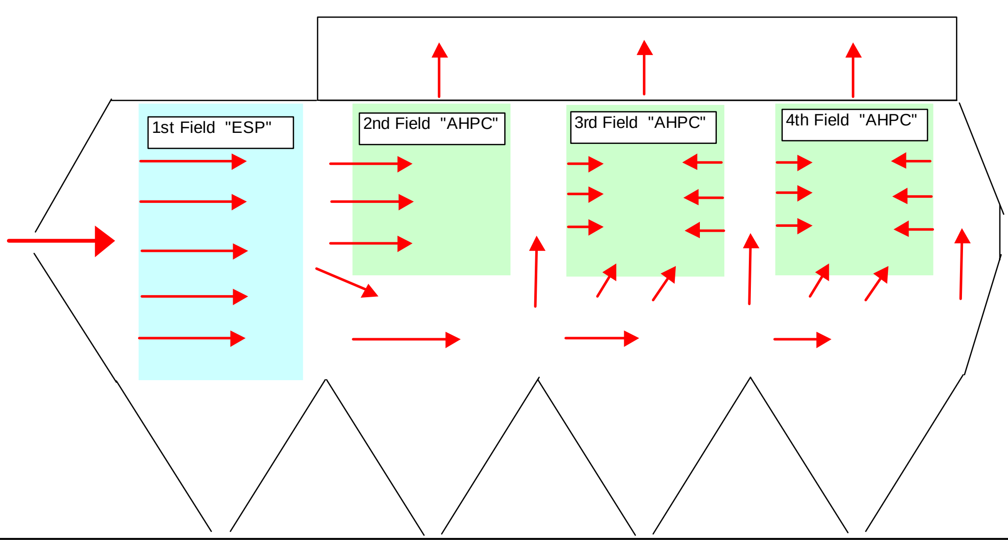
Possible Reasons for Performance Differences

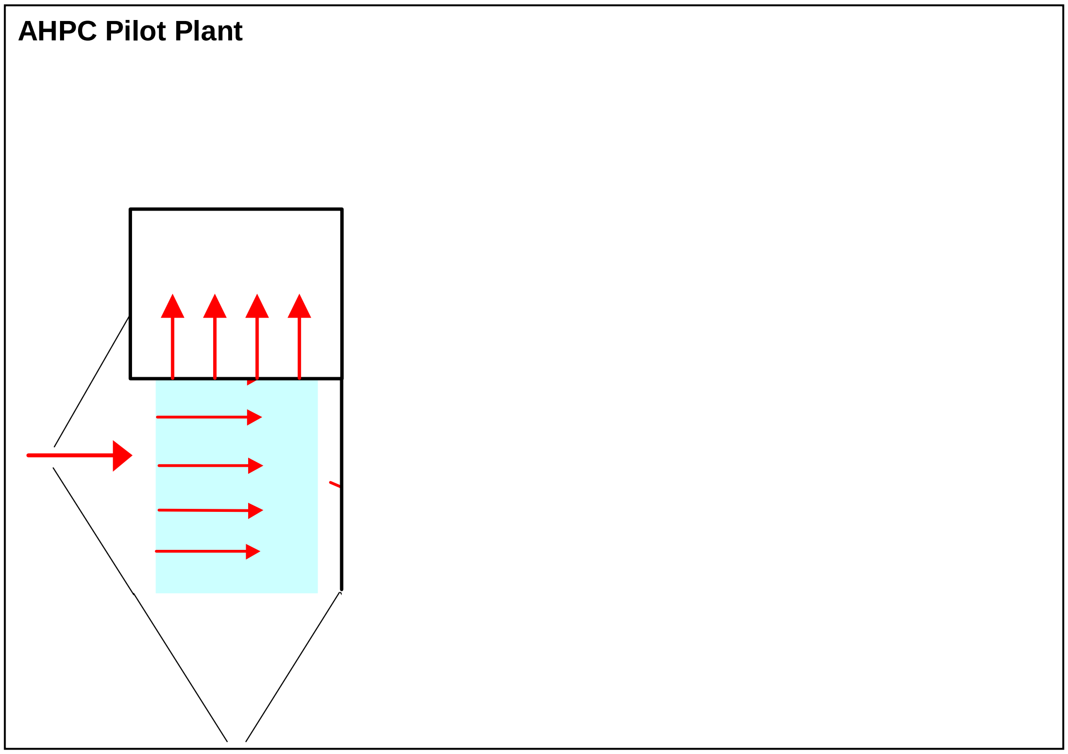
Trying to formulate a plan for improving the performance of the system involves putting together several hypothesis as to why the performance may be different than expected, how it can be verified, and what can realistically be done to improve the system.

Possible explanations for the ESP efficiency difference have been a flow distribution difference as the pilot unit is a side entry system and the full-scale unit is more of a combination of 1/3 side entry and 2/3 bottom entry. Some flue gas may also be bypassing the ESP section if there is a significant portion of the flue gas that is coming up from the area below the bags.

A better description of the flow differences can be found in the following diagrams. The diagrams represent the flow as modeled by ELEX AG at the beginning of the project. Some of the flow is vertical as represented by the red arrows. However, the pilot unit flow is more represented by the flow only in the first field. After entering this field in the pilot, the gas flow is upwards and into the clean gas plenum. There are no “back fields” of Advanced Hybrid components in the Pilot unit.

AHPC Big Stone Plant
Current gas flow pattern within one chamber and to the 3 fields of AHPC.
Red arrows define flow direction and relative magnitude.
The gas flow in this configuration can enter the AHPC ESP zone from the front, back or bottom of the field.





At this time, no reasonable improvements to the Advanced Hybrid ESP portion could be ascertained. The only suggested improvements are power off rapping or the potential for flow baffles that would require significant funding and mechanical changes to the system.

Possible explanations to the residual drag issue are more resistance due to bag material or manufacture, cleaning system deficiencies, or ash characteristics limiting removal during pulsing.

We investigated the effect of the burning of soybeans in the Big Stone Plant as an alternative fuel. During the first two months of the year, approximately 15,000 tons of soybeans (5% of the total fuel) were burned, with the obvious effect of fouling the steam tube surfaces inside the boiler furnace. This might have had some effect on increasing the residual drag of the system by depositing ash on the bags that cannot be easily removed. The EERC analyzed the residual ash cake taken from a bag in service and found a high percentage of potassium. An analysis of soybeans and corn (which is also an alternative fuel fired at the Big Stone Plant) is included in Appendix B16. We should have documented the residual drag of the system at the end of December and the residual drag of the system after the soybeans were burned. This would have given us more information as to how much of the residual drag difference between the pilot unit and the full-scale unit was due to combustion of higher potassium fuels. The EERC determined it is likely the flyash from the soybeans was a factor in the increase of the residual drag. The e-mail from Stan Miller from the EERC is included in Appendix B25.

Performance Improvement Plan

A great deal of effort was put into assembling a performance improvement plan. There were two tactics taken as a part of this effort; a short-term plan designed to help the plant get back to full-load capability, and a long-term plan to bring the Advanced Hybrid system performance up to expected levels.

Short-term Improvement Plan

- Testing the off-line cleaning system
- Testing power off rapping
- Improvements to the ESP Inlet Field
- Washing the filter bags
- Pitot tube data gathering

Off-line Cleaning

The intention of the off-line cleaning system was to close the outlet damper of one of the twelve compartments of the system and pulse that chamber while no gas flow is passing through the bags. In theory, this would allow a better cleaning of the bags, reducing the residual drag and the differential pressure of the system. Once the issues with the compressed air regulators were resolved, this technique was attempted several times. Although there were times when there appeared to be a slight improvement in differential pressure, the results were miniscule at best and this path was not further pursued. The existing cleaning system was removing the ash at the same rate in either cleaning mode. Another difficulty in this arrangement is that simply closing the outlet damper to a single compartment raised the dP by 1.0 – 1.5 INH2O and this could cause the existing condition of limited fan capability to worsen and result in an ID fan stall.

Power Off Rapping

Power off rapping was also tried to improve the overall field strength of the ESP system. In almost all cases the field strength was increased, but the overall effect on differential pressure was minimal or non-existent. The existing system did not have a true power off rapping system installed, so the test of the system was done manually by shutting off the power to the TR to a certain field, and manually commanding the plate and electrode rappers to run. Since little to no benefit was seen with regards to power off rapping it was not adopted as a performance improvement strategy.

Improvements to the ESP Inlet Field

The performance of the inlet ESP field seemed to vary considerably from chamber to chamber. Since the original ESP equipment was over 25 years old and difficult to maintain improvements to plate spacing or rapping could be made to bring the ash removal abilities of the inlet field to the maximum. Although improving this section of the system does not improve the Advanced Hybrid system, it was determined that the field would be analyzed by technicians from ELEX AG and modifications made to try to improve the overall performance.

Washing the Filter Bags

W.L. Gore personnel recommended washing the existing bags to remove the residual dust cake that could not be removed by pulsing. This seemed like an attractive option as the concern over the potassium rich flyash from the soybeans burned in the Big Stone Boiler could be eliminated. However, there was an even larger concern that water would be in direct contact with the flyash in the Advanced Hybrid box. This material is much like concrete dust and if some of the dust were to get wet and not be removed, this could cause major problems inside the system. More investigation was needed to make this decision.

Pitot Tube Data Gathering

One of the corner stones to decision making was the effort by W.L. Gore and Associates to install a substantial number of pitot tubes directly over an individual bag. This should allow better specific information with regards to potential improvement options. The effort to complete this task was significant, and the decisions that were made with regards to bag washing and bag replacement were in large part based on this tool. A brief description of this effort is needed to understand the measurement history.

