

The Ultimate ESP Rebuild: Casing Conversion To a Pulse Jet Fabric Filter, a Case Study

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Abstract

An Electrostatic Precipitator (ESP) may require major upgrade or replacement due to present and future emissions considerations such as the ESP is not meeting outlet emissions/opacity requirements due to fuel switching to a lower sulfur coal, addition of mercury emissions control by sorbent injection upstream of the ESP, addition of a wet or dry FGD system, and compliance with upcoming fine particulate control (PM_{2.5}) regulations. A lower cost option to consider for compliance strategy is the conversion of the existing ESP casing to a pulse jet fabric filter.

This paper discusses the decision making process, design, installation and performance of the electrostatic precipitator casing conversion to intermediate pressure, long bag pulse jet fabric filter at Otter Tail Power Company's Big Stone Plant Unit #1, a 475MW cyclone-fired boiler burning PRB coal. The conversion was completed in late December, 2007. Also discussed is the criteria that makes an existing ESP a candidate for conversion to a fabric filter and the advantages and disadvantages of conversion.

Introduction

In response to the Clean Air Act of 1970, hundreds of electrostatic precipitators (ESPs) were installed on coal-fired boilers throughout the U.S. The long established technology of the ESP was considered the best choice to meet the particulate emission requirements. The precipitator's collection efficiency could be maintained within the normal variations in boiler operation but it is sensitive to the electrical characteristics of the fly ash as related to the type and source of the coal burned. These ESPs are now 25 to over 35 years old. Many have been rebuilt with new and improved plate and emitting electrode systems, power supplies and control systems.

Today, there are new challenges for existing ESPs whether they have been rebuilt in the past or not. These challenges go beyond just meeting outlet emissions and stack opacity requirements and in some cases may require the replacement of the precipitator with a fabric filter baghouse. A cost saving alternative is conversion of the existing ESP casing to a pulse jet fabric filter if the unit meets the criteria for conversion.

Considerations for Replacement/Conversion to Fabric Filter

Present and future considerations that may include the option of replacing or converting the existing ESP with a baghouse include: a) the ESP is currently not meeting outlet emissions or opacity requirements, b) fuel switching has adversely effected ESP performance, c) adding a scrubber upstream or downstream of the ESP for SO₂ reduction, d) control of mercury emissions, and e) control of PM_{2.5}, future fine particulate control legislation.

If the ESP is not consistently meeting outlet emission or opacity requirements due to aged internals and close electrical clearances between electrodes, then a rebuild is required. In some cases, the performance problems are compounded if the ESP is treating a higher than original design gas volume. When considering future emission requirements, this ESP may be a candidate for replacement or conversion with a fabric filter.

Switching to a low sulfur coal, especially a sub-bituminous PRB, will result in a higher resistivity ash and degradation in ESP performance with de-rating required in many cases to maintain emission and/or opacity requirements. Depending on the severity of the performance deterioration, upgrade requirements may include the addition of sections to the ESP, gas conditioning, or replacement /conversion to a fabric filter.

With the addition of a spray dryer FGD system for SO₂ reduction, a pulse jet baghouse downstream is a logical addition due to the additional adsorption of SO₂ in the baghouse filter cake reducing lime consumption requirements of the spray dryer. If a wet limestone forced oxidation FGD system is to be added producing commercial grade gypsum, the existing ESP's performance needs to be evaluated. Depending on the amount of ash exiting the ESP and its chemical composition, potential problems could occur with the gypsum quality byproduct and the chemistry of limestone dissolution affecting SO₂ removal efficiency. The role of the existing ESP, when adding a WFGD system, thus extends beyond achieving the stack opacity requirements. Depending on the mechanical condition of the ESP and whether it can consistently

meet the required fly ash loading limitations to the scrubber, may require the consideration of adding a baghouse.

The Clean Air Mercury Rule (CAMR) was vacated in early 2008 by the DC Circuit Court of Appeals followed by the same decision in July to vacate the Clean Air Interstate Rule (CAIR) that required significant reductions of sulfur dioxide and NO_x in the eastern states. Despite the invalidation of the Mercury Rule, many states are moving forward with their own plans to limit mercury emissions from coal-fired plants. The Clean Air Interstate Rule was reinstated in December of 2008 while the EPA fixes flaws in the implementation/compliance plan. Reinstating the Mercury Rule is also expected. Thus, the requirements of the Mercury Rule are not going to go away, they are most likely to become more stringent.

Mercury removal efficiency with sorbent injection is highly dependent on coal type, LOI, flue gas temperature, chlorine content in the coal, and SO₃ content of the flue gas. A number of test programs with injection upstream of an ESP of various sorbents and enhanced sorbents conducted by a number of sorbent suppliers with funding from the DOE, show mercury removal rates of 30 - 90%. For many coal-fired plants, the best option presently for consistent, high mercury removal efficiencies ($\geq 90\%$) is sorbent injection followed by a fabric filter.

