WPCA NEWS
Worldwide Pollution Control Association
www.wpca.info

A Bi-Annual Newsletter Sponsored by the WPCA Spring - 2014

Executive Summary (page 1)

Steam Turbine Efficiency and Heat Rate Improvements for Fossil-Fired Operating Plants

By Michael W. Smiarowski and James Auman, Siemens Energy, Inc.

Projections made by the Energy Information Administration estimate that around one-third of U.S. generation will still be based on coal in the coming years. These coal plants will be the "survivors", which are typically the larger (200MW+) and newer units that are equipped with pollution control equipment. This article will provide an overview of some of the available efficiency improving options for fossil-fired power plants.

Full Story….

High Ratio Fabric Filters with 12m Long Bags for Large Coal Fired Power Plants

By Peter Wieslander, Stephen L. Francis and Ajay Vajpeyi, Alstom Power

This article presents information on key issues that need to be considered when designing and evaluating a HRFF with 12m long bags for a large coal fired boiler installation. Aspects of gas/dust flow distribution to the individual compartments of the filter as well as the concerns regarding large flow/loading into the bag nest in each compartment will be discussed. A very efficient, newly developed, cleaning system has been incorporated in the filter to clean the bags properly without increasing dust emissions, and allowing the system pressure drop to be kept as low as possible. The reduction in HRFF first cost with 12m as compared to 10m long bags, and tighter bag row pitch, is estimated at approximately 10%.

Full Story….

Innovative On-site SCR Catalyst Pluggage Removal Method

By Mike Dunker and Dorothee Seidel, STEAG Energy Services

STEAG's has developed and patented a unique process for in-situ cleaning of all SCR catalyst types i.e. corrugated, honeycomb, or plate inside the SCR reactor without removing the modules. This process utilizes dry Ice Blasting which cost effectively removes the channel pluggage which reduce SCR pressure drop and effectively increases the catalytic potential as more catalyst surface area becomes available without the pluggage.

Full Story….

ModuPower Reduces Particulate Matter Emissions from Undersized ESPs

By Jason Horn, Stock Equipment

Stock Equipment recently supplied ModuPower SMPS's for two 135 MW pulverized coal generating units located in Tocopilla, Chile. To control PM (Particulate Matter) emissions each unit was originally equiped with a 1990's vintage Mitsubishi electro-static precipitator powered by conventional TR sets (Transformer Rectifiers). The original design collection efficiency of the ESPs was 98% which resulted in an estimated 211 mg/Nm^3 emission rate at full load when using an imported bituminous coal with 10.6% ash content. Changes to government regulations would require compliance with a reduced PM emission limit of 50 mg/Nm^3 in 2014.

Full Story….

Continued on next page

WPCA NEWS
Worldwide Pollution Control Association
www.wpca.info

A Bi-Annual Newsletter Sponsored by the WPCA Spring - 2014

Executive Summary (page 2)

Enhanced Capture of Mercury in Baghouse by Using Novel Filtration Media and Filter Design

By Vishal Bansal, Robert W. Taylor, Pete Maly, and Bryan Yetter, Clarcor Industrial Air

A study was conducted at a 5-MW equivalent slipstream facility of Gulf Power's Plant Crist Unit 5 located in Pensacola, FL. The facility is also commonly referred to as Mercury Research Center (MRC). During the trials lasting 10 days, the effect of a range of process variables was studied. The variables included flue gas temperature, air-to-cloth ratios, interval between cleaning, and the effect of removing some of the fly ash by an electrostatic Precipitator (ESP) upstream of baghouse, etc. CLARCOR Industrial Air tested a novel membrane-based filtration media formed as pleated elements.

Full Story….

WPCA NEWS
www.wpca.info
A Bi-Annual Newsletter Sponsored by the WPCA
Spring 2014
WORLDWIDE POLLUTION CONTROL ASSOCIATION

Steam Turbine Efficiency and Heat Rate Improvements for Fossil-Fired Operating Plants

By Michael W. Smiarowski and James Auman, Siemens Energy

Abstract

Projections made by the Energy Information Administration estimate that around one-third of U.S. generation will still be based on coal in the coming years. These coal plants will be the "survivors", which are typically the larger (200MW+) and newer units that are equipped with pollution control equipment.

This article will provide an overview of some of the available efficiency improving options for fossil-fired power plants.

The options discussed include:

1. Applying Latest Technology to the Steam Turbine to recover Parasitic Load Losses due to Pollution Control Equipment and provide other benefits
2. Load Following Design Features, adapted to following fluctuating demand versus base load service (also influencing nuclear units)
3. Summary of condenser evaluations and modernizations

A reference project implemented in Germany in 2012 involved the full turbine train modernization and condenser optimization. This project example at the Ibbenbüren Power Plant highlights many of the efficiency improvement measures to be discussed and shows how the application of advanced technology can achieve up to 6% efficiency improvements.

Applying Latest Technology to the Steam Turbine for Efficiency Gains

The main areas of the steam turbine that yield efficiency improvement are the following areas listed below[1] :

Three Dimensional (3D) Reaction Airfoils (Bowed)

Turbine efficiency is determined primarily by the blading and airfoil design as these are the components that actually transform the available energy of the steam into useful work for generating power. Industry developments of airfoil designs have progressed from simple cylindrical designs of the early 1900s to tapered designs introduced in the 1970s up to the latest design integrally shrouded blade designs. These designs use bowed, tapered and twisted airfoil technologies. The Siemens design philosophy is to apply the advanced three dimensional airfoil profiles as a function of steam conditions and turbine design. An example of the 3D blade design appears in Figure 1 below.

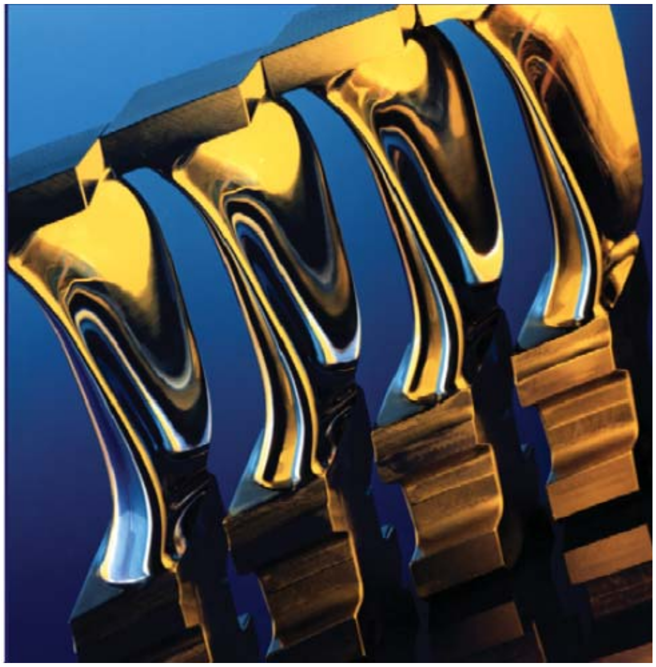


Figure 1 – Siemens 3-D Blading

Benefits of the 3D Blade Design are:

- Forward leaning geometry to reduce blade loading near end wall (base and tip) reducing secondary flow loss
- Taper of the profile to give optimum blade loading from base to tip reducing profile loss
- Twist to align steam and blade angles minimize incidence loss
- Profile section design for highest reliability and lowest profile loss
- Integral shrouds allowing improved sealing arrangements and hence reduced leakage loss
- Bow (lean) angle is optimized for specific blade path requirements
- Proven Efficiency Improvement: modern 3D blade designs have been tested and proven to have 2% efficiency improvement over previous cylindrical designs.

Increased Stage Count

As part of a turbine modernization project, it is common to increase the number of stages or rows of rotating and stationary blading. This achieves more work from the steam. For example, a HP turbine design from the 1960s may have 10 stages as compared to a latest technology design would pack 13 stages in the same axial space.

Reaction versus Impulse Blade Designs

Stage reaction is the percentage of the total stage pressure drop attributed to the rotating blade. In theory, a reaction stage is where the rotating blade contributes half of the stage pressure drop – 50% reaction. Conversely, an impulse stage is where the total stage pressure drop is across the stationary blade. In practical use, a reaction blade path has a range of 30% to 45% reaction while an impulse blade path has a range of 20% to 30% reaction but typically is 25% reaction. From a turbine application view, the main differences between impulse blading technology and reaction blading technology are, first, that a reaction stage is more efficient than an impulse stage (as shown in figure 2) and, secondly, that an impulse stage does more work (produces more power) than a reaction stage.

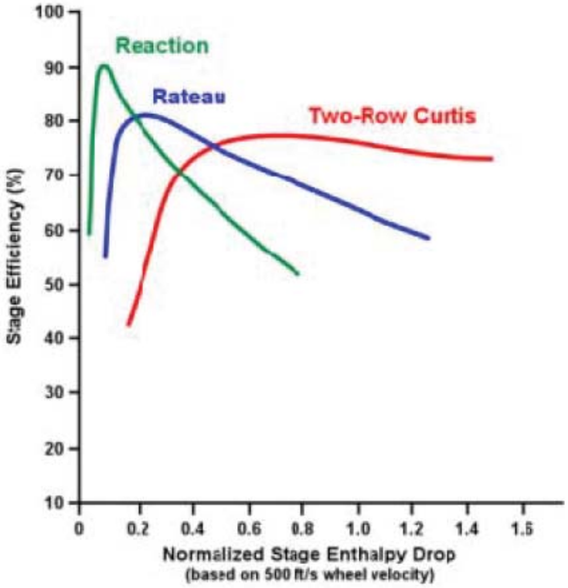


Figure 2 – Efficiency Comparison of Reaction and Impulse Designs

Advanced Control Stage Design

The main design feature that allows steam turbines to operate at partial load and low loads is the Partial Arc (PA) design. In the example below, this old design control stage was redesigned from 180° turn around flow to a straight-through flow, to achieve improved turbine efficiency. Elimination of the 180-degree turn-around reduces pressure losses and thereby improves overall turbine performance.

In addition to thermal advantages there are also hardware advantages;

- The new design has replaced the bolted-on nozzle block with a slide-in nozzle block design which provides enhances reliability by eliminating the risk of service issues with loose or broken bolting.
- The contoured-end wall nozzle block also reduces secondary flow loss and the risks of solid particle erosion (SPE) and nozzle vane chipping.
- The steam flow is turned at a lower velocity, which enables any solid particles to follow stream lines more closely, rather than impinging on the airfoil.