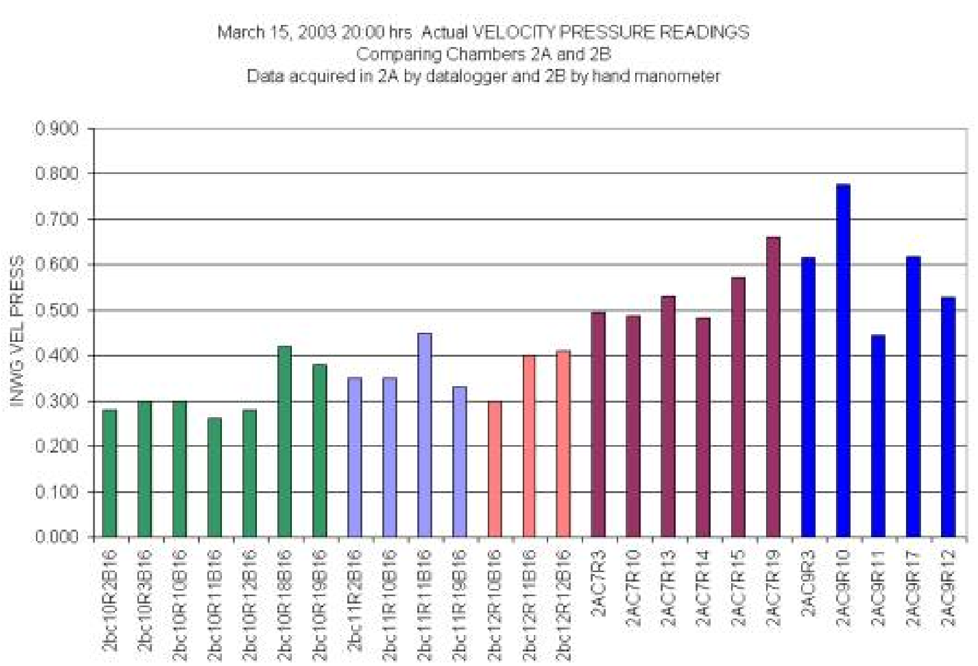
Pitot Tube Measurements

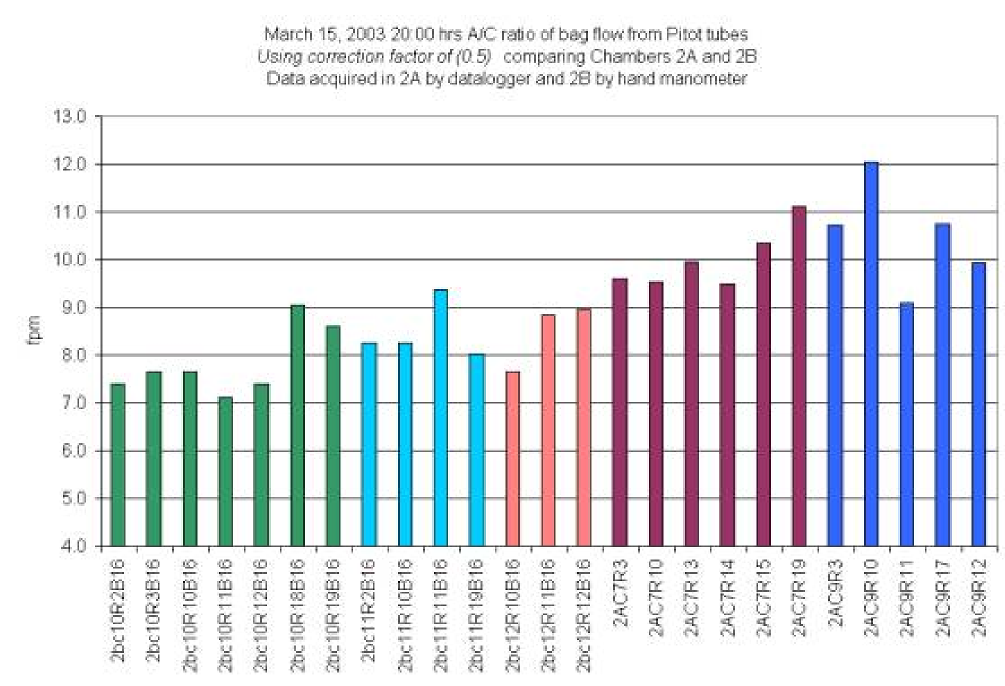
Pitot tube measurements were used successfully on the Pilot unit and reported to the NETL by the EERC. The best description of the Pitot tube effort is the pictures included in Appendix B26. These are photographs depicting the installation of the pitot tubes as they were clamped on to the pulse pipes and extended into the bags. Also included in Appendix B27 is a document from Rich Gebert of W.L. Gore and Associates with more specific design and details of the pitot tubes. The placement of the Pitot tubes can be found on a specific bag layout chart in Appendix B28. These pitots were installed during the boiler wash outage from February 26 through March 2. Low pressure transmitters (Appendix B29) were set up near these compartment locations to record the velocity and static pressure data. There were a limited number of transmitters available for velocity pressure readings, so the connection lines to the transmitters have to be moved frequently to show multiple compartment data.

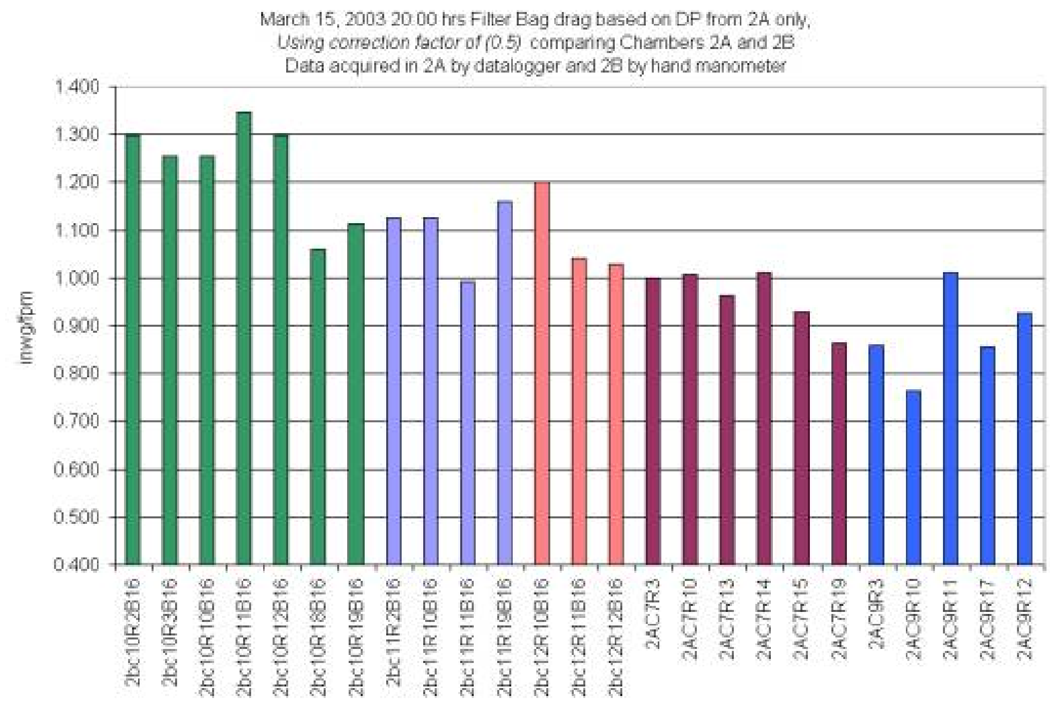
Data from Pitot Tube Measurements

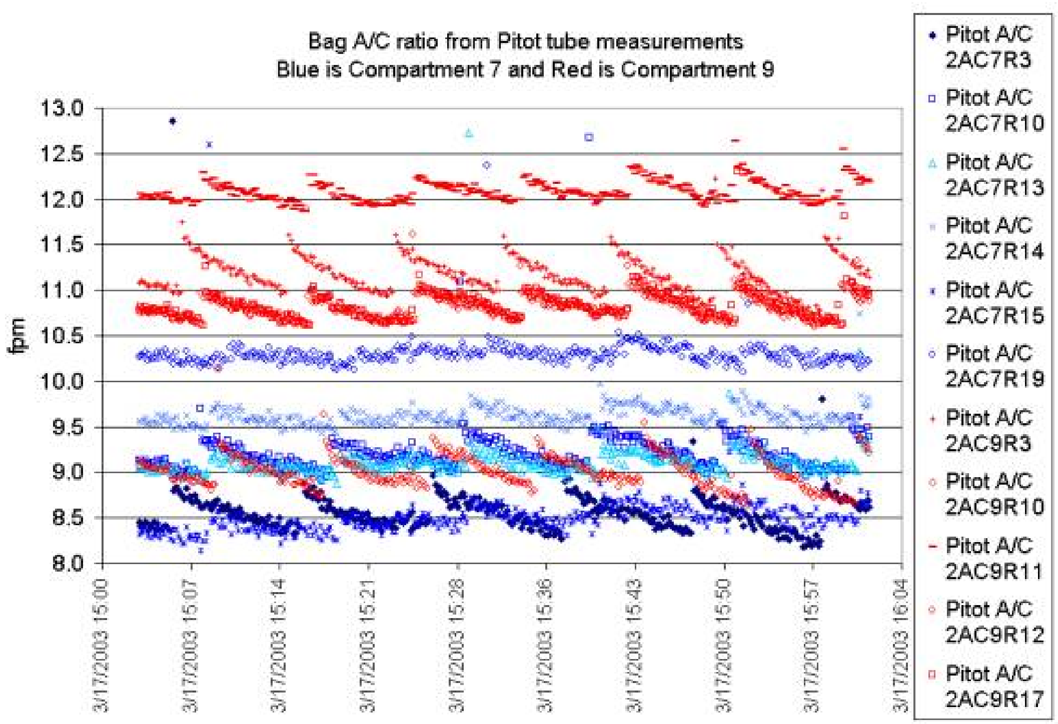
By the end of the quarter, only limited data was available for analysis. The following graphs are some examples of the data that was retrieved and reported by W.L. Gore and Associates personnel. There are three different types of information that could be garnered from the data; velocity pressure, air-to-cloth ratio, and filter bag drag. (These are represented in the first three graphs below). The fourth graph represents an example of the actual data as it is read from the PLC recording the data from the instruments. No substantial conclusions could be made as to the overall performance of the system by the end of the quarter. The limited data seemed to indicate there were fairly significant flow differences between compartments and between bag locations within compartments. However, the team did feel this was going to be a valuable tool and would aid in the evaluation of the following two aspects in the next quarter;

- Flow differences before and after a bag wash
- Flow differences between bag materials




March 15, 2003 20:00 hrs A/C ratio of bag flow from Pitot tubes
Using correction factor of (0.5) comparing Chambers 2A and 2B
Data acquired in 2A by datalogger and 2B by hand manometer
fpm
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
2bc10R2B16
2bc10R3B16
2bc10R10B16
2bc10R11B16
2bc10R12B16
2bc10R18B16
2bc10R19B16
2bc11R2B16
2bc11R10B16
2bc11R11B16
2bc11R19B16
2bc12R10B16
2bc12R11B16
2bc12R12B16
2AC7R3
2AC7R10
2AC7R13
2AC7R14
2AC7R15
2AC7R19
2AC9R3
2AC9R10
2AC9R11
2AC9R17
2AC9R12


March 15, 2003 20:00 hrs Filter Bag drag based on DP from 2A only,
Using correction factor of (0.5) comparing Chambers 2A and 2B
Data acquired in 2A by datalogger and 2B by hand manometer
inwg/fpm
1.400
1.300
1.200
1.100
1.000
0.900
0.800
0.700
0.600
0.500
0.400
2bc10R2B16
2bc10R3B16
2bc10R10B16
2bc10R11B16
2bc10R12B16
2bc10R18B16
2bc10R19B16
2bc11R2B16
2bc11R10B16
2bc11R11B16
2bc11R19B16
2bc12R10B16
2bc12R11B16
2bc12R12B16
2AC7R3
2AC7R10
2AC7R13
2AC7R14
2AC7R15
2AC7R19
2AC9R3
2AC9R10
2AC9R11
2AC9R17
2AC9R12


Bag A/C ratio from Pitot tube measurements
Blue is Compartment 7 and Red is Compartment 9
fpm
13.0
12.5
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
3/17/2003 15:00
3/17/2003 15:07
3/17/2003 15:14
3/17/2003 15:21
3/17/2003 15:28
3/17/2003 15:36
3/17/2003 15:43
3/17/2003 15:50
3/17/2003 15:57
3/17/2003 16:04
Pitot A/C 2AC7R3
Pitot A/C 2AC7R10
Pitot A/C 2AC7R13
Pitot A/C 2AC7R14
Pitot A/C 2AC7R15
Pitot A/C 2AC7R19
Pitot A/C 2AC9R3
Pitot A/C 2AC9R10
Pitot A/C 2AC9R11
Pitot A/C 2AC9R12
Pitot A/C 2AC9R17

General Discussion (Third Quarter 4/2003 – 6/2003)

Significant amounts of work, testing, evaluation, and many accomplishments have taken place during the third quarter of operation of the Advanced Hybrid system. Most of the efforts have taken the project in a new direction than was ever planned or possibly anticipated. In keeping with the format of previous quarterly reports, a quick description of the mechanical issues will precede a much longer description of system performance issues.

Mechanical Issues

The primary mechanical issue yet to be resolved was the functioning capability of the existing plate rapper system. As has been discussed in previous reports, there were two problems found with the plate rapper system. The first was a sizing problem with the first section of rapper shaft as it penetrates the wall of the Advanced Hybrid system. This was solved during a scheduled boiler wash outage in the first week of June by replacing all of the first section of rapper shafts with the proper diameter shaft. The second issue was the misalignment of the rapping components and the internal walkway that had fixed points at opposite ends. These systems were better aligned and adjusted so there would be no interference while in the hot condition. It appears that these fixes will resolve the remaining startup mechanical issues.