In the future, standards will likely be enacted for stationary sources limiting particulate matter of 2.5 micron diameter and less. Solid particulate, as \leq PM_{2.5}, would likely be limited to 0.01 or 0.015 lb/MMBtu. Utilities may also need to control air toxics with particulate matter becoming the surrogate for a group of Hazardous Air Pollutants (HAPS) in the form of heavy metals, a large percentage of which are emitted from coal-fired boilers as fine particulates. For many older, relatively smaller SCA (collecting plate area/1000 acfm of flue gas treated) ESPs, performance upgrades required to achieve PM_{2.5} emission limits could be extensive with replacement or conversion of the existing ESP with a baghouse being a viable option.

Due to the considerations discussed above, the conversion of an existing ESP casing to a pulse jet fabric filter, where applicable, is a process that is becoming increasingly common as more power plants seek air quality control system retrofitting to minimize emission and improve air quality. Many conversions have successfully been completed over the past 20 years in Europe, Australia, South Africa and in the U.S. A key to successfully applying this retrofit technology is using long filter bags and perfecting the ability to clean effectively the full length of these long bags which are typically over 25 feet long and presently up to 30 foot in length.

Advantages of ESP to Fabric Filter Conversion

The advantages of converting an ESP casing to a pulse jet fabric filter include:

- Lower cost option than replacing with a new ESP or new baghouse
- Installed in the existing ESP footprint
- Minimal ductwork modifications/additions
- Reuse of existing hoppers and ash conveying system
- Fuel Flexibility - a fabric filter is more forgiving than an ESP

- Ready for more efficient and consistent mercury emissions reduction with sorbent injection
- Ready for future PM2.5 legislated particulate emissions standards

There are two basic criteria that must be met for an ESP to be a good candidate for conversion. The casing must be large enough in volume to accommodate the required cloth area and the casing should be structurally sound with a minimum of corrosion. Other considerations for conversion that must be evaluated include the additional pressure drop with a fabric filter, approximately 8” W.G., that may require the ID fans to be rebuilt or replaced and potential structural reinforcement of the ESP casing and ductwork if the original design pressure is exceeded.

ESP to Pulse Jet Fabric Filter Conversion Case Study

An ESP to fabric filter conversion was completed by Buell APC in December 2007 on Otter Tail Power Company, Big Stone Plant, Unit #1. The Big Stone Plant is located in Big Stone City, South Dakota.

History

The Big Stone Plant was bought on line in 1975 with a Wheelabrator designed electrostatic precipitator for particulate emissions control. The 475MW cyclone-fired boiler originally burned North Dakota lignite coal. In 1995 the unit converted to burning sub-bituminous Powder River Basin coal. The precipitator consists of four chambers in parallel each with four electrical fields. Each field measured 40 ft high x 45 ft wide x 14’ deep. The plate spacing is 12” with 45 gas passages across each field. Guillotine type inlet and outlet dampers are used to close off a chamber if necessary. The discharge electrodes are ‘star’ wires mounted on pipe frame supports. Collecting plates are rapped with tumbling hammer rappers while the discharge electrodes use a falling hammer/cam-drop style of rapper.

ESP Inlet Flue Gas Design Conditions

Gas Volume	2,100,000 acfm
Inlet Temperature	340°F
Inlet Loading	0.9 to 1.7 gr/acf
Mean Particle Size	6 microns

With the switch to PRB coal, performance problems occurred with the ESP due to the higher resistivity ash and subsequent back corona formation resulting in problems meeting the 20% stack opacity limit. A humidification system was added to condition the ash but did not prevent back corona formation and performance problems persisted. A decision was then made in 1997 to consider a potential ESP retrofit technology, the Advanced Hybrid Particulate Collector, being developed by the University of North Dakota’s Energy and Environmental Research Center (EERC). The Advanced Hybrid Particulate Collector (AHPC) technology development was

initially supported by the Innovations for Existing Plants component of the DOE Fossil Energy R&D Program and then demonstrated under the Power Plant Improvement Initiative.

The AHPC concept combines fabric filtration and electrostatic precipitation in the same housing. Fabric filter bags are interspersed with 45% open area perforated ESP collecting plates and emitting electrodes as shown in Figures 1 and 2. Flue gas first flows through the ESP charging and collection zone and then through the perforated collecting plates to the filter bags. During bag cleaning, a majority of the dust cake that is released from the bags during pulsing, is projected through the perforated plates and captured in the ESP zone. Optimum particulate collection is achieved by removing over 90% of the flyash in the electrostatic precipitator zone with final ash collection by the filter bags. With a majority of ash collected in the ESP zone, the fabric filter zone can be a high A/C ratio of 12 ft/min. Charge on the particulate enhances collection and minimizes pressure drop in the filtration zone of the AHPC since charged particulate tends to form a more porous dust cake. The barrier that limits operation at a high air-to-cloth ratios is not so much the dislodging of ash from the bags as it is the transferring of the dislodged ash to the hoppers. The AHPC would overcome this limitation by trapping the released dust cake during pulsing in the electrostatic zone after being projected through the perforated plates.