Figure 3 below shows a comparison of the original 180° turn around control stage and the new straight through control stage.

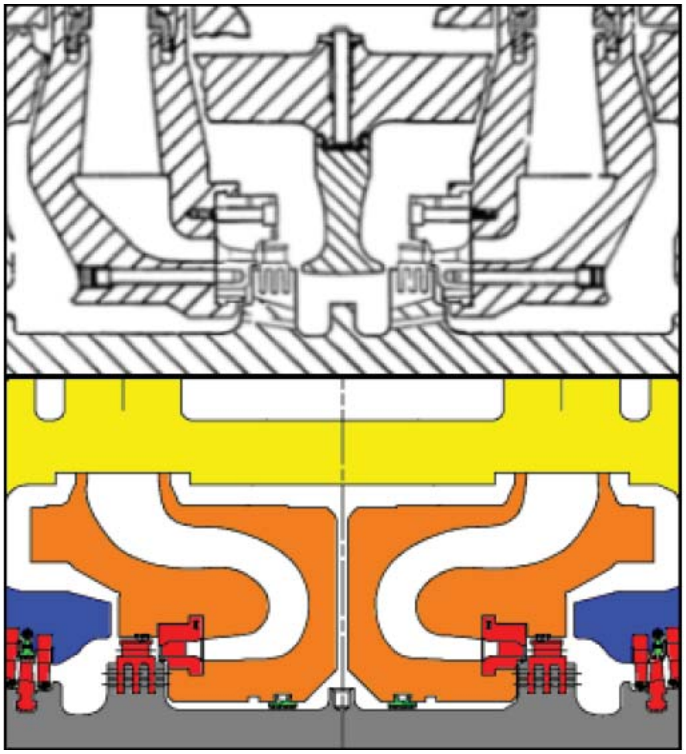


Figure 3: Original Nozzle Design (Top) vs. New Design (Lower)

Using a partial admission control stage, improves the part load turbine heat rate by several hundred BTU/kWh compared to a full arc HP turbine. This type of design is more efficient at partial load operation, which is typically in the range of less than 95% of full load.

The PA design steam turbine is best suited for load following and low load turn down operation that many coal-fired plants are seeing in order to accommodate other type of generation given priority dispatch, such as renewables and CCPPs.

There is even discussion of utilizing this type of HP turbine design for nuclear power plants that have traditionally operated as base loaded units.

Optimized Sealing Technology

Turbine efficiency is determined primarily by the blading and airfoil design as these are the components that transform the available energy of the steam into useful work for generating power. However, seal leakage also needs to be considered as this contributes to loss of stage efficiency.

Since the advent of the steam turbine, labyrinth seals have been used to minimize steam leakages across the stages. These leakages are of primary concern when considering stage efficiency because they are a major contributor to stage performance loss for a given blade geometry. This is significant when considering that it is possible for two percent of the steam flow to be diverted over the top of a blade row without producing any useable power. The losses are actually even higher due to the disturbing effect of the leaking steam re-entering the main steam flow path downstream as proven from computational fluid dynamics (CFD) analyses as shown below.

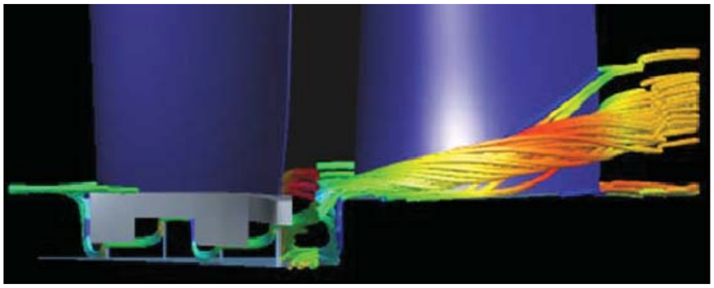


Figure 4 - Seal Leakage Interaction from CFD Analysis

The above seal design is representative of a labyrinth blade path sealing most common in areas of high pressure and smaller axial expansion. Other sealing arrangements include: spring-back seals, retractable seals, and abradable seals.

Select LP Annulus Area for Best Efficiency

In order to improve efficiency in the Low Pressure (LP) turbine elements, similar improvements in blading and sealing as previously discussed can be employed. Additionally, a key factor is choosing the best LP annulus size to match the exhaust volumetric flow. For example, the cross section in figure 5 shows a modernized low pressure steam path. To optimize the LP efficiency improvement, the annulus area and the corresponding last three stages of blades were carefully matched to the application and steam conditions.

Special attention was also given to improving the stationary blade profile design. The objective of any advanced stationary blade profile is to provide optimal mass flow distribution for the rotating blades over their entire length. The Siemens advanced forward leaning, tapered and twisted blade profile provides optimal flow distribution with increased flow at the hub avoiding flow separation, and reduced flow at the moving blade tip for minimizing boundary losses.

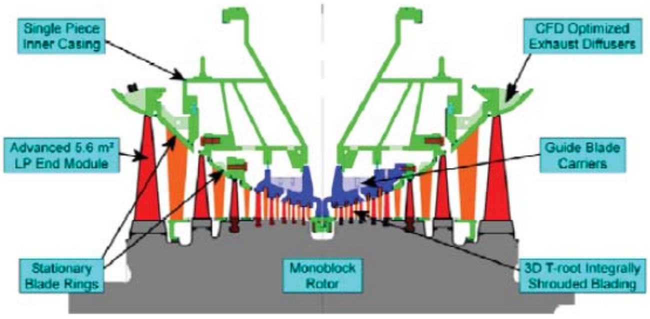


Figure 5 – LP Turbine Modernized Steam Path

The best performing center section of the rotating blade receives an increased mass flow due to this better distribution. An example of this forward leaning blade design is shown in figure 6 below.

Figure 6 – LP Last Stage Stationary Blade Ring with Forward Leaning Design

Project Application - HP/IP Steam Turbine Modernization

Figure 7 shows a single-casing High Pressure/Intermediate Pressure (HP/IP) with the old design in the lower-half and latest technology in the upper-half. The most pronounced design difference is that the new design uses fewer and more robust components.

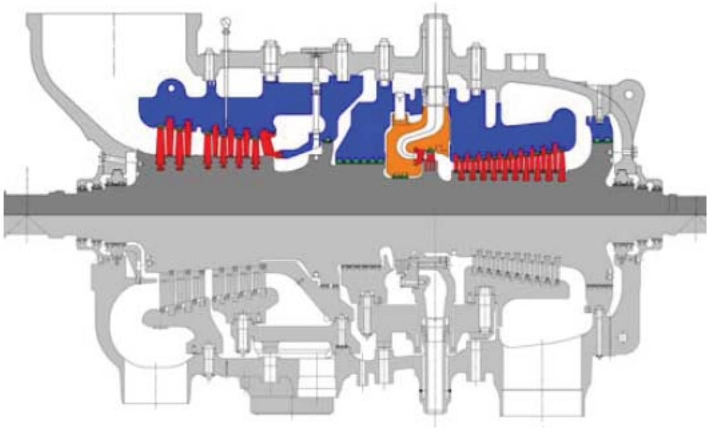


Figure 7: Single Casing HP/IP Turbine (Old Design in Lower-Half and New Design in Upper-Half)

The scope of the HP-IP modernization includes:

- Partial arc configuration based on unit operating mode and boiler capabilities
- Fully integral, mono-block rotor design, eliminating rotor bore inspections
- T-root, integral shroud stationary and rotating blading
- Optimized thermal performance
- New, two-piece inner casing with horizontal joint bolting
- Slide-in nozzle block eliminating nozzle bolting
- Designed for ease of installation
- Contour-end-wall nozzle block helps improve efficiency and reduce solid particle erosion
- Improved aerodynamic analysis
- Reduced secondary losses
- Enhanced sealing
- Over 50% less bolting and alignment parts

The upgrade of a HP/IP turbine can be a highly cost-effective way to help improve the thermal performance and reliability of a steam turbine plant.

Benefits can include:

- Increased output and efficiency
- Optimal installation time
- Faster start-ups
- Shorter maintenance outage
- 100,000 equivalent operation hours (EOH) outage inspection interval.
- Reduced life cycle costs
- Potential to increase system output without increasing emissions. [2]

Steam turbine modernizations have been one of the most cost effective means to improve performance, typically showing efficiency improvements in the range of 2-6% on technology only based on individual project scope of supply.

Condenser Evaluations and Modernizations

Another area of the power plant to achieve improved performance is a condenser optimization. The goal here is to optimize the flow patterns and heat exchange properties of the condenser to achieve the following: [3]

- Optimized tube bundle arrangement - performance improvement/efficiency increase
- Lower back pressure - higher power output
- Increased condensate dearation
- Lower condensate sub-cooling

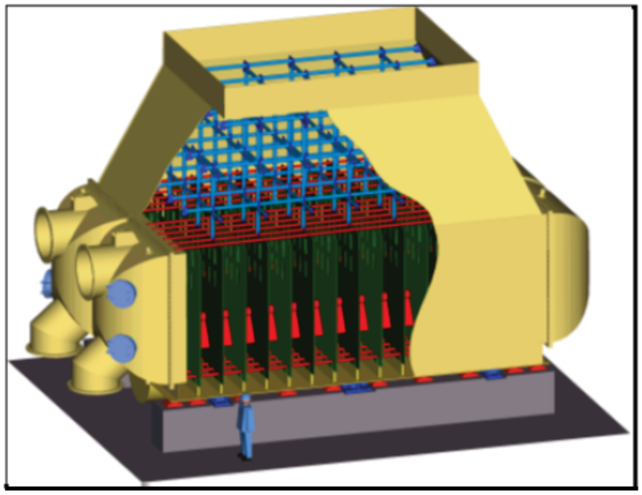


Figure 8 – Typical Vertical Discharge Condenser

Some of the drivers for modernization and upgrades to steam condensers are:

- New materials (Titanium, Stainless Steel) - benefits for maintenance and reliability
- Reduced condenser tube corrosion and erosion
- Reduced bio-fouling and improved cleanliness factor
- Reduced cooling water in-leakages , resulting in a “tight condenser“
- Minimized stress corrosion in steam/water cycle initiated by condenser problems (at nuclear power plants (NPP) operation with high pH-values)
- Safety and environmental aspects (in NPP)

Project Example - Ibbenbueren Modernization Project

A project that provides an excellent example of the application of steam turbine and condenser efficiency improvement measures was undertaken at the Ibbenbüren hard coal-fired power plant in 2012 . [4]

This plant is owned by RWE Power AG had an initial installed rated gross power output of 752 MW and was commissioned in 1985. In 2009, Siemens modernized the high pressure (HP) turbine, and intermediate pressure (IP) turbine, the two low pressure (LP) turbines and the two condensers with deployment of the latest turbine and condenser technology.