Performance Issues

The primary idea from the previous quarter was to instrument and study potential modifications to the system to improve the performance (specifically the high differential pressure) so the restricted ability of the power plant to produce electricity is removed.

The Advanced Hybrid team members met on April 8-9 to review the current status and set a course to improve the existing performance. We agreed to evaluate the following;

- Filter bag washing to reduce residual drag
- Pulse cleaning system modifications
- Flue gas conditioning
- Reduction of gas volume in-leakage
- Install pressure relief valves
- Removal of ID Fan outlet dampers
- Investigate other bag types

Filter Bag Washing

The first item considered was an in-place filter bag wash to remove the residual dust cake that could not be removed from the bags by pulsing. This was met with some hesitance on the part of the Big Stone Plant staff as the results of mixing water and flyash have been disastrous. Flyash will set up like cement in the right type of atmospheric conditions.

The power plant was derated to enter the Advanced Hybrid system for a couple of tasks. First, the inlet field was inspected by ELEX personnel to try to evaluate if the inlet field performance could be improved through normal maintenance during the scheduled June wash outage. The following issues were found during the inspection;

- Chamber 1B Field 1: No problems found
- Chamber 2B Field 1:
  - Four discharge electrode support insulators are cracked
  - One discharge electrode rapper is not functioning correctly
  - One discharge electrode support frame is out of alignment

This did not appear to be a great deal of work or potential improvement, but if even one section of the ESP portion is significantly out of alignment, it could affect the entire field. It was determined to be worth the effort to go into the system and make these repairs during the June wash outage.

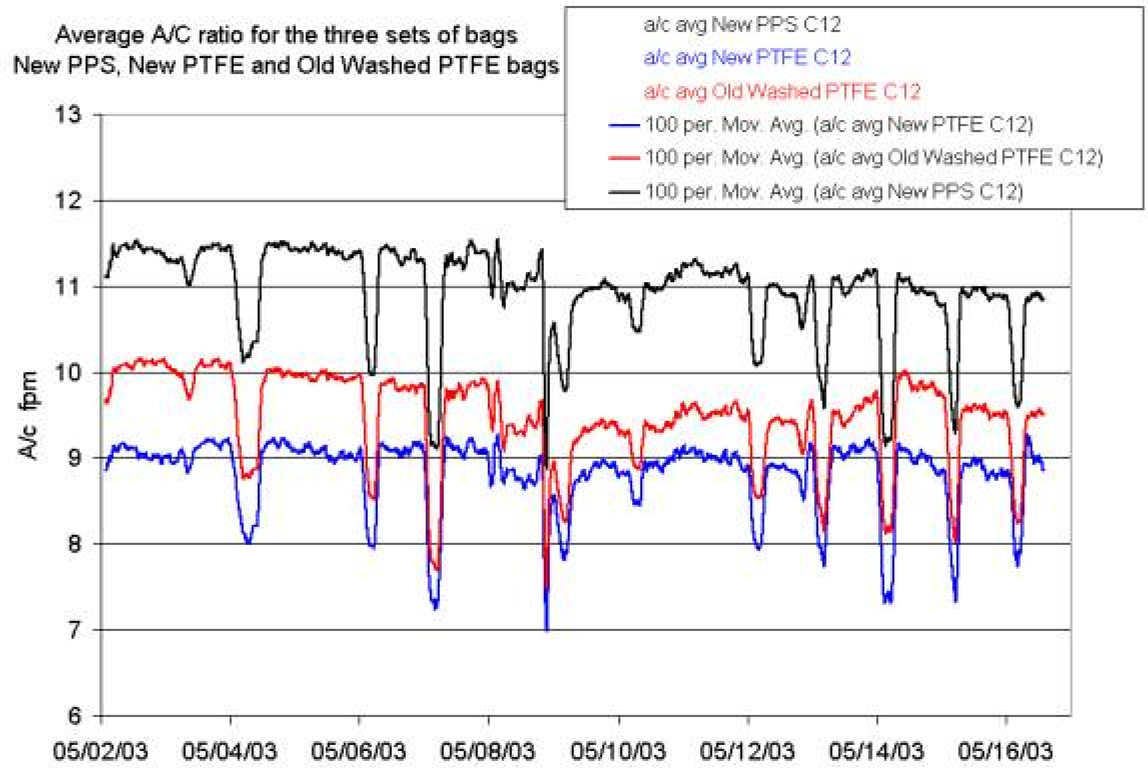
The second effort during the outage was to remove one of the filter bags from service and attempt a wash of the bag while it was not in the system. The bag wash appeared effective as the visual dust cake was removed and the black finish of the original bag was clearly seen. The decision was made to try some type of mass bag washing.

Bag Comparison Test

Approximately ten days later, the boiler experienced another outage due to an unrelated equipment failure. At that time, several different bag options were installed and instrumented with pitot tubes to aid in the data gathering and decision making process for potential solutions. These bags were;

- A new original style all-ptfe bag
- An original all-ptfe bag was removed from the system, washed outside of the system, and then replaced
- A new conductive PPS bag with ptfe membrane

The location of these bags seemed to be of importance because a difference in flow and the corresponding bag position within a compartment seemed to vary if the bags were not in close proximity to each other. This effect was noted and the bags were placed to minimize this effect. The earliest graph of significance in this regard is included below. This graph shows a distinct difference in A/C ratio between the new PPS



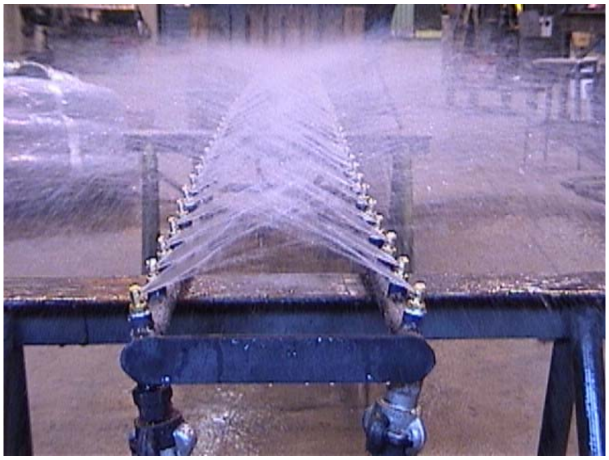
bags and the ptfe bags. The A/C ratio of the PPS bags is nearly 15 – 20% higher than the ptfe bags.

This result was very significant since it was the first evidence that a different bag type could result in a dramatic reduction in differential pressure or increased flow capabilities at the existing pressure drop.

Bag Washing

During the month of April, we developed plans to wash the Advanced Hybrid filter bags while they were in place. Many problems had to be resolved such as; how to handle the wet ash slurry as it flowed down through the hoppers, how to get the water on to the bags in an even and consistent manner, how to assure that the ash washed down the bags with no patches of ash remaining that could damage or restrict the bags, and the logistics of getting the work done in as safe and timely a manner as possible.

Working with W.L. Gore and Associates personnel, a bag wash boom was developed and built at the plant by Big Stone Plant personnel. The picture below shows the boom during testing in the plant maintenance shop. This boom was designed to completely wash one row of bags during a single lift and decent cycle. This would ensure the bags were washed fairly well on the way up, and then rinsed on the way down to lessen the risk of leaving material on the bags. Three booms were built allowing all three compartments in the same chamber to be washed at the same time, reducing the overall duration of the plant derate.



The first bag wash occurred on April 29. It required nearly all of the available plant personnel to complete in approximately 24 hours. Employees washed all of the bags in chamber 2B. A presentation was prepared with pictures of the wash and these are included in Appendix B30. This was an extremely difficult task to accomplish and a lot of credit goes to the Big Stone Plant employees for accomplishing this task under difficult circumstances.

Bag Wash Results

After the 100 MW derate for approximately 24 hours, the plant was able to regain approximately 10 MW of load. This was dependant on the temperature of flue gas into the Advanced Hybrid.

A second bag wash in chamber 1A was completed on May 8. This was similar to the previous bag wash although the total time required to complete the task was reduced to approximately 16 hours. The results were about the same, with the plant able to increase the load carrying capability by another 10 MW.

Conclusions from Bag Wash

Bag washing at the plant appeared to be beneficial to the system. Washing the bags for half of the system reduced the restriction of the bags by about 20 MW total. If the remainder of the bags were washed, the plant might have been able to recover approximately 40 MW of load, at least for the short-term. However, the ambient temperatures were going to increase significantly during the summer months and as long as there was no operating margin at the time, load was going to continue to be restricted. This would cause a significant problem at the plant as the high cost of power through the summer months would make the situation worse. More improvements needed to be found to improve the system through the summer months.

Bag Type Evaluation

W.L. Gore and Associates began evaluating several different bag types at the end of April. The results of these bag studies continued to show a reduced flow resistance when compared to the original all PTFE design. One option considered was a complete or partial bag replacement with PPS or some other style bag. The bags considered for replacement included;

- Original all PTFE design
- PTFE membrane with Conductive PPS backing (rastek scrim)
- PTFE membrane non-conductive PPS backing (PPS scrim)

This decision was not an easy one. We decided that every effort to bring the plant back to full load must be undertaken, and the bags would be completely replaced. This involved some risk, as non-conductive bags had not been tested in the pilot unit for a period of time. PPS bags had not been exposed to the flue gas conditions at Big Stone and their reliability to withstand these conditions was a relative unknown. A decision needed to be made in the first week of May so that the bags could be fabricated and delivered to the site in the first week of June

June Outage Activities

The Big Stone Plant had a scheduled wash outage and the following list of tasks was completed in the AHPC;

- All bags replaced
- Inlet fields inspected and repairs made
- Rapper shafts replaced
- Rappers aligned
- Pressure relief dampers installed

All of the existing bags were replaced during the boiler wash outage in June. Due to the very short time frame to get the bags to the site, W.L. Gore and Associates had to supply some of each of the bag styles to make the delivery date. All bags replaced had a PTFE membrane, the differences occurred in the backing and scrim material, and bag conductivity. Please refer to Appendix B23 for a more informative description of the location, type, and number of bags installed.

The inlet field was inspected and there was not a significant amount of work accomplished. This work mostly centered on replacement of some of the insulator crocks that support the electrodes. Some electrode frames were re-aligned and plate rapper hammers were repaired.

The Advanced Hybrid rappers were repaired as described in an earlier section.

The last significant accomplishment was the installation of pressure relief dampers that could possibly pass approximately 5-10% of the flue gas after ESP cleaning only. This would be used as a last resort in case the system improvements were not sufficient to lower the differential pressure.

<u>Results After Startup</u>

The Big Stone Plant was put back on-line on June 11. Early results were extremely positive, as the differential pressure was controllable.

Some tests with the inlet field on and off were conducted but these tests went on through the summer and will be covered in the next quarterly report.

The pressure relief dampers were tested for operation on June 17, and opacity was not acceptable during this short test (approximately 20 minutes). As a result, these dampers were never used to control the differential pressure and remained closed.

General Discussion (Fourth Quarter 7/2003 – 9/2003)

General Comments

In general the Advanced Hybrid system has performed significantly better this quarter than in previous quarters. The system is still not performing as is required to demonstrate it commercially. The excellent performance seen immediately after the outage in June has not been maintained, as the differential pressure has risen from 7 to 8.5 INH2O at the highest A/C ratios seen so far. The inlet ESP field remains charged to reduce the ash loading to the Advanced Hybrid system.

The focus of this quarter is to maintain stable operation of the power plant and delve further into the available data and instrumentation tools to understand the root causes of the performance differences between the pilot unit and the full-scale unit demonstrations.