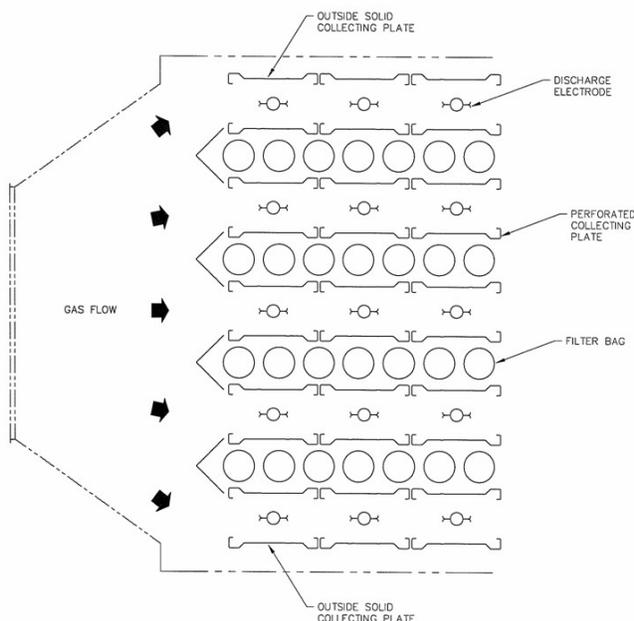


Figure 1: AHPC Concept Plan View



Figure 2: AHPC ESP & Filter Zones

Following successful slipstream pilot testing (9,000 scfm) at the Big Stone Plant in 2001, the decision was made to retrofit the AHPC full scale into the three outlet ESP fields in each of the four ESP chambers with the inlet field in each chamber left in place but not energized. Each ESP chamber had 1226 filter bags of 6" diameter and 23' long. The A/C ratio was 12.0 ft/min. with on-line cleaning used. The retrofit was completed in October 2002.

Shortly after startup of the retrofit, performance problems began to occur and continued for the next two years. These problems included a high tubesheet differential pressure exceeding 10" W.G., continuous cleaning with pulse pressures raised to between 100 to 110 psi and bag failures occurring within 6 months. The result of these problems were boiler derates of 30 to 50 MW due to ID fan limitations with the high bag pressure drops and the stack opacity exceeding the 20% limit due to bag failures. During this two year period, a number of different bag types were tried as well as alternate bag cleaning strategies. Also, the ESP inlet field of each chamber was energized to pre-collect a portion of the ash loading before it entered the AHPC sections.

In the spring of 2005, the inlet electrical field of each of the four ESP chambers was converted to AHPC to reduce the air-to-cloth ratio to 9.0 ft/min to reduce tubesheet pressure drops and the intensity of pulse cleaning to extend bag life. However, the same problems persisted and the AHPC technology was then abandoned. The key point of failure of this technology was that applying it to the Big Stone application would not eliminate the high resistivity ash condition and back corona formation which severely limited the effectiveness of the electrostatic zone of the AHPC. A decision was made by Otter Tail Power Company to replace the collector with a new conventional design pulse jet baghouse that would be built alongside the existing collector. The existing ESP would be demolished after tie-in of ductwork to the new baghouse.

Buell Division of Fisher-Klosterman proposed to the Big Stone Plant management and engineering staff the cost saving alternate approach of converting the existing ESP casings to an intermediate pressure, long bag pulse jet fabric filter. The ESP met the criteria for conversion to a fabric filter. The casing volume was large enough to accommodate the required air-to-cloth ratio and the casing mechanical integrity was good. The ESP conversion to fabric filter would be less than half the turnkey cost of a total replacement with a new baghouse. With the ESP configuration of four independent chambers, an added benefit for a conversion was that each chamber could be blanked off during a short outage and then converted while on-line at a reduced boiler load. After competitive bidding, Buell was awarded a contract for engineering and material supply for the ESP to fabric filter conversion. Otter Tail Power Company contracted the construction scope directly.

Big Stone Pulse Jet Fabric Filter Design Parameters

The pulse jet conversion design parameters are as follows.

A/C Gross: 3.4 A/C Net 1: 3.6 with Off-line cleaning
16 Compartments total, 4 compartments in each ESP Chamber
Interstitial/Can Velocity = 178 ft/min

Filter Bags: 21 oz. Woven fiberglass with PTFE membrane,
acid resistant coating, 6" diameter, 25' long

Cages: Split cage, carbon steel, 24 wire
Bags/chamber = 4028, Total Bags = 16,112
27 bags per blowpipe, two (2) blowpipes per bag row

Guarantees

Opacity	- 10%
Outlet Loading	- 0.01 lb/MMBtu
Bag Life	- 3 years
Maximum ΔP	- 8" W.G.