Prior to the project, a detailed plant assessment in cooperation with the power station’s owner RWE was conducted. A project specific product development resulted from the assessment study deliverables, whereby only reasonable economic and environmental approaches have been chosen to achieve the business and emission goals of the customer.

The stated customer objectives were:

- Performance increase (efficiency increases of all turbines and the condenser) associated with CO_2 reduction,
- Lifetime extension,
- Improved reliability
- Improved availability

These objectives could be achieved by installing new turbine rotors and inner casings with advanced blading and seal technologies combined with the installation of optimized condenser tube bundle modules. Once the retrofit was completed, the successful modernization measures yielded the following results:

- Increase in generating capacity: 86 MW
- Improved energy efficiency: 43 MW resulting from increased thermal efficiency, so-called "green MW".

This means:

- Additional power output with the same fuel consumption
- Reduced emissions: A considerable CO_2 emission reduction of about 260,000 tons/year was achieved.

This helped to:

- Ensure achievement of German CO_2 targets
- Improved availability and reliability
- Lower production and maintenance costs by
  - –Improved profitability
  - –Improved operating characteristics (rotor and bearing vibrations and acoustic emissions)
  - –Increased operational flexibility
  - –Lifetime extension until 2030

Critical success factors

The major success of this modernization project can be attributed to various reasons. The most important success factors are listed below:

- Establishment of a project organization characterized by open communication and a willingness to jointly resolve issues;
- Joint elaboration of a detailed project plan with clear interfaces and responsibilities;
- Establishment of a culture of occupational safety, health and environmental protection which was implemented throughout the entire project;
- Support of power plant personnel by Siemens Engineering in modernization of the cooling tower, the cooling water pumps, the generator cooling system and the boiler to ensure optimum coordination of the modernization measures;
- Detailed quality assurance plans (manufacturing, assembly and field erection) accounting for the results of earlier projects;
- Detailed planning of commissioning, commitment and hard work by power plant personnel and the Siemens commissioning team during commissioning and trial operation.

Figure 9 – Turbine Deck at Ibbenbüren Plant

Conclusion

This article showed the efficiency improvement areas that are achievable through modernizing the steam turbine. These applications are possible at fossil-fired power plants as well as nuclear and combined-cycle plants.

When looking at applying latest technology improvements to an operating plant, such as the Ibbenbüren example, an efficiency improvement of approximately 6% increase due to technology has been achieved. It must be stated that each such project needs to be evaluated individually to determine improvement potential.

References

[1] *Siemens Internal Publication: Technical Descriptions of Steam Turbine Components. Steam Turbine Tendering Department. 2013.*

[2] *Siemens Publication: Energy Service Division (E50001-W520-A365-X-76). BB243PA HP/IP Turbine Modernization. 2011.*

[3] *Siemens Presentation. Condenser Overview for New Apparatus and Condenser Upgrades. 2003.*

[4] *Walsh, John. Modernizing of Steam Turbines and Condensers at Ibbenbüren Coal-Fired Power Plant, VGB PowerTech 8/2012.*

For further information contact
Michael Smiarowski at michael.smiarowski@siemens.com
or James Auman at jim.auman@siemens.com

-

Michael Smiarowski is the Senior Manager for the Steam Plant Modernization group of Siemens Energy, Inc. located in Orlando, Florida, where his responsibilities include the development and marketing support of both Fossil and Nuclear Steam Turbine Modernization Projects in the Americas. He has been involved in different aspects of steam turbine maintenance and replacement since joining Siemens in 1986, which includes field service, repairs, project management, manufacturing, and marketing. Mr. Smiarowski earned a bachelor's degree in mechanical engineering from Clarkson University (Potsdam, New York USA) and a Master's Degree in Engineering Management from the Milwaukee School of Engineering (Milwaukee, Wisconsin USA). Smiarowski is a member of the American Society of Mechanical Engineers (ASME) and is the out-going chairman of the Turbine, Generator, and Auxiliaries Committee for 2012/13. He is currently a member of the ASME Power Executive Committee responsible for the ASME 2014 Power Conference Program coordination. He has authored and co-authored a number of technical and industry conference papers on the subject of steam turbine modernizations and related topics throughout his career.

James Auman is a Fellow Engineer in the Steam Turbine department of Siemens Energy, Inc. located in Orlando, Florida. He provides technical support for the marketing of fossil and nuclear Steam Turbines for new power plants and for turbine modernization projects in the Americas and world-wide. His Siemens career began in 1972 working in steam turbine service engineering in Lester, PA. Other assignments included commercial and technical project management for steam turbine and generator repairs. He was Technical Service Manager in Raleigh, NC with responsibilities including operation support and maintenance planning for fossil and nuclear steam turbines, gas turbines, and generators. Recent positions include Manager of Field Service Engineering for steam turbines in Orlando, FL. Auman holds a Bachelor of Science degree in Mechanical Engineering from Lehigh University (Bethlehem, PA). He is a registered Professional Engineer and a member of ASME.

SIEMENS

WPCA NEWS

Is a bi-annual newsletter sponsored
by and for the
Worldwide Pollution Control
Association
www.wpca.info

Purpose

To foster new ideas and greater
awareness concerning pollution
control in the energy industry

Publisher

Reinhold Environmental Ltd.

Comments & Other Inquiries to:

Reinhold Environmental
3850 Bordeaux Drive
Northbrook, IL 60062 USA
1.847.291.7396
sreinhold@reinholdenvironmental.com

For more information on the WPCA
Please visit our website at
www.wpca.info

High Ratio Fabric Filters With 12 m Long Bags for Large Coal Fired Power Plants

By Peter Wieslander, Stephen L. Francis and Ajay Vajpeyi, Alstom Power

Abstract

For many years, electrostatic precipitators (ESPs) have been used to collect particulate emissions from coal fired boilers. Today, with the need to produce the lowest cost electricity with the lowest possible emissions, coal fired boilers need to have flexibility to burn a wide variety of coals and at the same time achieve very low emissions. In this case the size, cost and arrangement of the ESP becomes very large and plants are now considering the use of high ratio fabric filters (HRFFs) to meet these requirements. While HRFFs have been used to collect particulate emissions from coal fired boilers for many years, designing the filters to meet the required emissions from large 800 to 1100 MWe boiler systems is a more challenging task than for smaller boilers (100 to 600 MWe).

The most effective means to reduce the steel weight and footprint of HRFFs is to increase the bag length, while maintaining, or even reducing, the bag-to-bag pitch. Alstom has more than 20 years experience of 8m (meter) long bags, on-line cleaned, and more than 5 years successful experience of 10m long on-line cleaned bags in coal fired boiler applications. Alstom Power has now developed a HRFF design with 12m long bags, and reduced bag-to-bag pitch, for large coal fired boilers, as a continuation of the HRFF design with 10m long bags successfully launched in 2008.

This article presents information on key issues that need to be considered when designing and evaluating a HRFF with 12m long bags for a large coal fired boiler installation. Aspects of gas/dust flow distribution to the individual compartments of the filter as well as the concerns regarding large flow/loading into the bag nest in each compartment will be discussed. A very efficient, newly developed, cleaning system has been incorporated in the filter to clean the bags properly without increasing dust emissions, and allowing the system pressure drop to be kept as low as possible. The reduction in HRFF first cost with 12m as compared to 10m long bags, and tighter bag row pitch, is estimated at approximately 10%.

Introduction

HRFFs are gaining market share over ESPs for solid fuel fired power plant applications, for a number of reasons, e.g;

A major advantage of the HRFF is its ability to cope with most fly ashes, with practically no change in the outlet emission. This allows the user to burn a wider range of fuels than would be possible with an ESP. The particulate collection in a fabric filter is not effected by the electrical properties of the ash. The tolerance for variations in boiler operation is larger for a HRFF than with an ESP, provided the gas temperature entering the filter stays above the flue gas acid dew point and at or below the maximum design level. A fabric filter efficiently collects the very finest particles, and may also be designed in such a way that a PM_{10} or $PM_{2.5}$ emission limit can be obtained. [1]

Fabric filters offer a distinct advantage for scrubbing with dry sorbents in its capability of further enhancing, as compared with ESPs, the absorbtion process, due to the forced contact with the absorbent on the surface of the bags. [2,3]

The most effective means to reduce the steel weight and footprint of HRFFs is to increase the bag length, while maintaining, or even reducing, the bag-to-bag pitch. An extensive effort of further increasing the amount of filter area that can be installed in each compartment of a HRFF, by further increasing the bag length to 12m and, at the same time, reducing the bag-to-bag pitch is currently being completed.

The new HRFF design with 12m long bags, which is a continuation of the current design standard with 10m long bags, aims to further reduce the capital cost - as well as offer a smaller footprint due to its more compact design - with no degradation in performance with regard to outlet emission, pressure drop and bag life. The major technical challenges are to achieve low velocities close to the bags (avoiding bag erosion), the same or lower pressure losses, and to ensure that the pulse cleaning system has sufficient cleaning capability for the 12m long bags and increased bag area per pulse valve. At the same time, the design should be robust enough to withstand normal variation in filter operating conditions, as well as capable of handling extreme conditions.

This article presents the key aspects of the required HRFF design to address gas and dust distribution and pressure drop issues, as well as the pulse cleaning system design and capacity with 12m long bags.

Cleaning system

The performance of the bag cleaning system is an essential part of successful HRFF operation. The quality of the cleaning system has a great influence on:

- Bag life
- Gaseous and particulate emission
- Pressure drop across filter bags
- Total energy consumption

The most important design criteria for the cleaning system is to quickly produce a high pressure inside the filter element, by rapidly injecting a large volume flow of pressurizing air against the resistance offered by the filter fabric.[6] A very high rate of volume flow rapidly injected into the filter element is essential to achieve the large cleaning forces required for efficient on-line cleaning of long bags. In the Alstom pulse system design, these requirements are met by using components with low pressure loss, large flow cross section areas, and an optimum geometry, see figure 10. The system is designed to work with a pressure in the pulse tank between 2.5 - 3.5 bar.