Performance Testing

A series of performance tests were conducted to measure current performance. These tests are:

- A/C ratio range testing with the inlet field not energized
- Power Off /Plate Rapper Testing (POPR)
- Humidification Testing
- Further pitot testing as a basis for Computational Fluid Dynamic Modeling

The A/C ratio range testing is documentation of existing performance with the inlet field on and off to determine performance over an A/C ratio range. These results are summarized in the following two tables;

Date	A/C	Inlet Temp	K2Ci	Drag	Pulse Interval
	ft/min	deg F		Residual	min
8/5/03	9.67	294.29	4.22	0.61	36.81
8/3/03	9.66	288.21	3.66	0.59	47.17
7/15/03	9.49	287.83	4.01	0.53	56.87
7/19/03	9.48	306.32	3.80	0.61	45.77
8/24/03	9.15	309.42	3.99	0.67	38.55
7/14/03	8.79	289.11	3.25	0.52	94.75
7/13/03	8.66	279.42	2.45	0.50	140.64
8/2/03	8.36	270.88	2.64	0.56	124.63
9/17/03	8.05	286.92	3.06	0.63	103.27
9/2/03	8.00	269.94	2.44	0.61	138.64
9/1/03	7.98	268.47	2.74	0.60	127.58

Table 2 - Advanced Hybrid Performance with inlet field OFF

Date	A/C	Inlet Temp	K2Ci	Drag	Pulse Interval
	ft/min	deg F		Residual	min
8/6/03	10.17	296.20	1.81	0.61	68.76
9/28/03	10.15	289.03	1.91	0.63	57.00
10/22/03	9.77	295.33	2.06	0.62	69.23
8/7/03	9.60	287.57	0.82	0.57	234.36
8/12/03	9.49	288.73	0.76	0.58	252.96
9/12/03	8.84	282.05	1.11	0.61	211.54
9/10/03	8.69	290.25	0.66	0.66	322.00
10/5/03	8.57	274.37	0.82	0.64	288.75
9/16/03	8.17	280.08	0.35	0.64	839.79
9/4/03	7.71	270.58	0.38	0.67	869.04

Table 3 - Advanced Hybrid performance with inlet field ON

The test periods were limited to times of reduced plant load in the evenings. During these periods either the inlet field was de-energized (Table 2) or the conditions were noted if the inlet field was left on (Table 3). The results are similar to those obtained in the second quarter of the demonstration period. When referring to the results from Table 2, there is a considerable difference in the K2Ci values of the system when compared to the pilot unit. It is estimated that the K2Ci valued for the pilot unit would be less than 1 at an A/C ratio of 9.0 fpm. The full-scale unit K2Ci at 9.0 fpm appears to be about 4.0. This is an ash loading rate to the bags of four times the rate when compared to the pilot unit. These results lead us to focus on performance improvement effort in the Advanced Hybrid ESP section. Contrarily, the residual drag portion of the system is now comparable with the results of the pilot unit at approximately 0.5 – 0.6 INH2O/ft/min.

The Power Off Plate Rap tests were performed by turning off the power to the individual compartments and rapping the ESP components to try to improve the ash collection of the ESP section. A graph of these results is included in Appendix B32. In this specific test, as in almost all the power off rapping tests, the ESP power increased slightly, but had no significant effect in the K2Ci, Residual Drag, or differential pressure. This may indicate there is a portion of flue gas bypassing the ESP zones or another problem with flow distribution.

The humidification test was another short-term improvement test to determine if the existing plant flue gas conditioning system could be used to improve ESP performance. The humidification system was used to inject a minimum amount of water and proprietary chemical to determine if an improvement could be made. As can be seen in the graph in Appendix B25, very little improvement was seen during this test.

The last significant testing was the analysis of the existing pitot tube data. As was described by W.L. Gore and Associates, there appears to be a fairly significant K2Ci performance difference between the first, second, and third section of some individual compartments. Pitot testing indicated the K2Ci value of the bags in the middle section of Chamber 2A Field 3 was about 2.0, while the back section of Chamber 2A Field 3 was abut 5.0. In another interesting comparison, the front section of Chamber 2A Field 4 was about 4.5, while the middle section of Chamber 2A Field 4 was about 1.5. This is described by the graph in Appendix B26. All of these test results point towards a gas flow distribution issue that may help explain the difference in loading rate between the pilot and full-scale unit.

<u>Performance Improvement Effort</u>

Now that the Big Stone Plant has returned to full load capability, an effort towards a long-term improvement is being made. This effort is focused on the gas flow dynamics of the system and how an understanding of these dynamics may aid us in improving the system. Fluent Inc. was brought on board to evaluate the system through Computational Fluid Dynamic (CFD) modeling of the existing system. A description of the effort by Fluent Inc. is included in Appendix B33. The most reasonable approach to improvement of the ESP portion of the system is the addition of baffles below the bag rows in each section. A proposal in the form of a presentation is included in Appendix B34 with further details on the principal theory of the baffles.

The results of the Fluent Inc. modeling should be completed in the next quarter of demonstration.

General Discussion (Fifth Quarter 10/2003 – 12/2003)

General Discussion

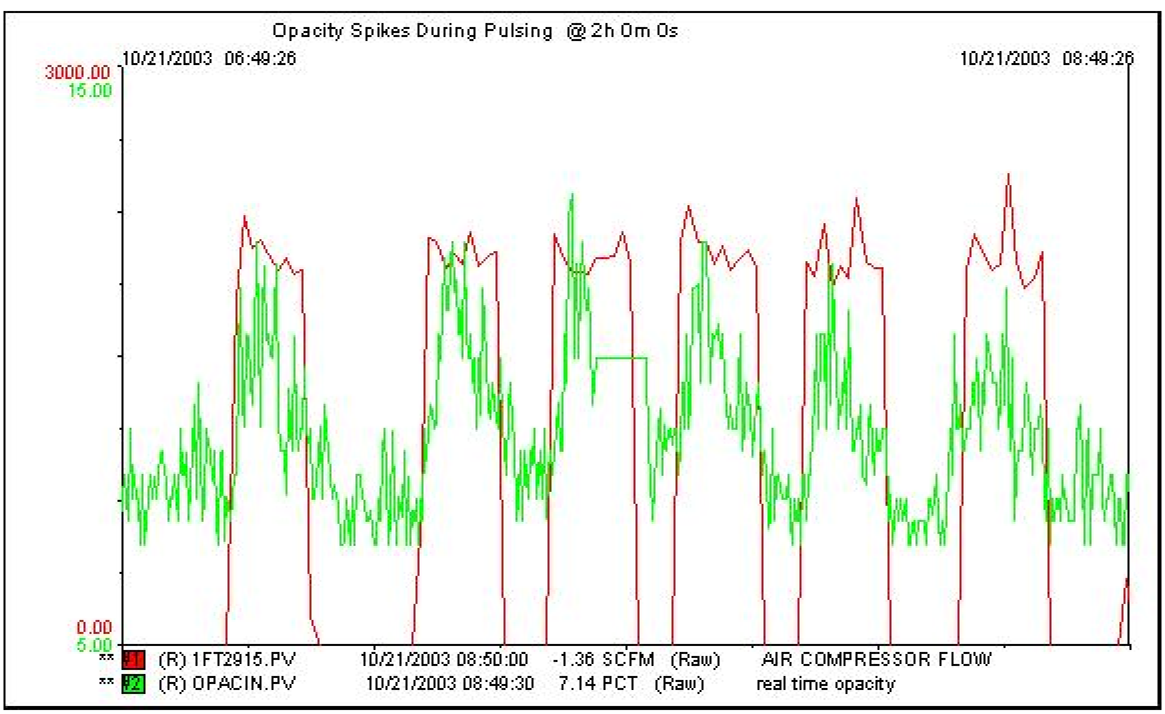
Problems have again developed with the Advanced Hybrid system. Significant bag failures have occurred in the PPS bags with the PPS scrim since installation three months prior. Indications and likely reasons for bag failure are included below. As a result, a competitive bidding effort has taken place with several different suppliers of various bag materials. This should allow us a greater flexibility of bag options, but also increase the amount of unknowns.

Other than the bag failures, performance has been maintained and even slightly improved as cooler gas temperatures into the Advanced Hybrid are realized. The cooler temperatures are due to lower ambient temperatures heading into the winter.

Some modeling results from Fluent Inc. are available and will be reviewed.

Bag Failures

In early October, it became apparent there were opacity spikes occurring during periods of pulsing. The graph below shows a two-hour time duration and the observed indications. During periods of pulsing (red), opacity (green) is increasing from around 8% to about 10-11%. These spikes contribute to an overall opacity rise, seen in Appendix B8.

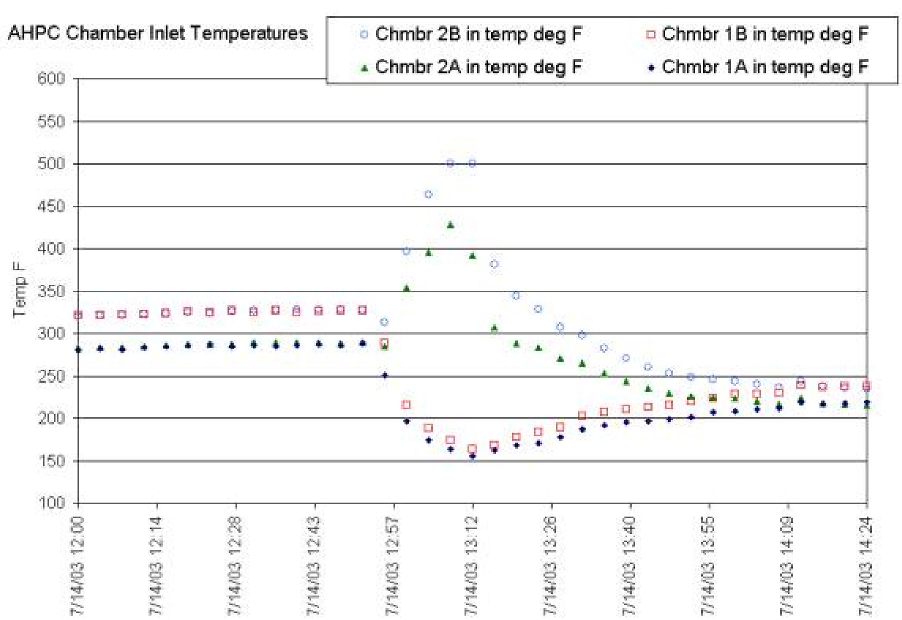


Specific Bag Failures

An exact number of failed bags is not known. The failing bags were the PPS bags with the PPS scrim. The reasons for failures appear to be the weakening of the strength of the fibers and cleaning pulsing. The temperature is likely the primary factor in weakening the bag material. The compartments of PPS bags with the most failures to the least failures are ranked in this order

1. Chamber 1B Field 3 (most failures)
2. Chamber 1B Field 4
3. Chamber 2B Field 4
4. Chamber 2A Field 4

The PPS bags in Chamber 1A appear to have few, if any, failures. The all-ptfe bags had no failures, and the PPS bags with the rastek scrim show only a few failures occurring in chamber 2B. There is an operating temperature difference between the chambers due to the regenerative style air preheater used to transfer heat from the flue gas to incoming air. As a result, 1B & 2B chambers operate approximately 20 degrees higher average temperature than 1A & 2A. This would logically explain why the compartments in chambers 1B and 2B have the most failures of PPS bags. However, the failures that occurred in Chamber 2A don't seem to follow this same pattern. A likely contributing factor to these failures was a high temperature event experienced in July 2003. During a plant trip, a failure of the air heater system caused a short-term temperature excursion. The temperatures into Chambers 2A & 2B exceeded the 375 degrees rating of the



PPS bags for about fifteen minutes.