Conversion Design and Construction

The ESP chambers were partially converted to a pulse jet with retrofit of the AHPC technology. The walk-in outlet plenums, vaned outlet dampers, and outlet ductwork installed with the AHPC retrofit were retained, Figures 3, 4, and 5. The ESP chambers were gutted with the removal of precipitator plates and emitters, support channels, rappers, bags, cages and tubesheets from the hybrid design. Gas flow baffle plates were removed from the inlet pyramidal nozzles. After all internals were removed, new tubesheets were installed supported by a shelf angle around the perimeter of each chamber. Three partition walls were installed in each chamber to compartmentalize each chamber into 4 pulse jet compartments. Each compartment utilizes off-line cleaning by closing off the existing vaned damper located on the roof of the outlet walk-in plenum. No damper was added to the inlets of the compartments. An inlet transition duct with turning vanes was added to each inlet pyramidal nozzle that fed the gas flow to a pulse jet compartment inlet plenum that extended down the lower center of the chamber its full length. Gas flow entered each of the four compartments via a vaned opening on either side of the inlet plenum, Figures 6, 7, and 8. The top of the rectangular inlet plenum has a peaked 'roof' at the top to prevent buildup of ash from bag cleaning.

For bag cleaning, a total of 32 completely shop assembled air header assemblies were installed utilizing a 4" Goyan solenoid valve for each blowpipe. Each row of 54 bags each on the tubesheet has two blowpipe assemblies with 27 bags per blowpipe and 19 rows per compartment, Figure 9. The blowpipe pulse discharge hole sizes vary along the length of the blowpipe to assure equalized pulse air cleaning volume to each bag from the intermediate pressure pulsing design. For access to the header assemblies and solenoid valves, three new platforms were installed: two outboard of the end precipitator chambers (with weather cover) and one under the existing control room located between the two pairs of ESP casings. For bottom access to each pulse jet compartment a walkway was added with a new side access door.

A new control system was provided using an Allen Bradley PLC with a Control Logix 5561 Controller to control the 608 pulse valves and 16 compartment outlet dampers, Figure 10. A cleaning cycle for the 16 compartments would be initiated when the integrated average of the four chambers' pressure drop reaches a setpoint or by a timer control with a pressure drop setpoint over-ride. The pulse cleaning mode, with pulse pressures of 45 to 55 psi, is off-line cleaning but with the capability of on-line cleaning for outlet vaned damper maintenance if required. Each pair of blowpipes on either side of a row of 54 bags will be pulsed simultaneously in sequence from row 1 through 19. In the on-line cleaning mode, a staggered blowpipe pulsing sequence would be used. The individual compartment tubesheet differential

pressures are monitored and compared to the before cleaning values to display the bag cleaning effectiveness.