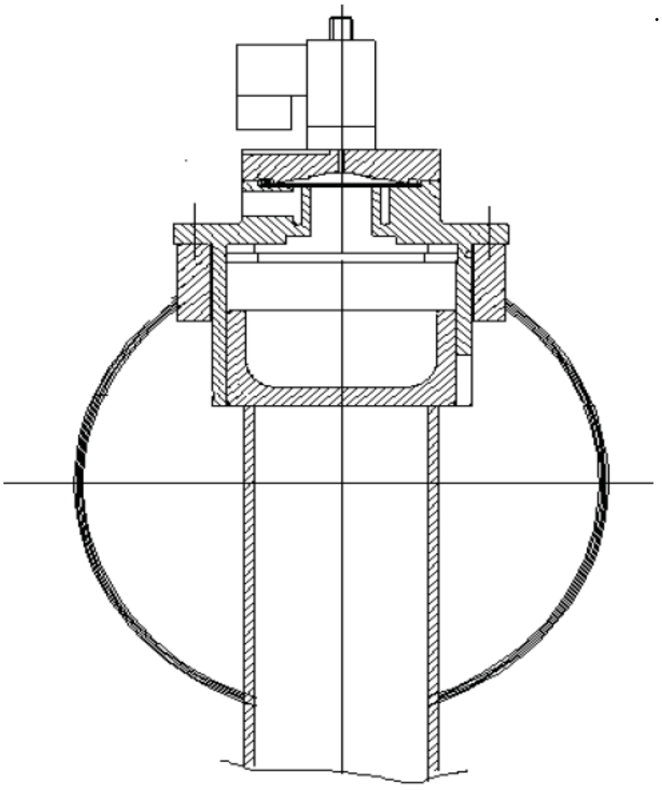


Figure 10:. Pulse cleaning system with valve, tank and pulse pipe.

The pulse cleaning system has been developed and continuously improved during the last 30 years, utilizing e.g. a full-scale pulse test rig, where the static pressure inside the filter bag during pulsing is measured using pressure sensors. The test rig is further described in [9] .

The cleaning system produces a large flow rate of cleaning air. Peak pressure in the bag is reached in about 10ms. The high cleaning energy can be utilized in several ways, for example:

- Cleaning very long bags and many bags at same time
- On-line cleaning is no problem
- Cleaning flexibility as required for process changes

The fast action of the pulse air delivery system results in a minor stretch of the fabric when it is expanded to the circular form. At the same time no bending of the fabric or friction against the cage occurs in this expanded circular form. Hence, the fast, efficient cleaning will have no negative effect on the bag life. On the contrary, it prolongs the bag life by keeping the fabric clean and in full operation throughout the life of the bag. When the pulse pressure across the filter bag decreases to a value less than the differential pressure across the filter bag, the return of the bag towards the bag cage starts. The return force is of the same magnitude as the previous cleaning force if the pulse is cut off in a fast manner (short pulse), and will result in an aggressive landing of the bag on the cage, with abrasion and increased local stress in the bending zones, as well as significant emission peaks due to seepage and straight through PM penetration. Seepage is normally dominating. [10]

The negative landing effects of the bag on the cage can be very much reduced by decreasing the pulse pressure gradually in a controlled way to achieve a soft landing of the filter bag on the cage. Alstom has developed and implemented as standard for more than 10 years the Modulated Pulse Cleaning (MPC) system, to reduce PM emissions and bag wear in connection with pulse cleaning of bags. The MPC cleaning system can be described as a 3 step operation, with a rapid acceleration during the pulse, followed by flushing with a large quantity of air, and finally a slow decrease of pulse pressure to reduce the impact when the bag returns to the cage, see Figure 11 on page 10.

The MPC system fulfils the important factors for long bag life by a very effective and even cleaning of all of the bags in each row. This is achieved with very low stress on the bag during the whole cleaning action, expansion and return of the bags to the cages.

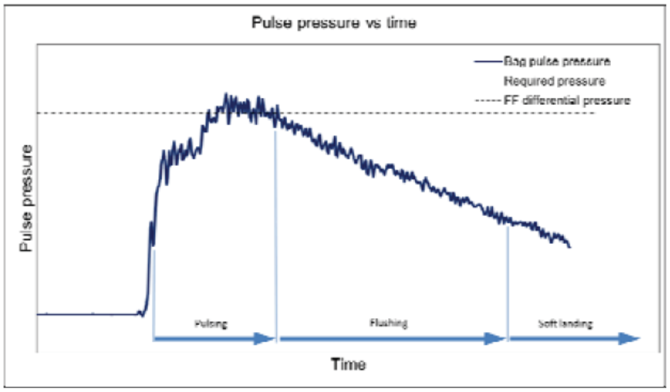


Figure 11: Typical pulse pressure profile vs time, MPC cleaning system

To enable the new HRFF design with 12m long bags and increased total bag area per pulse valve as compared to the existing design with 10m long bags [5], an enhancement of the pulse system performance was a prerequisite.

Prior to initiation of the development work, benchmark design criteria with regard to minimum and maximum bag pressure, as well as the pressure distribution along the nozzle tube were set, based on Alstom Power´s experience. The cleaning pulse must reach all the way to the bottom of the bag, without either excessive pulse overpressure in the top of the filter bag, or insufficient pulse pressure in the bottom portion of the bags in the row.

A systematic investigation of the potential to improve the currently used pulse cleaning system was performed, utilizing flow modelling work with CFD (Computational Fluid Dynamics) transient compressible model simulations, and test rig measurements, as well as dynamic Finite Element Analysis (FEA) for fatigue resistance. Each system component, from pressure vessel to filter bag inlet, was studied to a varying degree, focusing on minimized pressure loss.

A new nozzle pipe design, denoted Radius Nozzle pulse pipe, was developed. The revised nozzle pipe design uses the dynamic part of the pressure to a high extent. The usage of the dynamic pressure decreases the pressure loss between the tank and the bags. The nozzle also provides a homogeneous shape of the jet, which gives a uniform cleaning pressure along the bags, see figure 13.

Pulse system performance measurements, to verify sufficient cleaning power for the increased total bag area per valve for the new FF design with 12m long bags, were performed, see figure 12 and figure 13.

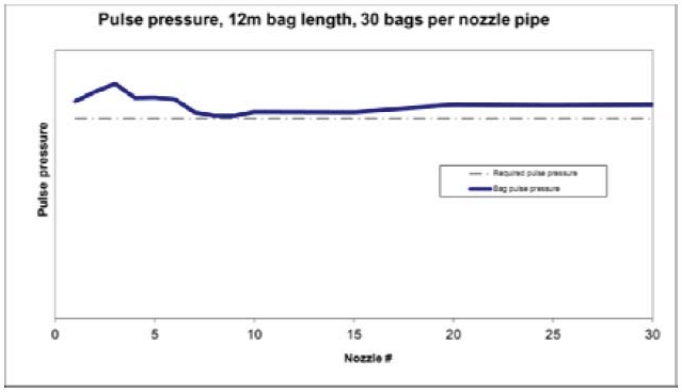


Figure 12: Pulse pressure along nozzle tube with 12m long bags. Radius Nozzle pulse pipe

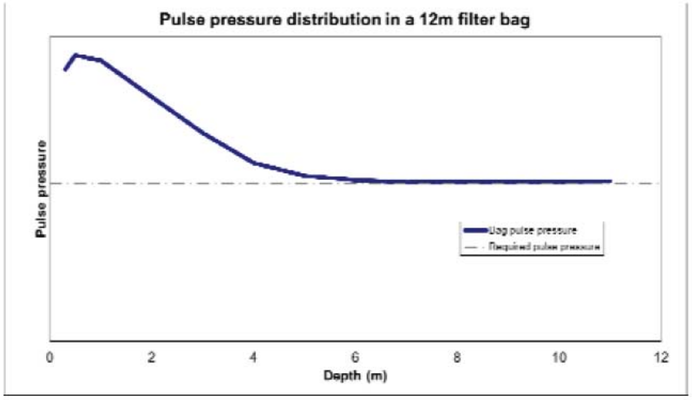


Figure 13: Pulse pressure along the depth of a 12m long bag. Radius Nozzle pulse pipe

The results from these tests confirm that the benchmark design criteria have been met, and that approximately 20% more bag area per pulse valve can be efficiently cleaned.

Gas Distribution Design

Proper gas distribution into each bag nest in each compartment of the filter system is essential in order to facilitate online cleaning of long bags, and to achieve long bag life. In the HRFF design the raw gas enters the filter compartments from the inlet distribution plenum via inlets equipped with guide vanes to direct the gas towards the upper section of the filter bags. This arrangement creates a downward gravimetric gas flow along the filter bags, assisting ash transport into the hopper at cleaning of the bags. The optimized gas distribution system further ensures that local high approach velocities of the gas/ash mixture are avoided at the filter bags, which is very important to avoid erosion damages on bags and to achieve long bag life.

The new HRFF design was targeted to use 12m long bags, and in addition, a reduction in the bag row pitch of around 10%. This required the development of a revised gas flow design, as a continuation of the current HRFF design. [5]

Benchmark design criteria with regard to velocities in the inlet plenum and dampers, and velocities close to the filter bags were set, based on experience. Likewise, design criteria for the mechanical pressure drop were established, based on experience and contract requirements.

Extensive flow modelling work with CFD and physical modelling, was performed to develop the gas flow design.

The aim of the model testing was the following:

1. Verify and tune the design of the inlet distribution plenum, dimensions, inlet dampers and the design of guide vanes, taking into account the risk of dust accumulations.
2. Verify and tune the maximum gas velocities, approaching the bag nest, at the bag face and in-between the filter bags, not to exceed certain criteria.
3. Minimize the mechanical pressure drop from the common inlet duct to the filter bag plane.
4. Verify the design of the outlet gas flow path, including pulse tubes.
5. Minimize the mechanical pressure drop, from the bag plane to the common outlet plenum, including the restriction of the pulse tubes and the outlet dampers.
6. Verify that the design is robust with regard to varying velocity profiles throughout the system.

The flow modelling was performed at a typical gas-to-cloth (G/C)-ratio for power plant applications, 75 m/h (4.1 fpm). In order to optimize the flow modelling work, physical scale model testing and CFD analysis were planned and performed to complement each other.