Bag Replacement Decisions

Some bag replacement was necessary during the scheduled boiler wash outage in December. A significant operational performance improvement was made with the decision to replace the original all-PTFE bags with PPS bags in June 2003. The original style bags would not likely be considered for replacement due to high differential pressure concerns. Only PTFE membrane bags were considered allowing the fundamental goal of 99.99% particulate removal to be maintained. We considered bags of the following materials for use in the Advanced Hybrid system:

- All PTFE (new)
- All PTFE (original bag washed outside the Advanced Hybrid system)
- P-84
- Nomex
- PPS with the rastek scrim
- Fiberglass
- Superflex^{TM}

The only bags with operational history were the all-PTFE bags and the PPS bags with the rastek scrim. Both of these options seemed questionable because of either high differential pressure issues (all-PTFE), or questionable reliability strength issues (PPS). We decided to install one compartment of P-84 bags into Chamber 2B field 4, one compartment of NOMEX bags into Chamber 1B field 4, and one compartment of original all-PTFE washed bags in Chamber 2A field 3. Approximately 1000 bags were washed in the Big Stone Plant turbine bay prior to the outage. Fortunately this was accomplished, because an unexpected outage extension of 7 days occurred (unrelated to the Advanced Hybrid system). The bags in a fourth compartment Chamber 2A field 4 were also replaced with original washed all-PTFE bags. Bags in four of the twelve compartments were replaced during the December boiler wash outage. For more description of the specific type and styles, see section 2.1.2 or Appendix B23.

Fluent Modeling Effort

During the previous quarter, an effort was undertaken by Fluent Inc. to model the gas flow dynamics of the system. This was attempted to gain a better understanding of where gas flow dynamics may be adversely affecting performance, and what could be done to improve performance. The most likely improvement was the installation of flow baffles to direct gas flow from the bottom more directly into the ESP zones of the Advanced Hybrid components. Preliminary results indicated approximately 15% of the flue gas flow could be entering the area directly beneath the bag rows and bypassing the ESP zone. The significance of this is fairly strong. If the flue gas passing through the ESP portion of the Advanced Hybrid system is being cleaned at a rate of 90%, and if 15% of the flue gas is bypassing this ESP zone with 100% of the ash loading, this would result in an overall ESP efficiency of only 76.5%. This may be better understood by taking the example of a loading rate of 1 grain/acf, and working through the potential ESP efficiency calculations. First, assume a true 90% ESP efficiency rate;

$$\text{Ash loading to bags} = 1 \text{ gr./acf} * (100\% - 90\%) = 0.1 \text{ gr./acf}$$

However, if the actual case is a 15% gas bypass of untreated flue gas, the result is;

$$\text{Ash loading to bags} = 85\% * (1 \text{ gr/acf} * (100\%-90\%)) + 15\% *((1\text{gr/acf} * (100\%)) = 0.235 \text{ gr/acf}$$

This would mean a loading rate to the bags nearly 2.4 times the estimated rate of an ESP efficiency of 90%. This level of change would be needed to approach the loading rate demonstrated in the pilot unit. The full-scale unit loading rate is nearly four times the loading rate of the pilot unit.

Unfortunately, final modeling results were not available at the time baffles needed to be ordered for installation during the December boiler wash outage. Otter Tail Power Company personnel decided to purchase and install 3 sets of these baffles to allow an operational evaluation. The only reliable information in this limited format would be issues associated with installation and with operation (specifically whether or not the baffles plugged with ash during operation).

Three sets of baffles were designed by and purchased from Southern Environmental Inc. Installation was accomplished with Big Stone plant personnel. Some difficulties during installation were noted and modifications will be made if more baffles are ordered. A picture of the baffles is included in the Appendix.

A section of pitot tubes was installed across the bags with these baffles, but limited data and analysis is expected due to such a small number of baffles.

<u>Blowpipe Modifications</u>

Big Stone plant personnel modified one of the existing blowpipes so a single pulse valve pulsed 19 bags instead of 10. This was accomplished in a forward-looking manner, as there may be reasons in the future to modify the system to remove the stacked blowpipe arrangement. This arrangement has caused a definite increase in bag replacement costs when compared to a standard baghouse arrangement with no stacked blowpipes. If successful, this would lower the cost of the existing system by reducing the required headers, pulse valves, control system and pulse pipes by half. There may also be an improvement in performance, as all the valves could be cycled through in half the time. Assuming an equal cleaning efficiency per pulse, this could result in a lower residual drag. Lastly, there is evidence that we are still over-cleaning the bags, indicated by an increased rate of bag failure on the short blow tubes as compared to the long blow tubes. A picture of this blow tube is included in the Appendix B39. The Big Stone Plant pitot instrumentation will be placed on the bags on this tube and some analysis may be possible.

General Discussion (Sixth Quarter 1/2004 – 3/2004)

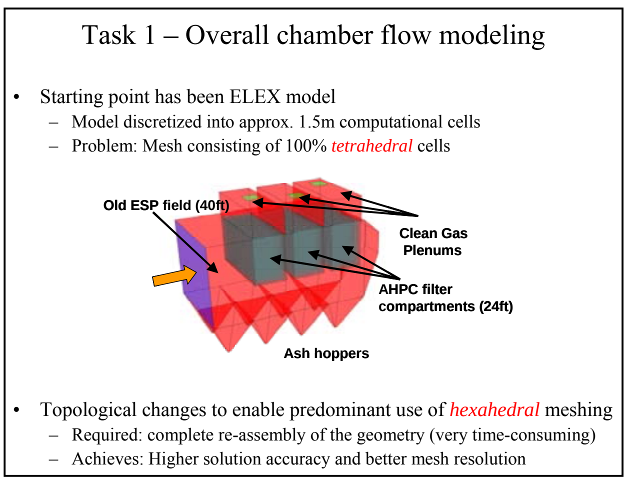
General Discussion

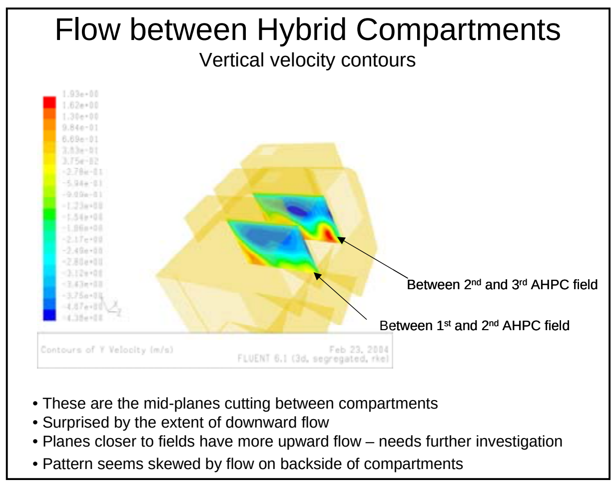
Operation of the Advanced Hybrid system has been stable since startup after the December boiler wash outage. The bags are still being aggressively cleaned. There have been no significant plant limitations due to the Advanced Hybrid system since prior to the June 2003 boiler wash outage. There have been four primary efforts this quarter. These are;

- Performance improvement investigation – Fluent/baffle effort
- Evaluation of changes made – baffles, blowpipe, bags
- Review of technology results and goals – Technology team
- Proposal and review of second phase of project

Performance Improvement Investigation

The CFD modeling with Fluent continued through this quarter of demonstration. Some very informative and good modeling data has been generated. The figure below is taken from a presentation of the CFD results from Fluent. The first is a description of the assumptions and a three dimensional view of the





model. The second is a graphical display of the vertical gas flow components between the individual compartments in one chamber. This work aided the team to better understand the gas dynamics of the system, suggesting areas of improvement through baffling. Since mid-February this work has been on hold as the team has evaluated the overall goals and methods of improvement.

Evaluation of Changes Made

Several changes have been made to the system. These are

- Three rows of baffles installed
- A single blow tube installed
- P-84 and NOMEX bags installed

Three sets of baffles were installed in Chamber 2B field 3 during the boiler wash outage in December. These were installed to evaluate the ease of installation and to find any areas of concern during operation. A short pitot tube analysis was also completed, but as anticipated, the results have minimal reliability because so few baffles were installed. In general, the baffles may be reducing the ash loading by about 10% to the bags. During a short load drop on February 28, the baffles were inspected and found to be in satisfactory condition. There was no ash plugging and only a slight buildup on the baffles. An effort is underway to fund and install one complete chamber of baffles during the scheduled boiler wash in June of 2004.

Another change made was the modification of one blowpipe. Currently, one blowpipe charged by one three-inch pulse valve, is assigned to clean 10 bags. There are 20 bags in a cleaning row, meaning that two valves per cleaning row are necessary. The blowpipes for the system must be stacked so the compressed air to the second ten bags in any row is supplied through a solid line that travels over the blowpipe for the first ten bags. This current arrangement has advantages and drawbacks.

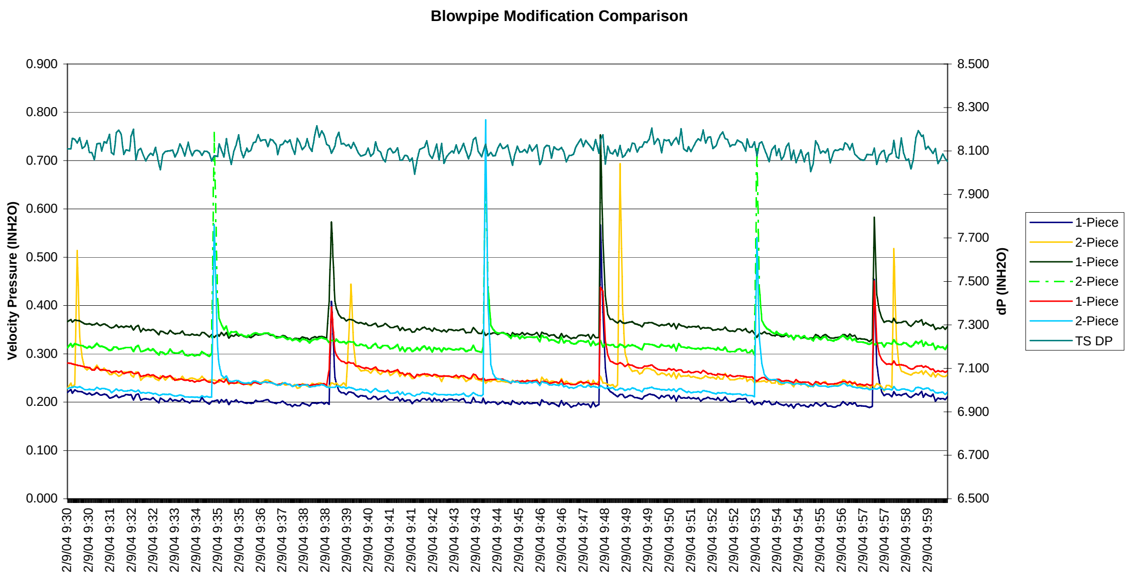
Advantages

- Better/more aggressive cleaning of bags

Drawbacks

- Significantly more expensive system
- Difficult to change bags/more expensive bag replacement
- Stacked blowpipe creates hazardous walking conditions inside plenum
- Aggressive cleaning may contribute to premature bag failure
- Longer time needed to complete one pulse cycle

One blowpipe was changed and instrumented with pitot tubes to try to determine if 20 bags could be pulsed effectively by one three inch pulse valve. The graph below depicts some of the pitot data as recorded by the Power Plant data historian.



The above graph shows the changes in velocity pressure as the bags are pulsed using either a 1-piece or 2-piece blowpipe. The chart below summarizes these changes (VP_i = Initial Velocity Pressure, VP_f = Final velocity pressure):

	Blowpipe	Load	Inlet Temp	A/C	Presure	Duration	VP_i	VP_f	Delta
		GMWH	^oF	ft/min	psig	ms	inwg	inwg	%
		468	283	11.2	80	200			
Pitot #1	1-Piece						0.196	0.517	164
Pitot #2	2-Piece						0.236	0.550	133
Pitot #3	1-Piece						0.333	0.654	96
Pitot #4	2-Piece						0.304	0.659	117
Pitot #5	1-Piece						0.236	0.566	140
Pitot #6	2-Piece						0.213	0.566	165

Further testing has been performed using various pulse pressures and pulse durations at different A/C ratios. All the data indicates that there is no significant change in pulse efficiency when comparing the 1-piece modified blowpipe to the 2-piece blowpipe.