Figure 3: Four ESP Chambers



Figure 4: AHPC Walk-in Plenums, Vaned Dampers, Outlet Tie-in Ducts Reused



Figure 5: Vaned Outlet Dampers on Walk-in Plenum Roofs

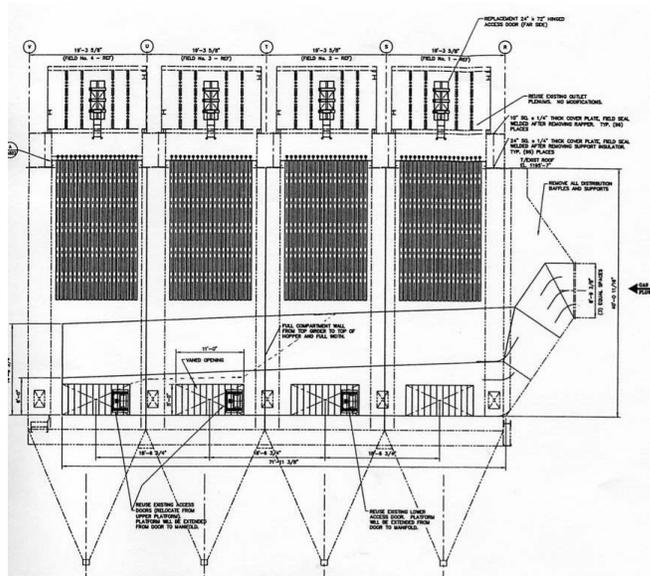


Figure 6: Side Elevation, Transition Duct and Inlet Plenum

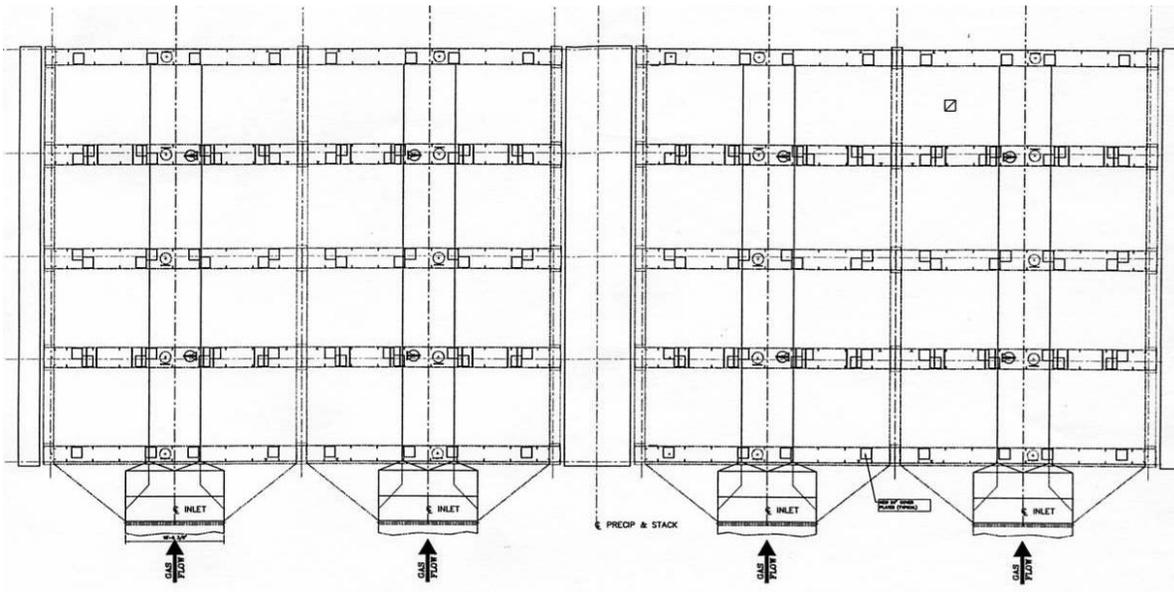


Figure 7: Pan View of 4 Chambers, New Inlet Transition Duct and Plenum

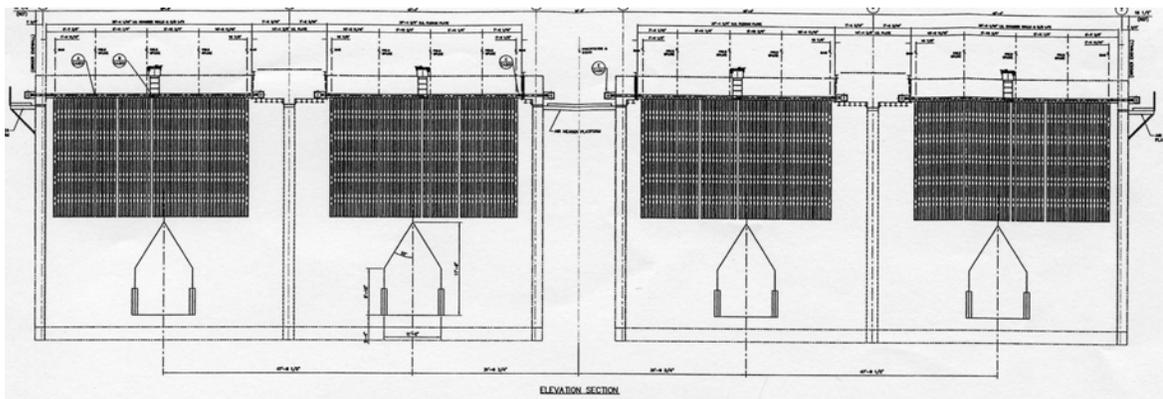


Figure 8: Front Elevation, Inlet

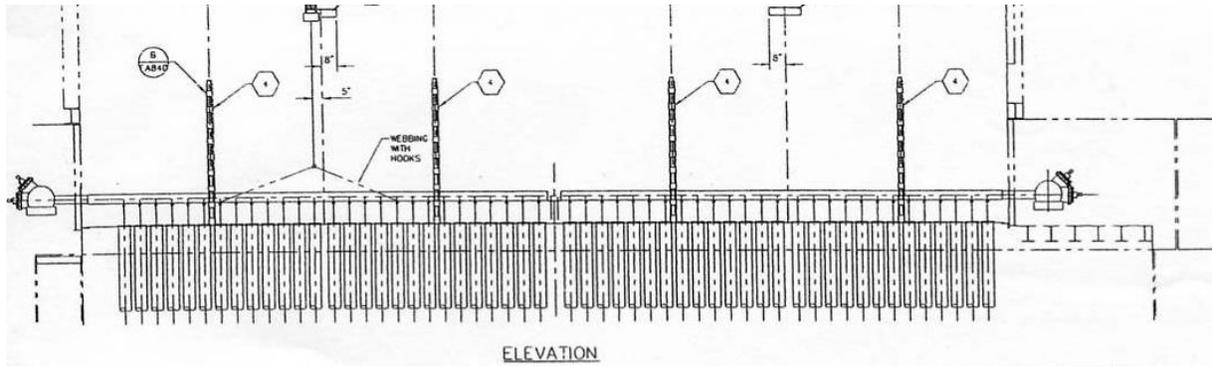


Figure 9: Dual Blowpipe Arrangement per Bag Row, 27 Bags /Blowpipe



Figure 10: New Pulse Jet Baghouse Control Cabinet

The outboard two ESP chambers were converted during the spring of 2007, one at a time, starting in early March. The first chamber was taken out of service in a short outage to allow blanking plates to be installed in the chamber's inlet and outlet rectangular ducts. The first chamber was converted during a six week period, with the unit at reduced load, and started up in April 2007 followed by conversion of the second outboard chamber during a six week period with startup of the converted chamber in June 2007. During the summer and early fall, the unit operated with the two converted pulse jet chambers and the two chambers with the Advanced Hybrid Design. The remaining two ESP chambers were converted to pulse jet during a scheduled late fall outage and the complete conversion was on-line in December 2007. Construction pictures are included in Figures 11 through 18.