CFD was the main design tool, and was utilized for modelling and optimizing of the ducting arrangement, as well as modelling of a single FF compartment with detail studies of the flow arrangement inside the compartment. Physical scale model testing was then performed to confirm and fine-tune the design derived from the initial CFD modelling.

Finally, a final round of CFD modelling utilizing the results from the physical scale model testing was performed to arrive at the final, recommended design.

CFD modelling, using ANSYS CFX software, was done on a single FF compartment model, see figure 14, on an inlet plenum consisting of inlet duct and inlets to 3 compartments. One compartment including filter bags was fully modelled, and the other two compartments were represented with an outlet and a fixed flue gas flow. The CFD model, and the physical flow model, reflects a FF design with 2 rows of compartments, each row with 3 compartments, i.e. in total 6 compartments, with 1200 bags in each compartment.

Figures 15, 16 and 17 illustrate the flow pattern and velocities for the recommended design from first round of CFD analysis. Among the newly developed gas distribution devices was a progressive bar grid to improve the velocity profile in side inlet duct.

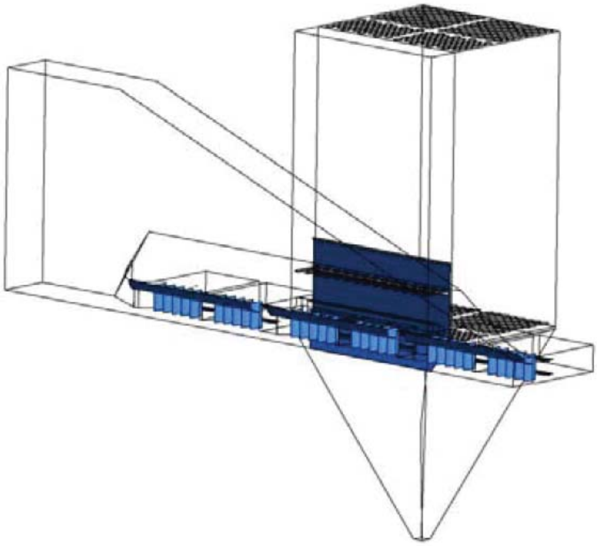


Figure 14: One chamber CFD-model

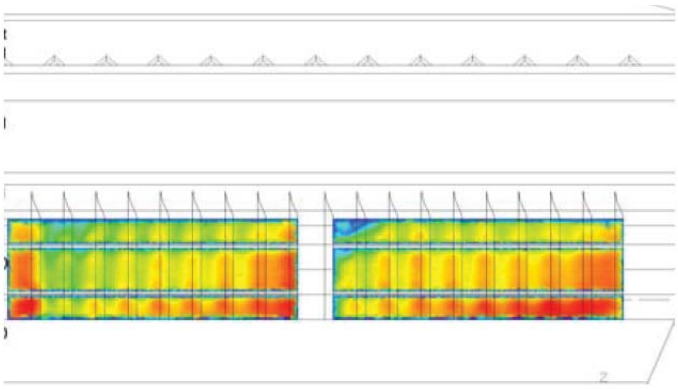


Figure 15: Flow pattern in inlet plenum. First round CFD design.

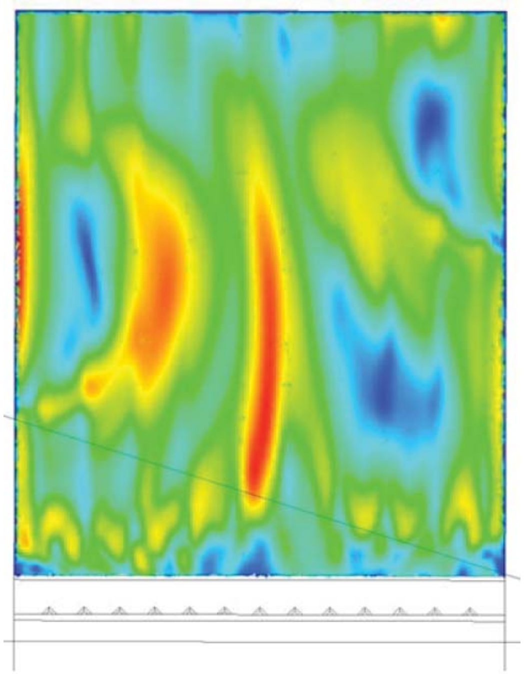


Figure 16: Velocities close to the bag nest. First round CFD design

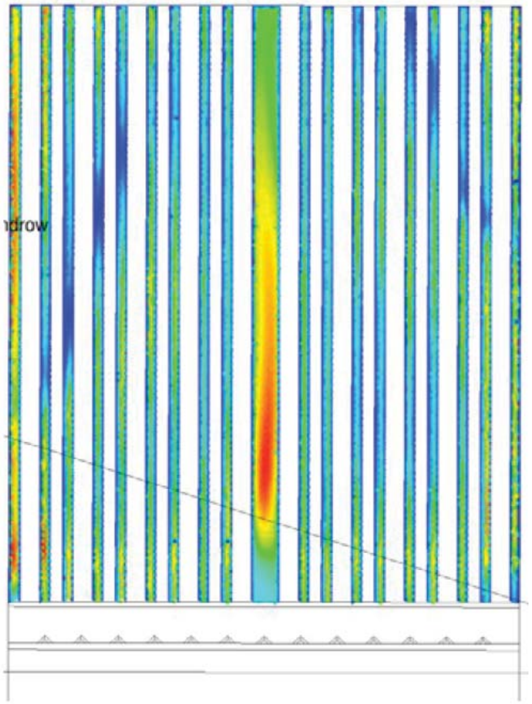


Figure 17: Velocities between first and second bag row . First round CFD design

The physical model, see Figure 18 and Figure 19, was built in scale 1:8.44, with perforated plastic tubes used to simulate the filter bags. One compartment of the FF is modelled. In full scale, there are 1200 bags per compartment. All required internals such as guide vanes, dampers and structures have been represented in the model. The model chamber and the chamber bypass duct are connected to a permanent flow exhaust system by separate calibrated venturi meters for flow control. The bypass duct is adjusted to have the same pressure drop as the filter chamber, and simulates the flow to the two chambers downstream of the tested chamber.

Figure 18: Physical flow model

Figure 19: Physical flow model with perforated plastic tubes

Figures 20, 21 and 22 illustrate flow patterns and velocities from the physical flow model testing.

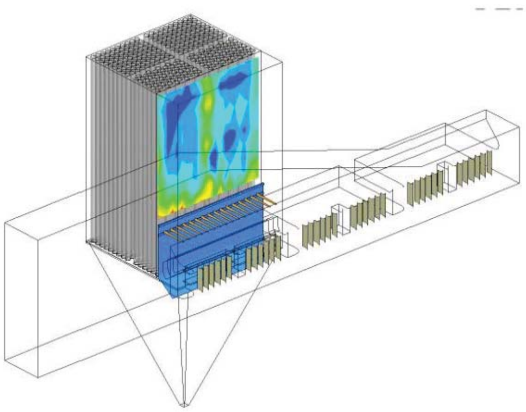


Figure 20: Velocities close to the bag nest. Physical flow model

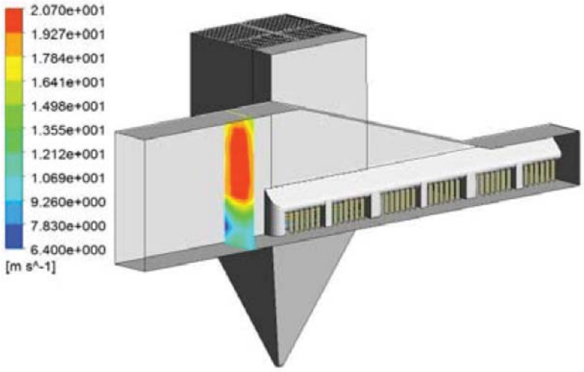
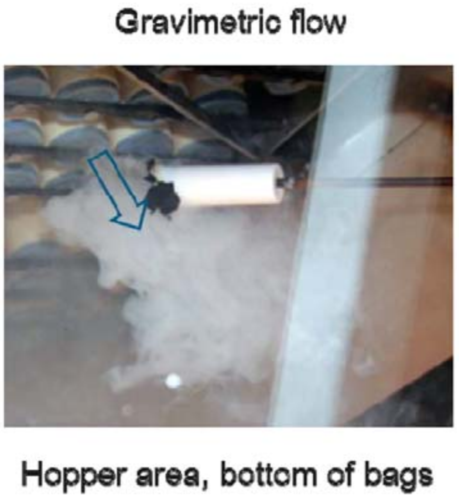


Figure 21: Skewed inlet velocity profile, robustness test. Physical flow model



Gravimetric flow

Hopper area, bottom of bags

Figure 22: Smoke test photo to verify gravimetric direction of flow in the bag nest. The arrow indicates the observed smoke flow direction from the bottom part of the bags down into the hopper area. Physical flow model

Figure 23 and Figure 24 illustrate the flow pattern and velocities for the final, optimized FF design with 12m long bags and a reduction in the bag row pitch of around 10% as compared to previous design. [5]

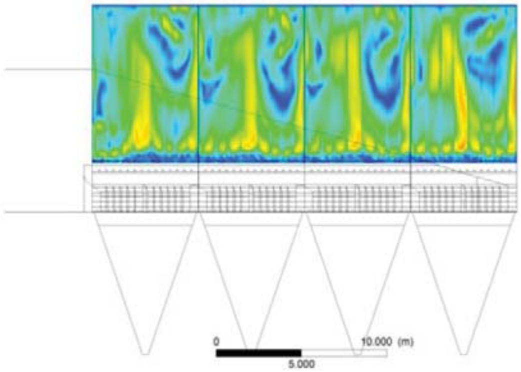


Figure 23: Velocities close to the bag nests. Final FF design

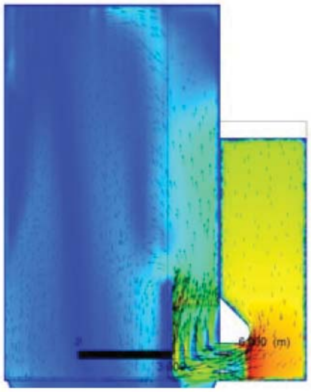


Figure 24: Gravimetric flow in bag nest. Final FF design

A gravimetric flow pattern in the bag nest is achieved, and all other benchmark design criteria have been met.