The last significant change was the installation of a compartment of P-84 bags and a compartment of NOMEX bags. The P-84 bags in Chamber 2B field 4 were inspected during the February 28 derate and no holes were seen at that time. At the end of this quarter, no specific information is known on the NOMEX bags as no other inspections have taken place.

Review of Technology Results and Goals

A group effort was undertaken in February to try to review the current status, goals and path forward for the technology. The real impetus behind this effort is a scheduled major outage of the Big Stone Plant in

April and May of 2005. If major changes to the system need to occur this would be the only reasonable chance until a projected outage some time in 2010. OTP facilitated a review in an attempt to reach a consensus. The current active stakeholders in the project and the technology include;

- Otter Tail Power Company (responded)
- National Energy Technology Laboratory
- Energy and Environmental Research Center (responded)
- W.L. Gore and Associates (responded)
- ELEX AG (responded)
- Southern Environmental Inc.

Four of the stakeholders listed above responded to questions to determine project status and goals. The main questions that need to be answered are;

- What defines successful operation of the Advanced Hybrid system?
- What A/C ratio can we currently claim would meet successful operation?
- What A/C ratio is needed for the technology to compete commercially?
- Is there a reasonable chance, through improving the existing system while maintaining the current A/C ratio, to demonstrate successful operation?

A summary of responses is listed below.

<u>What defines successful operation of the Advanced Hybrid system?</u>

Certainly particulate control and bag life are important factors to consider for successful operation. At the heart of the question is operation on a routine, minute-to-minute basis. In general, the best and simplest way to define successful minute-to-minute operation is the pulse interval. This is the time required to clean the bags completely through one cleaning until the differential pressure rises high enough to initiate the next cleaning. Approximately 30 to 60 minutes was the range discussed. OTP is of the strong opinion the pulse interval should be no less than 60 minutes. After some general discussion, this was agreed upon.

<u>What A/C ratio can we currently claim would meet successful operation?</u>

The approximate value is 8.0 fpm. This depends on the acceptable pulse interval from the previous question. At 60 minutes, the best approximation at this time is 8.0 fpm with the inlet ESP field off (true Advanced Hybrid).

What A/C ratio is needed for the technology to compete commercially?

The current commercialization partner feels strongly that an A/C ratio of at least 10 fpm is needed to compete commercially. Using the data from Appendix B7, the A/C ratio at full load has been 10.5 to 11.5 fpm since startup. This means that the system is in a competitive commercial range, but could be sized larger to reduce the A/C ratio by a range of 5 – 15%.

Is there a reasonable chance, though improving the existing system while maintaining the current A/C ratio, to demonstrate successful operation?

It is generally felt it would be difficult to demonstrate acceptable minute-to-minute performance at the current A/C ratios.

Several broad conclusions can be drawn from the opinions of the group. First, there is a significant difference between the current successful A/C ratio (8 fpm), and the actual A/C ratio (11.5 fpm). Second, the system can be resized by about 15% and still remain competitive commercially. Third, it would be difficult, if not impossible, to maintain the same A/C ratio and demonstrate successful minute-to-minute operation through improvements to the system.

Taking this thought process forward, Otter Tail Power Company personnel are proposing to re-size the existing system.

Proposal and Review of Second Phase of Project

Otter Tail Power Company has proposed that a new phase of this project be entered into to advance the needs of the power plant and improve the chances of bringing the technology to the commercial marketplace.

The proposed next phase of this project would be the replacement of the existing inlet ESP field with improved Advanced Hybrid components and some small changes to the existing system to improve overall performance. Primarily, this effort would reduce the A/C ratio of the system from approximately 11.5 fpm, to 70% of the current level or 8.05 fpm. This would accomplish two primary objectives. First, it would drop the A/C ratio to a range that has been demonstrated as acceptable during short term testing. Second, several design improvements could be implemented that may improve performance to meet a new goal of 10 fpm. Third, by sizing the system conservatively large, we will have the flexibility to increase the A/C ratio if changes made to the system are very successful. Conversely, we will not need to maintain minimum commercially acceptable A/C ratios to meet the full load needs of the power plant.

Improvement ideas being currently discussed are;

- Installation of bag row baffles
- Further baffling to improve gas flow distribution
- Closer plate-bag spacing
- 20% more cloth surface in the same footprint
- Enhanced ESP zones
- Blow tube modifications

General Discussion (Seventh Quarter 4/2004 – 6/2004)

General Discussion

Operation of the Advanced Hybrid has been fairly stable. There have been no significant derates of the power plant due to Advanced Hybrid system. The remaining PPS bags have begun to fail at an unacceptable rate, and it was a good decision to plan on replacing all of the PPS bags during the scheduled June shut down. The major activities of this quarter were;

- Work related to the boiler wash outage including;
  - Replacement of 1928 PPS filter bags with P-84/BHATex filter bags.
  - One complete chamber of Baffles installed
  - One compartment of blowpipes modified
  - 10 filter bags pulled and sent to independent laboratory for analysis
- Review of proposed design for installation of AH components in the inlet field
- Bag testing data reviewed

June Boiler Wash Outage

The plant was shut down from June 5th to June 12th for the scheduled boiler wash. During this period, Southern Environmental Inc. was contracted to come in and perform the tasks listed above. A complete report of these activities can be found in Appendix 24.

Overall, the work that was completed was done well and on-time. It appears that our choice of using the P-84 bag from BHA was a good one and will hopefully get us through the warm summer temperatures without premature bag failures.

Proposed Project for Installation of Advanced Hybrid components in inlet field

A meeting between OTP, EERC, and SEI was held at the Big Stone Plant on Friday, March 5, 2004. The purpose of the meeting was to discuss the bid requirements and design optimization for the following items:

1. Manufacture and install 1 Chamber of bag row baffles in June 2004
2. Modify one compartment of blowpipes in June 2004
3. Convert 4 inlet ESP fields into Advanced Hybrid compartments in April 2005
4. Include with item 3, installing ESP field below new AH compartments
5. Design and construct new AH chamber for construction in April 2005

An engineering review meeting was held at SEI headquarters on April 13-14. The bag row baffle design and blowpipe modifications for the June 2004 outage were finalized. SEI also presented their progress on the items 3-5 above. Main items of discussion were:

1. Changing the plate-to-plate spacing from 12 in. to 10 in.
    - This closer spacing allows for more rows of bags thus lowering the A:C
    - This will not degrade the ESP performance
2. Determining the maximum number of bags per compartment
    - Four additional rows of bags will be added in each compartment
    - Total of 1974 additional bags representing a 41% increase in filtration surface area
3. Extending the length and increasing the number of the electrodes and plates
    - Rigid electrodes and collecting plates will be lengthened from 25 feet to 37 feet creating an ESP collecting zone below the fabric filter components
    - Below the level of the bag row baffles, the collecting plates will be solid instead of perforated.
    - There will be no discharge electrodes in the gas passages below the filter bags
    - The area below the pulse headers will be filled from the hot roof to the top of the hoppers with new discharge electrodes and solid collecting plates
4. Rapping systems
    - Electromagnetic rappers will be used instead of tumbling hammers for the discharge electrodes
    - The drive from the existing collecting plate tumbling hammer rapper system will be relocated and reused.
5. Duct work tie in
    - Outlet ductwork from new inlet compartment will tie straight into the outlet duct from field two
6. Electrical & controls
    - Discussed cable splicing options and Hesch pulse controller capabilities to handle additional compartments
7. New compartments include bag row baffles and modified blowpipe design

A brief discussion was held concerning the design and construction of a new AH chamber. Few details were discussed as converting the inlet fields to Advanced Hybrid was agreed upon as the most economical performance improvement option.

Following this meeting, a purchase order was issued to SEI for bag row baffles in one chamber and modification of the blowpipes in one compartment. Both of which took place during the June 2004 outage. SEI has also submitted a firm bid to convert the inlet ESP fields into the Advanced Hybrid as discussed above. The quote for $3,625,000, would not include, filter bags, taxes, baffles or blowpipe modifications for the remaining compartments, or any additional costs as a result of NETL participation (EERC testing and reporting). They have requested a letter of intent and partial purchase order from OTP to begin engineering no later than August 1, 2004 to ensure construction readiness in April 2005.

<u>Bag Testing Data</u>

A significant amount of bag testing data was reviewed this quarter. The entire report by W.L. Gore and Associates is included in the appendix. The summary table from that report is included below.

Otter Tail Power Company
Big Stone Power Plant Improvement Initiative Demonstration Site
Filter Bag analysis summary chart - All Frazier #'s are reported as cfm/ft2@0.5 in.w.g. driving force

Location	Service Time	Max. exposed temp (F)	Backing	As rec'd (F-n)	Mullen Burst (psi)	Mullen Burst % Strength Retention	Tensile strength - cross machine direction (psi)	%Tensile strength retention - cmd	Tensile strength - machine direction (psi)	% Tensile strength retention - md	Comments
1BF3 R1B1	6/10/03 to 9/17/03	365	all PPS	2.9	249	72	113	39	83	61	membrane OK, tan felt color
1BF3 R1B3	"	365	all PPS	3.6	226	66					membrane cracking along some of the vertical cage wires
1BF3R1B4	"	365	all PPS	4	223	65					membrane cracking at vertical/horizontal cage wire junctures
1BF3 R1B6	"	365	all PPS	3.8	182	53			51	37	membrane delaminated during HEC cleaning
1BF3R1B7	"	365	all PPS	2.7	236	69	114	39	61	45	membrane cracking, tan felt color
2BF2 R3B5	"	500	all GT	1.9	717	100					membrane OK
2BF2 R3B8	"	500	all GT	1.5	735	100					membrane OK
2BF3 R19B6	"	500	cond PPS	2.3	481	96	181	54	243	100	membrane OK, chocalat brown felt color
2BF3 R19B7	"	500	cond PPS	2.2	473	94	180	54	200	83	bag turned inside out during removal
2BF4 R20B7	"	500	all PPS	2.8	208	60	90	31	73	53	membrane scraped during removal, dark tan felt color
1AF4 R11B11	6/10/03 to 9/27/03	322	all PPS	3.9	234	68	123	43	90	66	membrane cracking along vertical and horizontal cage wires
1AF4 R1B20	6/10/03 to 10/24/03	322	all PPS	3.6	368	78	104	36	42	31	membrane cracking in vertical direction between vertical cage wires
1AF4 R1B12	"	322	all PPS	4	229	67	73	25	24	17	membrane cracking at vertical/horizontal cage wire junctures, tan felt color
1BF3 R21B5	"	365	all PPS	6.9	203	59	48	16	10	8	holes formed through felt backer, choc. brown felt
1BF3 R21B6	"	365	all PPS	5	210	61	33	11	2	2	membrane delamination, holes in felt
2AF4 R21B14	"	450	cond PPS	2	463	92	115	34	197	82	tan discoloration, hole in felt
1AF2 R15B11	6/10/03 to 2/28/04	322	cond PPS	2.6	449	89	224	67	205	85	membrane OK
1AF3 R11B15	"	322	all PPS	3	214	59	125	43	78	57	holes formed at vertical/horizontal cage wire junctures
2AF4 R13B10	12/3/03 to 2/28/04	350	SUPERFLEX	3.5	870	100	483	100	405	100	membrane OK
2AF4 R13B9	"	350	Fiberglass	3.1	920	100	729	100	461	100	membrane OK, small areas scraped during removal
2BF4 R11B6	"	365	P-84	5.1	337		185		97		membrane delamination throughout entire length of bag
	new	80	NOMEX	5.4	513		408		160		brand new
			new all PPS		366		289		137		
			cond PPS		503		337		241		
			all GT		650						

The overall conclusions in the report from W.L. Gore and Associates are as follows:

Conclusions:

- GORE-NO STAT® filter bags continue to maintain excellent membrane integrity and physical strength.
- Laboratory analysis of the filter bags revealed no membrane damage caused by electrostatic discharge or sparking.
- After 10 weeks of service SUPERFLEX® and fiberglass backed filter bags exhibited no loss in physical strength and membrane integrity.
- The all PPS backed and conductive PPS backed GORE-TEX® membrane filter bags have shown they are sensitive to temperature upsets.
- Future physical strength analysis should include Tensile strength testing, preferably using the Instron instrument.