Figure 11: ESP Chamber Side Cut-Outs



Figure 12: Compartment Tubesheet Shelf Installation



Figure 13: Pre-Assembly of Inlet Plenum Sections



Figure 14: Blowpipe Fabrication



Figure 15: Inlet Nozzle Transition Installation



Figure 16: Pulse Header Assemblies



Figure 17: Pulse Header Assemblies Installed

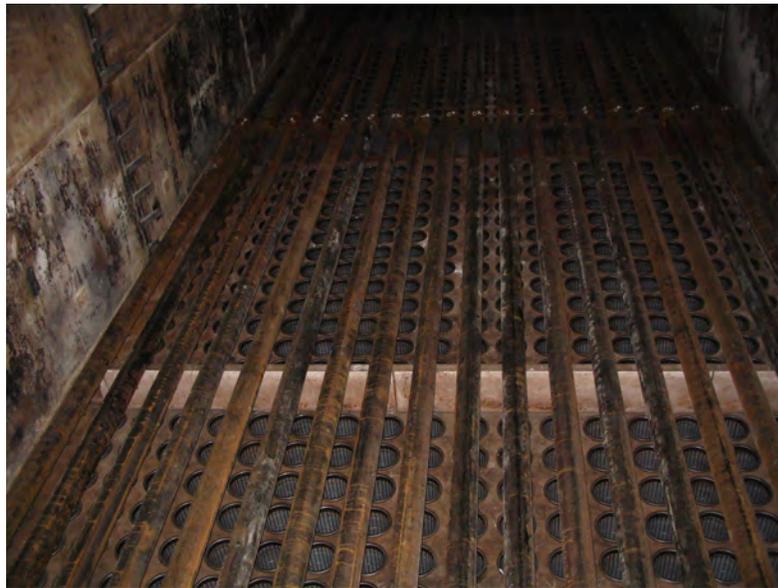


Figure 18: Completed Compartment Tubesheet

A number of steps were taken during the design, fabrication and construction phases of the conversion to assure the optimum performance of the baghouse. During fabrication, very tight tolerances were required and demonstrated for tubesheet flatness, tubesheet holes and spacing, blowpipe hole alignment and spacing, perpendicularity vertical centerline of attached split cages with the tubesheet, and filter bag width and length. During construction, Buell technical advisors provided daily QA/QC inspections to insure the required installation tolerances were achieved.

During the design phase, both a numerical model study and physical model study were performed of the pulse jet gas flow configuration. To assure optimum pulse cleaning of the 27, 25' long bags on a blowpipe, blowpipe design and optimization tests were conducted by the pulse valve supplier in a series of laboratory tests.

Model Study

Buell contracted Airflow Sciences Corporation (ASC) to perform a flow model study to ensure that the new baghouse conversion configuration met the Institute of Clean Air Companies (ICAC) standards for flow uniformity. The flow study utilized both numerical and physical modeling techniques. The computational model of the Big Stone conversion scope was from the guillotine damper just upstream of the inlet nozzle to the induced draft fan inlets, Figure 19, 20 and 21.