New HRFF Design

Catia dimensional parametric design was used to develop design drawings, see figure 25.

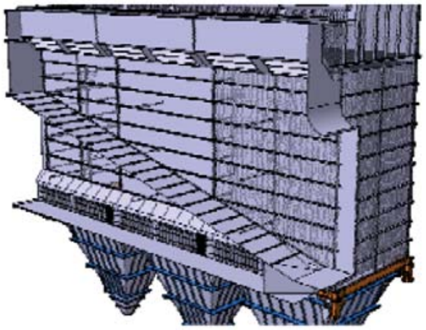


Figure 25: New HRFF design with 12 m long bags and tighter bag row pitch

A top door design or walk-in-plenum type is available, see figure 26.

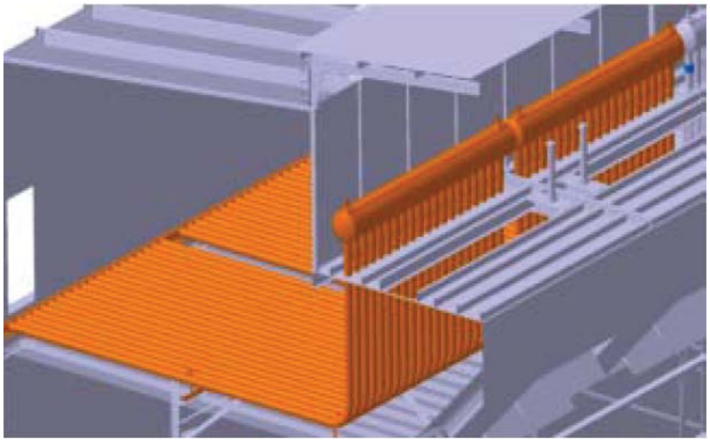


Figure 26: Clean gas plenum type walk-in-plenum, with upgraded pulse cleaning system

The estimated reduction in HRFF first cost with 12m as compared to 10m long bags, and tighter bag row pitch, is significant at approximately 10%.

Conclusion

Due to the increasing market demands for HRFFs for power plant applications, suppliers need to provide properly designed, efficient, cost effective HRFF designs. The major technical challenges with more compact and cost effective designs are to achieve low velocities close to the filter bags - to avoid bag erosion - the same or lower mechanical pressure losses, very low emissions, and to ensure that the pulse cleaning system has sufficient cleaning capability for the longer bags and increased bag area per pulse valve.

Alstom has developed a new HRFF design, with 12m long bags, and reduced pitch between bag rows, meeting these technical challenges and fulfilling all benchmark design criteria. Comparisons with the current standard HRFF design indicate a reduction in first cost of approximately 10%.

References

[1].Lillieblad L, Wieslander P, Hokkinen J and Lind T; PM2.5 and mercury emissions from a high ratio fabric filter after a pulverized coal fired boiler; MEGA Symposium, Washington DC, USA, May 19-22, 2003

[2].Lindau L; Operating experiences of mercury collection by PAC injection in bag filters; MEGA Symposium, Washington DC, USA, May 19-22, 2003

[3].Herrlander B; Flexibility and turn ratio down of Novel Dry FGD system; PowerGen Europe, Milan, Italy, June 7-9, 2011

[4].Francis S, MacPherson A, Marcheff J, Robertson C, Wieslander P; Conversion of existing ESPs to high ratio fabric filters to meet stringent emissions requirements; MEGA Symposium, Washington DC, USA, May 19-22, 2003

[5].Wieslander P, Francis S; Cost Effectively Increasing the Filtration Area in Fabric Filters for Large Power Plants; 11th International Conference on Electrostatic Precipitation, Hangzhou, China, October 20 -24, 2008

[6].Rissanen M, Kwetkus A; Fabric filter media and back-pulse cleaning: A review; 7th World Filtration Congress, Budapest, Hungary, May, 1996

[7].Hansen R, Van Rensburg R; Cost comparisons between electrostatic precipitators and pulse jet fabric filters and inherent challenges of both technologies at ESKOM´s 6 x 600 MW units at Duvha Power Station; 10th International Conference on Electrostatic Precipitation, Cairns, Australia, June 2006

[8].Popovici F; Filtration with High efficiency Fibres in Coal-fired Boiler Applications, VGB PowerTech 04/2010, 2010

[9].Hjelmberg A, Fredriksson M, Wieslander P: Evaluation of FF Pulse Cleaning Valves; 13th International Conference on Electrostatic Precipitation, Bangalore, India, September 16 - 21, 2013

[10].Leith D et al; Dust emission characteristics of pulse-jet cleaned fabric filter; Aerosol Sci. Tech. 1(4) 1982, pp. 401 - 408

For further information contact
Peter Wieslander at peter.wieslander@alstom.com

Peter Wieslander is a Principal Research Engineer specializing in fabric filtration. He has more than 20 years experience in fabric filters, filter media technology and FF field performance evaluation. Peter holds a Master of Science in Engineering Physics from the Royal Institute of Technology, Stockholm.

ALSTOM

Innovative On-site SCR Catalyst Pluggage Removal Method

By Dorothee Seidel and Mike Dunker, STEAG Energy Services LLC

Abstract

STEAG's has developed and patented a unique process for in-situ cleaning of all SCR catalyst types i.e. corrugated, honeycomb, or plate inside the SCR reactor without removing the modules. This process utilizes dry Ice Blasting which cost effectively removes the channel pluggage which reduce SCR pressure drop and effectively increases the catalytic potential as more catalyst surface area becomes available without the pluggage.

Introduction

The standard for removing nitrogen oxides (NO_x) from flue gases is the selective catalytic reduction (SCR) process which uses a titanium dioxide catalyst impregnated with vanadium pentoxide (also called a DeNOx catalyst). A reducing agent, ammonia (NH_3), is injected and mixed into the NO_x rich flue gas stream upstream of the SCR catalyst. With the right temperature, the catalyst in the SCR releases Oxygen (O_2) and a reaction of the NO_X with the NH_3 and the O_2 results in Nitrogen (N_2) and Water (H_2O).

The SCR reaction as described above is a very effective. Problems arise with the other constituents in the fuels such as solids (fly ash) and other de-activating compounds i.e. arsenic, phosphorus, etc. The focus of the STEAG in-situ cleaning process is on minimizing the pluggage from solids contained in the fly ash. This pluggage can lead to one or more of the following:

- Maldistribution of the flue gas
- Unacceptable NH_3 slip
- Excessive pressure drop
- Erosion of the catalyst from increased velocity in the sections of the catalyst that are not plugged
- An increase in NH_3 slip, as the amount of NH_3 is normally based on the amount of NO_X reduction required
- A reduction in the amount of surface area of the catalyst effects the amount of O_2 released

When fly ash accumulates on the catalyst it can attach or plug the surface area in three ways:

1. Fly ash can accumulate in the catalyst pores causing microscopic blockage (figure 27)
2. Fly ash can create a dense second layer of macroscopic blockage over the catalyst surface area. For example the combination of PRB coal creates a coating of calcium (Ca) or magnesium (Mg) (figure 28).
3. Fly ash can be poisonous and can chemically attack the pore system and surface area causing the catalyst active sites to deactivate. Arsenic, Phosphorous, Sodium, and Potassium are the four main deactivation elements (figure 29).

The aforementioned deactivation mechanisms (figure 27-plugging and figure 28 – masking) can be economically minimized with the use of STEAG's in-situe cleaning process. De-activation is resolved with either new catalyst purchase or regeneration of the existing catalyst.

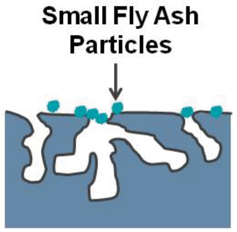


Figure 27: Plugging

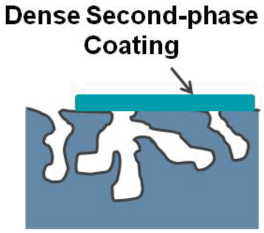


Figure 28: Masking

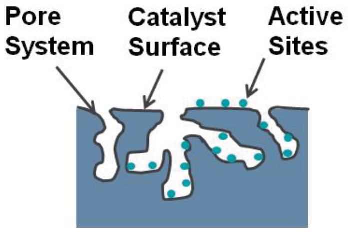


Figure 29: De-activation

Alternative in-situ cleaning methods

SCR catalyst structures, such as honeycomb, plate, and corrugated catalyst are typically dry cleaned by vacuuming, blowing with compressed air, shaking or manual cleaning using scrapers and/or poking type devices of various shapes and forms. A "riskier" method which can cause future pluggage and de-activation problems is wet cleaning from a pressure washer.

- **Vacuuming** – The catalyst top screen should be removed and the module is vacuumed which removes large piles of ash and the top layer of fly ash in the module. The microscopic and dense phase blockage cannot be removed with this method.

- **Compressed Air** - Blowing with compressed air lances can remove some of the catalyst surface and pore blockage however; if the plug is bound to the catalyst or in the center of the catalyst, it would normally not be removed with this method. With the amount of calcium in the fuels, this along with moisture tends to solidify and sticks the ash to the catalyst which just air lancing will normally not remove.

- **Mechanical Shaking** – This method is reserved for "plate type" catalyst. Shaking is a process of vibrating the module thus disposing the catalyst of fly ash. The pluggage starts at the point between the top and sub layer of the module. Only the top boxes are removed and shaken. The module is vacuumed between the top and sub layer of the module. Shaking of honeycomb can damage the seating surface and the packing that secures the modules. It is also not practical as the entire module needs to be removed.

- **Reactor shaking** – Specialized vibration equipment is installed beneath the catalyst layer. Specialized vacuum air hood equipment is applied to each catalyst module. This method has been applied to both honeycomb and plate catalysts.

- **Scraping / Poking** - Scraping and poking methods have proved effective with ash build up on sonic horns and reactor walls, but these methods most probably will damage honeycomb catalyst. Scraping can "poke" the fly ash through the catalyst cells/channels, but the metal rods scar the walls and can break the walls. The plug is only pushed down and without additional lancing will probably not be removed.