®GORE-TEX and GORE-NO STAT are registered trademarks of W. L. Gore & Associates, Inc.

As the power plant operator, we consider the information in this light, 'What bag should be installed in the system to give a balance of low resistance to gas flow and strength retention in service for prolonged mechanical life?'. With the operation results of the all PPS bags unacceptable with regards to mechanical bag life, it seems that our options looking ahead for filter bag backing are as follows (each of these bags would likely include a PTFE membrane);

- PTFE
- Superflex
- Fiberglass
- P-84
- NOMEX

At this time, it has not been determined which bag is the most likely candidate to give a good balance of performance. Additional testing and operation time is needed. Factors such as the Frazier number, as well as percentage strength retention need to be taken into account.

General Discussion (Eighth Quarter 7/2004 – 9/2004)

General Discussion

Operation of the Advanced Hybrid system has been stable during the last quarter. There has been very little change in operation or significant operational accomplishments. The plant was loaded a little bit lighter this summer due to an unseasonably cool temperatures. However, we still saw some derates and uncontrollable pressure drop during the warmest period of the summer.

Some of the significant points of discussion are:

- Independent bag analysis from Environmental Consulting Company (ECC)
- Full chamber baffle installation and blowpipe modification
- Bag life concerns with NOMEX
- Decision to move ahead with the inlet field modification
- P-84 Failures discovered

Independent bag analysis from ECC

An independent bag analysis company was contracted to perform testing and analysis on a variety of bags in the Advanced Hybrid system. The report is included in Appendix B41. The major conclusions are included below:

- NOMEX has undergone sulfur trioxide degradation and under the 6 month exposure has suffered high deterioration. NOMEX Aramid is not recommended for service in this application.
- The life projections for the following candidates based on limited testing data is as follows
  - Fiberglass 4-5 years
  - P-84 5-6 years
  - PTFE felt 8-9 years
- Other conclusions can be found in the Appendix

It was apparent to us that the NOMEX bags were beginning to fail unacceptably during the bag inspection last June. The analysis from ECC backed up those conclusions. However, of some concern is the estimate of 5-6 years of bag life remaining for the P-84 bags when some bag failures were seen during an impromptu inspection during a boiler tube leak outage in the last days of September. This is discussed in the last bullet item of this section.

Full chamber baffle installation and blowpipe modification

During the scheduled boiler wash outage in June, a full chamber of flow baffles was installed. This represents ¼ of the entire Advanced Hybrid system. There has not been a clear measurable advantage with the flow baffles in the system. Undoubtedly, the baffles are working to divert some of the formerly untreated flue gas into the ESP zone, but this is very difficult to measure.

Likewise, two blowpipe sections were combined into one long blowpipe to determine if this could be done to improve the overall usability of the system and reduce the system costs. Further research and testing will need to be done to evaluate if this is an acceptable option.

Bag life concerns with NOMEX

As mentioned earlier, our independent lab analysis of the NOMEX bags revealed that the strength of these bags was deteriorating at an unacceptable rate. It will be necessary to change these bags out during the scheduled boiler wash outage in October. It was determined that the most logical choice for replacement was fiberglass bags. Two options exist currently, a straight fiberglass bag or a fiberglass/PTFE composite (both membrane bags). A couple of these bags have been in service since December 2003, and have not failed, but a large scale (full compartment) needs to be tested in a warmer chamber. A purchase order was issued to Midwesco Inc. for a full compartment of fiberglass bags.

Decision to move ahead with the inlet field modification

A letter of intent and purchase order were issued to Southern Environmental from Otter Tail Power Company to install additional Advanced Hybrid components. This was done to lower the air:cloth ratio of the existing system to levels that have been demonstrated as successful. Currently the system operates at up to 12 fpm. The planned installation of 4 more compartments will reduce this to approximately 75% of current levels, or 9 fpm. A separate project is being considered for this work and it will not be covered under the existing reporting or project arrangement. It is uncertain at this time whether or not additional NETL participation will occur.

P-84 Failures discovered

The last item of interest was the discovery of a significant number of failed P-84 bags in the last compartment of Chamber 2B. These were discovered by chance during an unscheduled bag inspection that occurred during a boiler tube leak on September 29^{th}. Other than the NOMEX compartment, which had a very significant percentage of failed bags, the compartment with P-84 bags that were installed in December 2003 was the only other compartment to have visual evidence of a significant number of failed bags. An estimated 40 bags have holes in them and about 50% occurred in the 9^{th} and 10^{th} position of the short blowpipe in that compartment. Also, 100% of the failed bags were under the short blowpipe in other positions. This is a significant concern as the P-84 bags were considered the best, reasonable cost bag option until this time. The fact that the ECC bag analysis predicted 5-6 years of life and significant failures occurred in approximately 9 months needs further evaluation. The fact that these bags were all on the short blowpipe would also lead us to believe that there is an imbalance in the blow pipe design, and further refinement in the design is needed. Further testing and explanation of the failed P-84 bags with ECC will be completed.

General Discussion (*Ninth* Quarter 10/2004 – 12/2004)

Although not intended to cover an additional two months of reporting on the operations of the Advanced Hybrid system, Otter Tail Power Company is including data from the last months of the year in this final report.

The final demonstration period for the Advanced Hybrid system has been fairly stable. The most significant accomplishments were;

- Replacement of 1 compartment of NOMEX bags with fiberglass bags (with membrane)
- Replacement of ½ compartment of P-84 Bags with Superflex™ bags
- Independent analysis of the failed P-84 bags
- Continued work towards installing Advanced Hybrid components in the inlet field

Replacement of 1 compartment of NOMEX bags with fiberglass bags (with membrane)

The last compartment of Chamber 1B (Field 4, compartment #6) was replaced with membrane-style fiberglass bags from Midwesco. The installation went well, and only time will tell how these fiberglass bags will hold up during operation.

Replacement of ½ compartment of P-84 Bags with Superflex™ bags

One half of the bags in the last compartment of Chamber 2B (Field 4, compartment #12), was replaced with Superflex™ bags from W.L. Gore and Associates. All of these bags were under the short blow-pipe section. Again, only time and operational experience will tell if this type of bag will stand up to actual operational conditions.

Independent analysis of the failed P-84 bags

EEC was again contracted to perform and analysis on the P-84 bags which failed since the last outage. The report focused on the failure of the P-84 bags in service. It appears that the primary factor for failure was acid attack on the bags from moisture in the pulse air system. The report can be found in Appendix B42.

Addenda: General Discussion (Major Activities 1/2005 – 12/2005)

During 2005, the major focus has been the design, fabrication, construction and operation of additional Advanced Hybrid Components in the existing inlet field. The existing inlet field of the original system was left as designed in 1975 as a standard ESP section. The main goals of this modification were the following;

- Lower the A/C ratios to levels where acceptable performance has been demonstrated
- Improved ESP design and performance
- Improved pulse cleaning design
- Optimize bag placement and space consideration
- Return the Big Stone Power Plant to full load and stable operation

Lower A/C Ratios

The fundamental change to the system is the addition of 4 more AHPC compartments to bring the total number of compartments of the Advanced Hybrid system from 12 compartments to 16 compartments. In general, the operating air:cloth ratios have been reduced from 12 fpm to 8 fpm. This has been the air:cloth ratio that had been demonstrated from the performance of the initial system to be acceptable (see Tables 2 & 3 from "General Discussions Fourth Quarter). Also, see the performance graphs included as B45 Addendum - Performance Graphs from 10/2002 through 12/2005

Improved ESP design and performance

After the initial design, a likely improvement option from the opinion of most working on the project included improving the ESP design. These design changes included extending the plates and electrodes longer than the original design. In the original design, the plates were only extended to cover the length of the installed bags. In the new design, approximately 10 feet of additional collecting surface was extended downward. This should have improved the pre-collection effect, as approximately 75% of the total gas stream will pass below the inlet field to the back three compartments of each chamber. Also, the area of open space beneath the current header design will be filled with ESP components. This should have improved the pre-collection of the flue gas that would normally bypass around the ESP components laterally with the old design.

Improved Pulse Cleaning Design

With the original design, the blowpipes were arranged in a two-piece system. The first half blowpipe would pulse the first half of the bags closest to the pulse header and the second half blowpipe would pulse the second half farthest from the header. This design proved to be aggressive to the point of accelerating bag failures and very difficult from a maintenance perspective to replace bags. During extensive testing and a demonstration of the improved single blowpipe design in one of the original compartments, it was determined that a single blowpipe design was superior for long-term bag life and maintainability, without poorly effecting performance. As a result, both the four new inlet compartments and the existing twelve compartments were retrofitted for a single blowpipe design.

Optimize Bag Placement and Space Consideration

In order to maximize the new cloth surface of the system, the new design was implemented with 10" plate spacing rather than 12" plate spacing. This design will allow for three more rows of bags (21 bags per row) per compartment. Also, successful demonstration of this concept would shrink the footprint of the system by over 10%.

Return the Big Stone Power Plant to full load and stable operation

Although the effort at replacing the inlet field with Advanced Hybrid design took advantage of lessons learned during the initial effort, the primary reason was to return the Big Stone Power Plant to full load stable operation. The performance of the Big Stone Plant primary particulate collection device needed to improve. In particular, the differential pressure across the system needs to be brought below 8 INH2O to allow the existing plant ID fans to function normally at full load. Any improvement efforts of the Advanced Hybrid system that did not lend themselves to this concept were not considered. Failure of the effort to improve system performance enough to bring Big Stone back to full load would result in abandoning the technology from Otter Tail Power Company's opinion.

General Discussion in Conclusion

During a six-week outage at Big Stone in the spring of 2005, the inlet field of ESP components was replaced with improved Advanced Hybrid Design described in general above. The results of this effort are described in the next sections, but in general, the project failed to meet the primary goal of overall improved performance.

4.0 CONCLUSIONS

4.1 PERFORMANCE PARAMETERS

The four fundamental performance parameters of the Advanced Hybrid system are;

- Opacity (Appendix B8)
- Air-to-cloth ratio (Appendix B7)
- Tubesheet dP (Appendix B5)
- Compressed air flow (Appendix B22)

Particulate control is ultimate goal of the Advanced Hybrid system. Only one stack test was performed by the EERC during the demonstration, although the stack opacity readings were recorded during the entire demonstration and this graph can be found in Appendix B8. The results of that stack test met the ultimate goal of 99.99%. However, as the various bag types were tried in an effort to reduce the differential pressure across the system, significant bag failures resulted in particulate control that falls short of the goal. It is generally accepted that to reach the 99.99% collection efficiency goal, an generally low opacity reading would be measured. After the initial set of bags was removed, the opacity would rise above minimum values and we are quite confident that the system would not reach the 99.99% goal. Significant improvements in the existing system must be realized so that overall performance will be acceptable, and bag integrity maintained so that the 99.99% particulate capture goal is met in the short term.