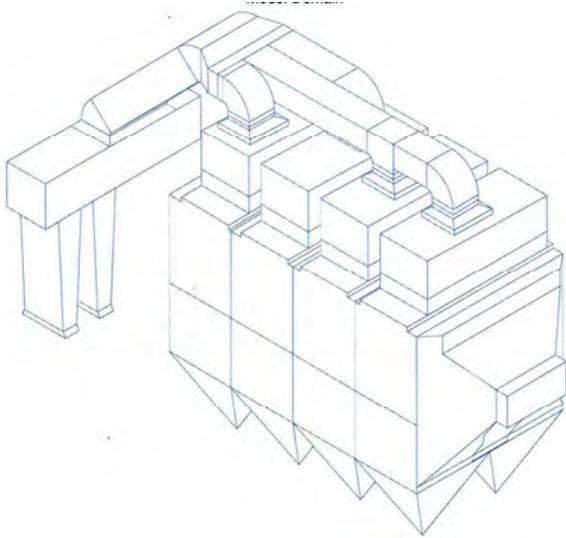


Figure 19: Numeric Model Scope

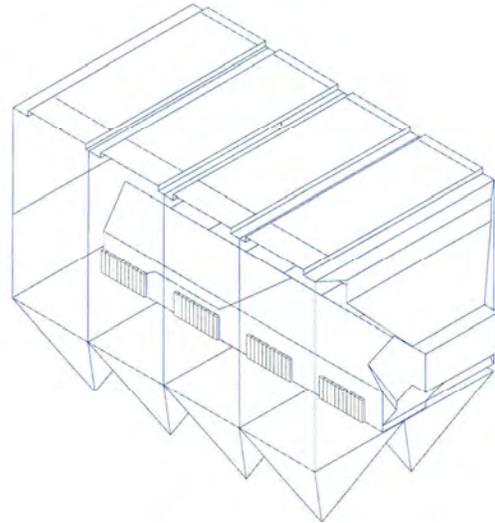


Figure 20: Numeric Model Scope, Inlet Plenum

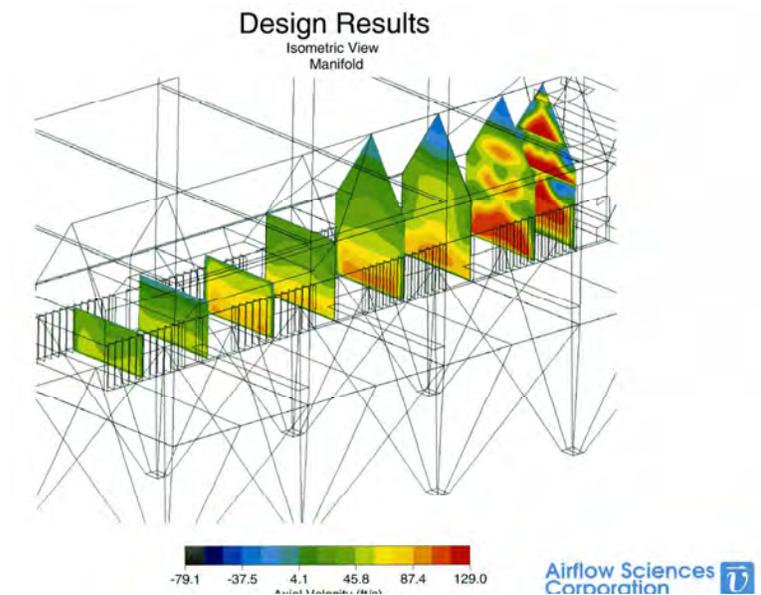


Figure 21: Sample Inlet Manifold and Plenum Numeric Run

The goals of the numerical modeling were to assure the flow split between compartments in a chamber met ICAC F-7 criteria (within +/-10%) and to optimize gas flow distribution and minimize losses in the inlet transition to the fabric filter inlet manifold. The results of the computational model were that the flow split between the four compartments in a chamber met the ICAC criteria and several changes were made to the inlet transition vanes which improved the flow distribution and reduced the losses in this section over that of the baseline design.

The physical model was 1/12 scale and, since the four chambers of the baghouse are identical, only a single chamber was modeled, Figure 22. The physical model scope extended from the inlet transition nozzle of the baghouse, through the outlet ducts to the common duct that leads to the ID fan inlets. The goals of the physical modeling were to confirm the numerical modeling results, ensure that no significant ash buildup occurred in the ductwork and inlet manifold floor through dust deposition tests and to quantify the system pressure losses.



Figure 22: 1/12 Scale Physical Model

The results of the physical modeling showed that there was good agreement between the numerical and physical model results and in the dust deposition tests, the majority of dust was swept clean from the inlet manifold floor at 75% of full load flow velocity and no significant buildup of dust was observed at 100% flow. The flow split between the four compartments was as follows.

	<u>% of Total Flow</u>
Compartment 1 (inlet)	23.1
2	22.8
3	26.6
4	27.5

Blowpipe Design and Optimization Tests

Blowpipe design optimization laboratory tests were conducted on the Big Stone blowpipe by Goyen Controls Co. Pty Ltd, Sydney, Australia. A 27 outlet blowpipe was fabricated per Buell's specification with the addition of pressure tapping locations. Due to the pulse cleaning air flow required for 27 bags per blowpipe, 4" blowpipes and valves were selected. The goals of the blowpipe optimization tests were to determine the staggered pipe orifice sizes along the pipe to provide equal pulse air volume to each bag within +/-10%, determine the optimum blowpipe air straightening nozzle diameter, length, and height above the tubesheet and to determine the air consumption required per blowpipe.

When testing a blowpipe system, the use of a clean filter bag is generally not very indicative of the cleaning performance with dust-laden filter bags. Rather than using a clean filter bags, Goyan accurately simulates a dust-laden filter bag using a jump pump duct. A significant advantage of the jet pump duct is that it is possible to simulate a range of dust loadings by altering the position of the blastgate (therefore altering the resistance to the pulse). This mimics the effect of varying dust loads on the filter bags. The jet pump duct is 3m long with a diameter of 150mm. A blastgate is located 1m from the entry of the duct. An orifice plate flow meter arrangement is located at the exit of the duct. Pressure taps are located halfway between the duct entry and the blastgate. Test runs along the blowpipe outlets were conducted at 45 and 60 psi pulse pressure. Results of the Flowrate Tests are plotted in Figure 23. A good distribution of cleaning flow along the blowpipe was achieved with cleaning flows within +/-10% of the average.