- **Power Washing** - Pressure washing of the catalyst can dissolve chemical compounds present in the fly ash (e.g., iron oxide and sulfates) and deposit them on the catalyst surface or surface of other components in the SCR system. These compounds can significantly alter the SO_2/SO_3 conversion rate of the catalyst. Further, on fuels with higher calcium content, the addition of water turns the fly ash solution into a cement type of compound and the ash will solidify to the ceramic material.

Figure 30 provides an overview of the currently available in-situ cleaning methods ranging from dry to wet cleaning performed on corrugated, honeycomb or plate catalyst.

Thus, there remains a need for additional and effective dry physical cleaning methods to not only remove fly ash from an SCR catalyst and system, but also to open and unplug catalyst channels and make catalyst surface accessible for the flue gas.

STEAG has looked at a number of techniques to remove the pluggage from catalyst in a "dry" form. The use of dry ice was the most effective at removing hard pluggage. In addition, the catalyst did not have any deterioration of performance from the cleaning or structural problems from the use of the dry ice.

What is Ice Blasting?

Dry Ice Blasting is a form of blasting where dry ice, the solid form of carbon dioxide, is accelerated in a pressurized air stream and directed at a surface in order to unplug fly ash from the catalyst cells. Dry Ice Blasting involves propelling pellets at extremely high speeds. Upon impact, the pellet sublimates almost immediately, transferring minimal kinetic energy to the surface and producing minimal abrasion.

The sublimation process absorbs a large volume of heat from the surface, producing shear stresses to thermal shock. This improves unplugging as the fly ash is projected thru the catalyst cells. The rapid change in state from solid to gas also causes microscopic shock waves that remove the fly ash pluggage. Dry Ice Blasting leaves no chemical residue as dry ice sublimates at room temperature.

Removal Systems	Benefits	Challenges
Vacuuming	Large ash removal	Top ash only
Air Lancing	Mechanical/light ash removal	Only 4-6 inches of pluggage removal
Mechanical Shakers	Large ash removal	On-site plate removal Honeycomb "verboten"
Reactor Shakers	Large ash removal	Unknown long-tern reactor effects
Scraping / Poking	Mechanical/light ash removal	Damages the catalyst surface – Logs normally need to be replaced before regeneration
High Pressure Wash	Large ash removal	Water reacts with SO_3 to form sulfuric acid, which deteriorates the metal substrate in plate, solidifies any remaining ash and releases iron oxide in ash to increase SO_2/SO_3 conversion rate
Dry Ice Blasting	**Mechanical cleaning for all types of catalyst**	**Unable to undo damages caused by other cleaning techniques**

Figure 30: Comparison of different techniques

Why does it work?

Ice Blasting works because of three primary factors: pellet kinetic energy, thermal shock effect and thermal-kinetic effect.

- Pellet Kinetic Energy: Ice pellet changes from solid to gas instantly upon impact, which effectively provides an almost nonexistent coefficient of restitution in the impact equation.

- Thermal Shock Effect: Instantaneous sublimation (phase change from solid to gas of CO_2 pellet upon impact).

- Thermal-Kinetic Effect: The combined impact energy dissipation and extremely rapid heat transfer between the pellet and the surface cause instantaneous sublimation of the CO_2 into gas. The gas expands to nearly 800 times the volume of the pellet in a few milliseconds in what is effectively a "Micro-explosion" at the point of impact. The "Micro Explosion" as the pellets changes to gas, is further enhanced for blasting pluggage through the catalyst. This is because of the pellets lack of rebound energy, which tends to distribute though the catalyst cells. The CO_2 gas expands outward along the surface and its resulting "explosion" shock front effectively provides an area of high pressure focused between the surface and thermally fractured particles. This results in a very efficient lifting force to carry the particles though the catalyst cells.

The utilization of dry ice within the SCR reactor is safe because here is no residence time of moisture on the catalyst walls, and therefore the formation of concrete-like pluggage is eliminated compared to other in-situ cleaning techniques. On-site Ice Blasting is convenient to the customer since it provides cleaning within the outage schedule.

Figure 5: On-site Ice Blasting

Figure 6: Dry Ice Pellets

Results

Since 2009 STEAG Energy Services has successfully removed catalyst pluggage on all catalyst types using the STEAG patented Ice Blasting process at their Kings Mountain, North Carolina and at customer sites. STEAG reached pluggage removal successes ranging from 100% before down to less than 5% after.

The images below illustrated the significant difference and improvements possible to each type of catalyst.

Honeycomb Before Corrugated Before Plate Before

Honeycomb After Corrugated After Plate After

Figure 33: Before (top row) and after (bottom row) Ice Blasting images of honeycomb, corrugated and plate catalyst

Recently STEAG conducted an onsite Ice Blasting cleaning to a Midwestern utility. The units are in a two reactor with 3 layer plus 1 spare layer arrangement. There are three layers installed in the three bottom locations with the top location empty. This arrangement is commonly used to assist in flow straightening and more evenly distributed flow. STEAG was contracted to perform Ice Blasting on all three layers in both reactors during the outage. Prior to the outage the pressure drop across the layer was approximately 5 inches WC and was improved to approximately 2.43 inches WC after Ice Blasting. The following data shows the results for each layer after Ice Blasting and as it compares to new catalyst (previous cycle) as illustrated in the chart below:

Figure 35 and 36 shows the same module within the reactor of the Midwestern utility before and after Ice Blasting. This module had a pluggage rate of approximately 63 percent before Ice Blasting was started, and was deemed 'clean' at approximately 5 percent. The pluggage rate of all the modules within the reactor that were selected for Ice Blasting was improved from approximately 47 percent to approximately 4 percent on average.

Figure 35: Before Ice Blasting

Figure 36: After Ice Blasting

Conclusion

This Ice Blasting process has proven to be a cost effective application to restore the reactor performance without the significant cost for catalyst removal. STEAG has had success on reactors that had previous method performed that have aggravated the pluggage issue and were able to clean the catalyst.

Catalyst Description	After Ice Blasting	New Catalyst/ Previous Cycle
Layer 1	Empty	Empty
Layer 2, Plate	0.68	0.61
Layer 3, Honeycomb	0.82	0.80
Layer 4, Honeycomb	0.93	0.99
Total	**2.43**	**2.40**

Figure 34

Ice Blasting is effective for unplugging catalyst for the following reasons:

- Ice Blasting will target the catalyst deactivation mechanism of pluggage with mechanical cleaning by removing plugging (microscopic pluggage – see figure 27) and masking (macroscopic blockage – see figure 28) of the catalyst.
- Ice Blasting equipment is light and mobile so that it can be easily mobilized and effectively moved from one layer to the next.
- Ice pellets are stored in 500lb totes and can be delivered by freight elevators or chain hoist lifting equipment. The catalyst removal access area can be utilized for the delivery of the supplies, and offers easy mobilization from one layer to the next.
- Ice Blasting crews are safety trained to include respirator and confined space training.
- Cleaning of multiple layers within an outage is possible.
- STEAG can clean the plugged catalyst on a module to module basis or a layer to layer basis depending on the catalyst pluggage ratio and pressure drop conditions.
- Ice Blasting is safe and effective for all catalyst types (corrugated, plate, and honeycomb) compared with other on-site cleaning methods.

STEAG's pluggage removal technique provides a highly efficient method to significantly reduce pluggage. This not only will reduce the pressure drop thus saving fan power and possible de-rating of the unit, but also offers better utilization of the catalyst's NO$_x$ reduction potential. STEAG's Ice Blasting technique provides a unique opportunity to clean any catalyst type (corrugated, honeycomb, plate) without removal of the modules or the module sealing system. This reduces material handling and outage time as well as costs. With this proven technique, pluggage can be reduced to less than 5%pluggage on average.

This technology is protected by US Patent Number 8268743 - Pluggage Removal Method for SCR Catalysts and Systems

For further information contact:
Mike Dunker at mike.dunker@steag.us or
Dorothee Seidel at dorothee.seidel@steag.us.

Mike Dunker is the Sales Manager of STEAG Energy Services LLC and is responsible for sales activities of STEAG for the North American Market since 2012, focusing on STEAG's patented ice blasting cleaning business. Mike has been in the industrial industry since 1989 and for the last 11 years he has managed several power plant and paper mill outages including cost controlling and critical path assurance. Mike has a Bachelor of Science in Business from Baylor University and a Business MBA from the University of Texas.

Dorothee Seidel is the Marketing Manager of STEAG Energy Services LLC and is responsible for marketing and communications activities of STEAG for the North American Market since 2008. Dorothee holds a Bachelor of Science in Management from Coastal Carolina University, SC and an MBA equivalent with a focus on Marketing from the International University of Applied Sciences Bad Honnef Bonn, Germany.

steag

ModuPower Reduces Particulate Matter Emissions from Undersized ESPs

By Jason Horn, Stock Equipment

Stock Equipment recently supplied ModuPower SMPS's for two 135 MW pulverized coal generating units located in Tocopilla, Chile. To control PM (Particulate Matter) emissions each unit was originally equiped with a 1990's vintage Mitsubishi electro-static precipitator powered by conventional TR sets (Transformer Rectifiers). The original design collection efficiency of the ESPs was 98% which resulted in an estimated 211 mg/Nm^3 emission rate at full load when using an imported bituminous coal with 10.6% ash content.

Changes to government regulations would require compliance with a reduced PM emission limit of 50 mg/Nm^3 in 2014. The chilean power customer had planned to meet the new requirements by replacing the ESP with a bag house. However in late 2013 the customer was informed of significant delays in delivery of the bag house and an accelerated schedule to meet the 50 mg/Nm^3 PM emission rate limit by the end of January 2014. In response, the customer was forced to source an alternate 6% ash coal and reduce production to 120 MW or below to stay in compliance.

The customer contacted Stock Equipment in December 2013 to discuss potential solutions for further reducing emissions and recover production capacity using Stock's ModuPower SMPS (Switch Mode Power Supply). The ModuPower SMPS reduces PM emissions by increasing the overall power input to the precipitator versus conventional TR sets. Stock was able to utilize their process expertise to provide the customer with performance estimates for a variety of scenarios. They then leveraged the global assets of their parent company, Schenck Process Group, to source trial equipment from their Chinese affiliate for delivery in January 2014. The confidence generated by this analysis prompted the customer to quickly exercise the proposed solution and successfully lower the PM emission rate.

The scope of the project consisted of replacing 3 of 4 conventional TR sets with ModuPower SMPS on each of the two units. The ModuPowers were installed at grade using 100 kV rated HV cable to connect the high voltage output with the precipitator discharge electrode frame.