The A/C ratio during the demonstration has been between 10.5 and 12 fpm during full load operation. Significant plant reductions in load (5 – 50 MW) have been taken at times as the plant ID Fans have begun to stall during operation. Although this range of A/C was the goal of the system, what was determined as acceptable performance was not reached for the vast majority of this A/C ratio range. In addition to this, there is a discrepancy with regards to the overall flue gas flow volume of about 10%. In other words, the flue gas volume that was predicted by the stoichiometric equations and the volume measured by the stack flow probe is different by about 10%. If the expected stoichiometric flow was used instead of the stack flow monitor, it would result in an A/C ratio of about 9.5 – 10.8.

The tubesheet dP goal for the demonstration was 8.0 INH2O. At full load conditions during the two-year demonstration, the differential pressure exceeded this value up to maximum of 10.5 IN H2O at full load operation.

The compressed air usage for the system is a good representation of performance if the differential pressure is being maintained below 8 IN H2O. If the differential pressure is above 8 IN H2O, it can be assumed that the pulse system is working at maximum and the compressed air flow would be represented at around 2200 acfm. However, at times when the differential pressure is below 8 IN H2O, the pulse system will automatically pull back to reduce the compressed air usage while maintaining the differential pressure at 8 IN H2O. It can be seen in Appendix B22 that the compressed air flow was at 2000 acfm or greater at the beginning of the demonstration and at the end. While testing the various bag types, the compressed air flow varied greatly from as low as 500 acfm, to the level consistent with constant pulsing.

4.1.(addendum) PERFORMANCE PARAMETERS (June 2005 – December 2005)

The four fundamental performance parameters of the Advanced Hybrid system are;

- Opacity (Addendum Appendix B45)
- Air-to-cloth ratio (Addendum Appendix B45)
- Tubesheet dP (Addendum Appendix B45)
- Compressed air flow (Addendum Appendix B45)

Opacity during this period remains a challenge. Although after modification of the inlet fields, the opacity of the system was in the 5% range, in four to five months, the opacity had risen again to 10-12%. The failed bags were replaced in December 2005. The primary bag type that had failed was the BHA fiberglass bags.

The A/C ratio after the installation of the Advanced Hybrid components dropped to 7-8 fpm as compared to the 10-12 fpm with the original design.

The tubesheet dP for the system has not decreased as anticipated. One clarification needs to be made with regards to the performance graph at the end of the report. The mode of control for the entire plant changed after the spring 2005 outage. Rather than being a base loaded plant, due to energy market fluctuations as part of the MISO market system, the unit has been cycling to lower loads during certain times. This has resulted in wider load swings than the system has seen in the past. This accounts for the greater variaation in the graphical data presentation in both the Tubesheet dP and Flange-to-flange dP in the addendum section.

The compressed air usage after the new inlet field system was installed shows an increase from 2000 acfm to approximately 2400 – 2750 acfm. This is consistent with the installation of additional bags and pulse valves associated with the inlet field upgrade. One other note is that the increase above 3000 acfm at the end of the graph was due to a modification in piping at the plant and not related to an increased demand to the Advanced Hybrid system.

4.2 BENEFITS ANALYSIS

4.2.1 Cost Baseline Analysis

The cost baseline analysis before and after installation of the system is based on three primary factors, electrical energy usage, ongoing maintenance costs, and bag replacement costs. The electrical energy comparison information is presented in the following table.

Table 3 Electrical Energy Comparison

		ESP Only		Advanced Hybrid™
Precipitator 1A	KW	188.8		110.1
Precipitator 1B	KW	190.4		93.4
Precipitator 2A	KW	172.3		130.4
Precipitator 2B	KW	133.0		98.3
Total ESP Usage	**KW**	**684.5**		**432.2**
ID Fan A	KW	1,552.0		1,888.5
ID Fan B	KW	1,567.6		1,835.7
ID Fan C	KW	1,541.7		1,835.0
ID Fan D	KW	1,573.9		1,851.1
Total ID Fan Power	**KW**	**6,235.2**		**7,410.4**
Air Compressor D	KW	105.5		173.6
Air Compressor E	KW	87.2		181.5
Air Compressor F	KW	127.9		174.9
Total	**KW**	**320.6**		**529.9**
Total Electrical Energy	**KW**	**7,240.3**		**8,372.5**
Difference	KW			**+ 1,132.2**

Table 4 Cost Comparison

		ESP Only		Advanced Hybrid™
Labor & Materials	$/month	$5,741		$35,670
Humidification Chemical	$/month	$7,022		NA
Bag Replacement Cost	$/month	NA		$174,028
Average	**$/Month**	**$12,762**		**$209,698**
Sum of Monthly Average	**$/Year**	**$153,144**		**$2,516,376**
Difference	**$/Year**			**+ $2,363,232**

Notes on the table above:
The Advanced Hybrid™ costs are derived from the spreadsheet AHPC Work Plan. The labor and materials are are taken from the operators and other union personnel time. The material cost is derived from the OTP costs with the bags removed.

Table 5 MWH - Derate Comparison

	ESP Opacity Derates	ESP Repair Derates		Advanced Hybrid™ Opacity Derates	Advanced Hybrid™ Repair & Operational Derates
1999	7,786	16,004			
2000	6,859	16,676			
Average MWH/Year	**7,323**	**16,340**			
2003				0	99,324
2004				706	29,108
Average MWH/Year				**353**	**64,216**
Difference by Category				**-6,970**	**+47,876**
Total Derate Difference					**+40,906**

4.2.2 Technical Baseline Analysis

The technical baseline information is a comparison of the last particulate loading test that was performed at Big Stone and the Stack test that was performed by the EERC in November 2002 after the installation of the Advanced Hybrid™ system.

Table 6 – Collection Efficiency Comparison

		ESP		Advanced Hybrid™
Particulate Matter[1]	gr/scf	.0068		.00004
Collection Efficiency[2]	Gr/acf	99.29%		99.996%

1 acf converted to scf by measured value during demonstration
2 Inlet loading during previous stack test assumed to be the same as the inlet loading during the EERC stack test.

4.2.3 Comparison Summary

Table 7 Comparison Summary Table

		ESP Only		**Advanced Hybrid™**
Collection Efficiency	**Gr/acf**	**99.29%**		**99.996%**
Cost Difference	**$/Year**			**+ $2,363,232**
Electrical Energy Usage Difference	**KW**			**+ 1,132.2**
Opacity Derate Difference	**MWH/year**			**-6,970**
Operational & Repair Derate Difference	**MWH/year**			**+47,876**

4.2.4 Baseline Analysis (Addendum)

There were no significant changes to the performance after the inlet field upgrade. So no additional comparison was made. However, as a point of note, the cost for the inlet field upgrade was approximately, $7,907,374.

4.3 Final Project Conclusions

4.3.1 Project Objectives

Demonstrate that the AHPC technology can be retrofitted into an existing ESP at the full-scale level

This objective was met. The overall installation of the Advanced Hybrid™ system into the existing Wheelabrator-Frye electrostatic precipitator box was a significant success. The installation of the equipment was accomplished during a 5.5-week outage in October 2002. There was no difficulty in making this installation timeline.

Demonstrate the ability of a retrofitted AHPC to meet performance specifications without derating the plant because of high opacity

This objective was not met, as the plant had to derate output in October of 2004 as the bags began failing.

Demonstrate the ability of the AHPC to provide >99.99% particulate collection efficiency for all particle sizes greater than 0.01 µm.

This objective was met as the results of the stack test performed in November 2002 showed. Although, in general, it may have been better to state this objective as meeting the particulate collection efficiency goal after a certain period of time that would be considered acceptable. A likely better objective would have been 99.99% collection efficiency after 3-5 years of operation. The Advanced Hybrid™ system would not have met the objective in this case due to the failure of the filter bags.

Demonstrate the reliability of the AHPC as defined by acceptable maintenance requirements that are the same or less than standard ESP's or Baghouses.

This is somewhat speculative to answer, although I would say that the spirit of this objective was met. Obviously, when comparing the benefits and cost comparisons in the previous section, the Advanced Hybrid system is significantly more expensive to maintain than the previous ESP system. However, there are two underlying components that need to be considered. First, there was some difficulty after startup with the plate rapping systems, and working the bugs out of the system. This occurred for about six months or until the next week-long outage. After this outage, these issues were resolved and the rapping system worked fairly well. The other, considerably larger, factor is the significant work with the bag changes. If we would remove these two factors, it is our opinion that this objective would have been met. Other than the ongoing bag concerns, the maintenance for operation is at acceptable levels.

Demonstrate the ability of the AHPC to achieve low-pressure (guaranteed) pressure drop at an air-cloth ratio of 12 ft/min

This objective was not met. Although the system was operated at 10.5 – 12 fpm (using the stack flow meter), the tubesheet differential pressure ranged from 8 – 10 IN H2O. Because of this, significant limitations of the plant output were realized. This is the primary objective that drives the view of success of this project, as well as the primary consideration looking ahead.

Demonstrate the long-term operability of the AHPC

This objective was not met, since the previous objective was not met.

Demonstrate the economic viability of the AHPC

This objective was not met. This judgment is based on the previous two objectives not being met, as well as the high cost of the replacement bags to date.

4.3.2 Overall Conclusions

When reviewing the project objectives, three of the seven objectives were met. Overall however, the system is not where the project team estimated it would be at the conclusion of this demonstration. This can be attributed to two primary factors, differential pressure and air:cloth ratio.

If the differential pressure had met the 8.0 IN H2O goal, there would not have been any plant output restrictions. The original filtration bags installed in October 2002 would still be in the system, and the significant cost and problems associated with attempting the use of various bag materials would not have occurred. The reason the differential pressure goal was not met is likely a scale-up problem from the pilot unit to the full-scale unit.

The most significant test and information came from a one-time test in February 2003. The details of this test can be found in pages 36-39 of this report. After this test the performance levels of full-scale system when compared to the pilot system were known. With a residual drag nearly 30% greater than previously reported results, and 3-5 times the rate of ash loading to the bags, the full-scale system was simply too far outside the reasonable range of performance. The system as designed and built was simply not able to demonstrate acceptable performance. All attempts to improve performance failed over the long-term, and the decision to re-size the system to a lower air: cloth ratio was made.

4.3.3 Looking Ahead

The current plans for the system involve the installation of improved Advanced Hybrid™ components in the existing inlet field at Big Stone. This will result in operation at an air:cloth ratio of approximately 8-9 fpm, or 75% of current levels. Using the table of demonstrated performance on page 54, this should result in acceptable performance. However, as was seen in the first phase of this project, unforeseen difficulties may still arise and the system needs to be demonstrated prior to being considered a viable market technology.

There are also questions as to which bag material is appropriate for the system. This has not yet been resolved, and will take additional demonstration before it can be concluded.

4.3.4 Final Conclusions (addendum)

The inclusion of Advanced Hybrid components in the inlet field of the Big Stone ESP failed to significantly improve performance to satisfactory levels. In fact, as can be seen by the performance graphs in the addendum section at the end of this report, differential pressure across the system actually increased during periods of full load.

The goal of installing the Advanced Hybrid system in the inlet field was improved performance demonstrated at lower A/C ratios during the operation of the Advanced Hybrid system and reported on Tables 2 and 3 in the Fourth Quarter General Discussion section of this report. It is the professional opinion of the authors of this paper that the reasons for this lack of performance improvement are due to the inability of the AHPC to precollect any flyash on the perforated collecting plates prior to the fabric filters. Main reasons for the lack of ESP collection are (1) high gas velocities, (2) high ash restivity, and (3) inability to maintain design clearances between the plates and electrodes. With out the benefit of ESP precollection on the perforated collecting plates, the AHPC operates just as a conventional PJFF does. In essence, we replaced a working inlet field ESP with a PJFF compartment operating at an A/C of 8:1.

As a result of the lack of performance improvement, Otter Tail Power Company has made the decision to abandon the Advanced Hybrid technology, and is looking at full-scale replacement of the primary particulate device.