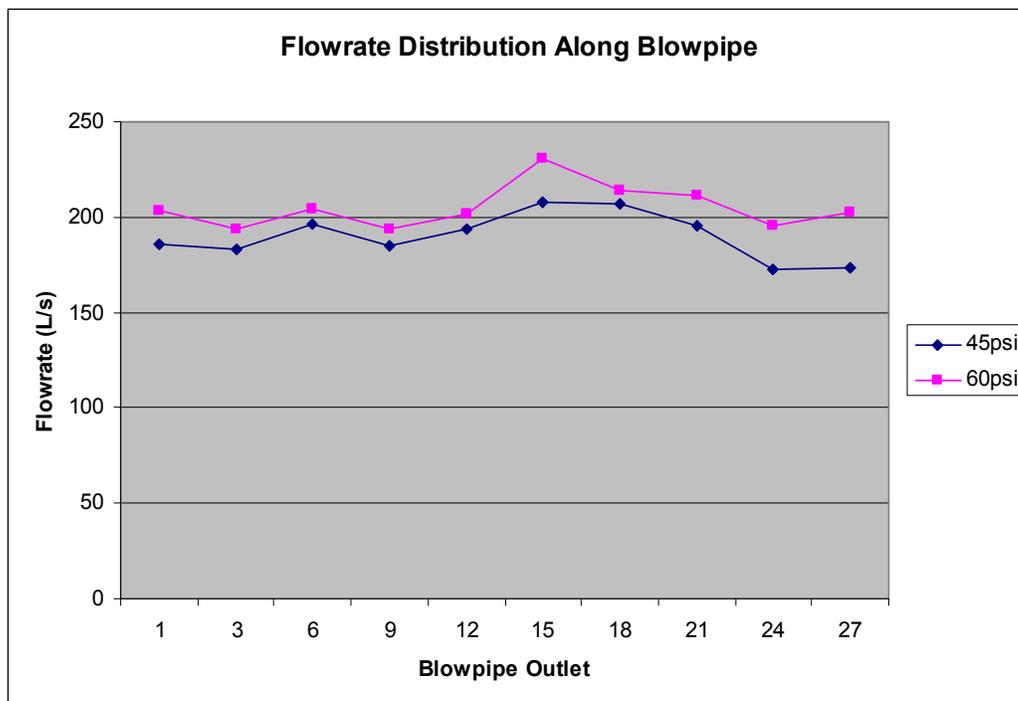


Figure 23: Flow Rate Distribution Along the Blowpipe

Pulse Jet Conversion Operation

The conversion of the first two chambers was completed in the spring of 2007 and the conversion of the remaining two chambers was completed in December 2007. All performance guarantees have been met, i.e. stack opacity and pressure drop. The stack opacity has been essentially zero which prompted the Big Stone Plant to forego the outlet emission tests. In 2008, Big Stone Plant Unit #1 achieved its highest generation ever, since the plant came on-line in 1975. Restrictions to generating capacity due to problems with meeting the opacity limit and/or exceeding the ID fans pressure drop limit are now in the past.

Conclusion

Based on the many successful ESP casing conversions to pulse jet fabric filter including the Big Stone Plant discussed in this paper, the option of conversion of an existing ESP which is large enough to accommodate the required cloth area can, for many applications, provide a significant cost savings when compared to complete replacement. Each case will be different, no two ESP installation configurations are alike. With emphasis applied during the design phase to maximize shop assembly of components and minimize existing ductwork modifications, and with proper planning for demolition and installation during construction, a conversion of an existing ESP to fabric filter can, for most cases, be completed during a typical outage duration. Therefore, a conversion of an existing ESP can be a viable, cost effective option to consider to solve a current particulate emissions/opacity problem, for consistent and efficient mercury emissions control with sorbent injection, for particulate removal with the addition of a wet or dry FGD system and as a future compliance strategy for PM_{2.5} fine particulate control.

References

Durham, M., Chang, R., Renninger, S., Monroe, L., Johnson, D.Chang. "Full Scale Results of Mercury Control by Injecting Activated Carbon Upstream of ESPs and Fabric Filters". Presented at POWERGEN International, 2003.

Gaikwad, R., Boward, W.L., "Economic Evaluation of Controls for PM_{2.5} - A Case Study". Presented at the EPRI-DOE-EPA Combined Utility Mega Symposium, August 1999.

Hrdlicka, T., Swanson, W., Demonstration of a Full-Scale Retrofit of the Advanced Hybrid Particulate Collector Technology, Final Report, 2006. Prepared for the United States Department of Energy, National Energy Technology Laboratory, DOE Award No. DE-FC26-02NT41420.

Precipitator Newsletter, May 2006, Issue 364, The McIlvaine Company.