This remote mounting capability is unique to the ModuPower allowing for flexibility in the final location of the equipment. Stock also provided a ground switch designed to mate up with the customer's existing insulator compartments. The combination of these features allowed for the majority of the installation to be performed with the ESP's in service and without removing of the existing TR sets. The final ModuPower tie in was performed during brief outages on each unit. Comprehensive support was provided throughout the duration of the project by performing pre-outage site evaluation, providing service engineers for installation support and commissioning, and additional support.

The customer was able to increase generation to full output while maintaining a PM emission rate below the 50 mg/Nm^3 limit after a successful startup of the boiler, ModuPower tuning, and refinement of the rapper control program. No other changes or repairs were made to the precipitator during the installation. The resulting performance improvement was better than expected and allowed the plant to resume full production.

The ModuPowers will remain in operation at the Chilean palnt until the bag houses are installed. The ModuPower's then may be transported elsewhere within the customer's system to reduce particulate emissions at another facility.

For further information contact Jason Horn at jason.horn@stockequipment.com

Jason Horn is the Director of Environmental Controls for Stock Equipment Company in Chagrin Falls, Ohio. He began his career in the power industry in 2005 as a corporate air emissions control engineer with American Electric Power. Since joining Stock Equipment in 2007, Jason has held various positions of increasing responsibility within the environmental controls product line. He currently serves as the secretary for the Worldwide Pollution Control Association and holds a Bachelor of Science degree in electrical engineering from Ohio Northern University.

stock
schenckprocess group

Enhanced Capture of Mercury in Baghouse by Using Novel Filtration Media and Filter Design

By Vishal Bansal, Clarcor; Robert W. Taylor, Clarcor;
Pete Maly, Clarcor; Bryan Yetter, Clarcor Indistrial Air/BHA

Abstract

A study was conducted at a 5-MW equivalent slipstream facility of Gulf Power's Plant Crist Unit 5 located in Pensacola, FL. The facility is also commonly referred to as Mercury Research Center (MRC). During the trials lasting 10 days, the effect of a range of process variables was studied. The variables included flue gas temperature, air-to-cloth ratios, interval between cleaning, and the effect of removing some of the fly ash by an electrostatic Precipitator (ESP) upstream of baghouse, etc. CLARCOR Industrial Air tested a novel membrane-based filtration media formed as pleated elements.

Data will be presented that shows that by using CLARCOR Industrial Air's novel filtration elements, mercury capture as high as 98% can be achieved by inherent fly ash alone (without needing to inject powdered activated carbon).

This was true in spite of majority (about 80%) of Mercury being in elemental form in the flue gas. Traditional round filter bags are typically known to capture significantly lower percentage of mercury in the flue gas by inherent fly ash. Data was also collected with injection of activated carbon upstream of baghouse (FF). It was found that by using these novel filtration elements, if a plant is already using powdered activated carbon the consumption of activated carbon can be reduced by as much as 85%.

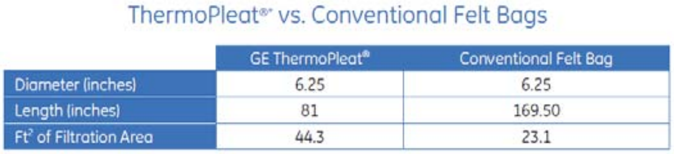
Data will be reviewed along with the proposal of mechanisms about how this novel filtration element works in achieving such high mercury captures, as compared to traditional round bags.

Introduction

Control of mercury emissions from coal-fired boilers is imminent. Several states have instituted mercury emission limits in lieu of a national standard. The U.S. EPA is issuing recommended standards for industrial boiler mercury emissions. Many of the mercury emission standards imply a reduction efficiency of about 80% to 90% will be required. As a result, an economical means of achieving the proposed mercury emission limits is required.

CLARCOR Industrial Air manufactures pleated filter elements for flue gas filtration from coal-fired boilers. These filter elements (BHA ThermoPleat®) are constructed from a patent-pending high density unsupported needle felt media that is stiffened by a state of the art thermal bonding process (a version of these made from Aramid fibers is available as well). These elements are a direct replacement for standard filter bags and cages. Their shorter length keeps the filter element out of the inlet gas stream, reducing abrasion problems and providing for a larger drop-out area.

Figure 37 shows a typical comparison of filtration surface area provided by BHA ThermoPleat® pleated elements as compared to traditional filter bags and cages. Figure 38 shows a picture of the BHA ThermoPleat® element, as an example.



ThermoPleat®* vs. Conventional Felt Bags

	GE ThermoPleat®	Conventional Felt Bag
Diameter (inches)	6.25	6.25
Length (inches)	81	169.50
Ft^2 of Filtration Area	44.3	23.1

Figure 37: Typical comparison of filtration area

Figure 38: An example of BHA ThermoPleat® Filter Element

Rationale for the Study

It is generally known in the coal-fired power industry that the fly ash in flue gas contributes to some capture of mercury[1]. The capture is dependent on the amount of unburnt coal in the fly ash (LOI of fly ash). The phenomenon is also sometimes referred to as native capture of Mercury by fly ash. This fly ash with mercury is then collected by traditional air pollution control equipment used by the plant (fabric filter baghouse or electrostatic precipitator). In general, this native capture of mercury is found to be larger by FF as compared to ESP.

Pleated filter elements provide significantly higher filtration surface area as compared to conventional round felt bags. As a result, it is hypothesized a greater native capture of mercury by a baghouse using these elements. This hypothesis was also built upon some anecdotal data collected from customers. To prove this hypothesis, CLARCOR Industrial Air conducted a scientific study at Southern Company's Mercury Research Center (MRC).

Study

PCT, Inc. conducted the testing for CLARCOR Industrial Air in the baghouse located in the MRC at Plant Crist Unit 5 in Pensacola, Florida. The MRC is a fully-functional, pollution control research facility located on a 5–MW sidestream of Unit 5.

PCT, Inc. provided flue gas mercury measurements at the MRC inlet, the baghouse inlet and at the baghouse outlet. The primary measurements were made using Thermo Fisher Scientific mercury CEM analyzers with quality control measurements made using sorbent traps. Coal and fly ash samples were obtained throughout the program for off-site LOI and/or mercury analysis. Velocity traverses utilizing a standard pitot were made daily to confirm flow rates. The sorbent injection system was comprised of a Porta-PAC™ injection skid.

The coals combusted during the test program were typically a blend of Drummond and Galatia coal. The Drummond is a low sulfur sub bituminous of Columbian origin and the Galatia is a bituminous coal from the Central Illinois Basin. The blend is a low sulfur (0.75%) sub bituminous analog.

Testing was conducted over the period of ten days, between September 7 and 16, 2010. A short period of break-in or "seasoning" of the bags took place from September 7 through September 12, followed by the four days of testing during which parametric variables such as cleaning times, flue gas temperature, and flow rate were changed.

Test Facility

Figure 39 shows a simplified schematic of the layout of the MRC facility in relation to Plant Crist. The MRC facility can be operated in a baghouse-only mode, ESP-only mode, or use ESP and baghouse in series. As an example, Figure 40 shows the arrangement of MRC in a baghouse-only mode. Most of the testing was conducted in baghouse-only mode. The SCR was bypassed during the entire duration of testing.

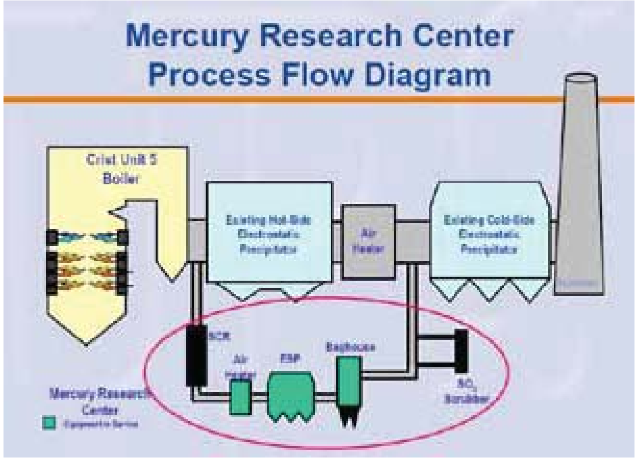


Figure 39: Mercury Research Center Process Flow Diagram

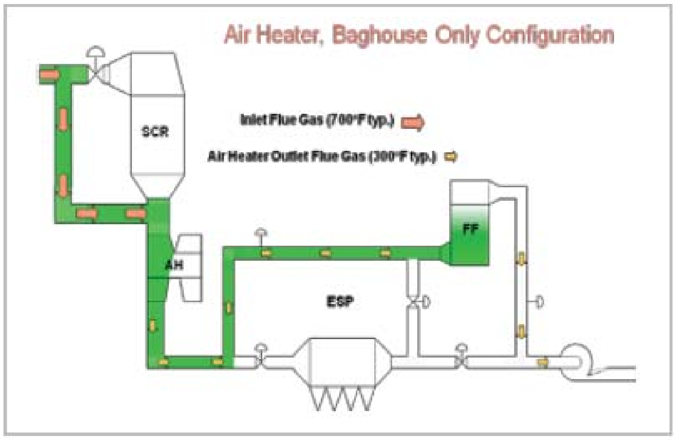


Figure 40: MRC in baghouse-only mode

Baghouse

The pulse jet baghouse had 82 filter elements arranged in 9 rows. The system was equipped to conduct cleaning based on pressure set points, or based on time. The pulse cleaning parameters were as follows – cleaning pressure of 55 psig, pulse time of 0.15 seconds, and time between pulses of 6 seconds.

The baghouse was designed for 27' long standard round PPS bags supported by wire cages. These bags and cages were removed, and the baghouse was fitted with 81" long BHA ThermoPleat® elements. The 81" long BHA ThermoPleat® elements provided the same filtration area as 27' long conventional round bags.

Filter Elements Tested

The BHA ThermoPleat® elements were 81" long with a diameter of 6.25". The filtration media in these elements was CLARCOR Industrial Air's proprietary laminate QR811.

The media uses a stiffened felt that is a blend of PPS and P84 fibers, and is laminated to a microporous expanded PTFE membrane, as the filtration surface. During the rest of this article, these elements will be referred to as QR811 elements.

Variables Studied

The study was designed to evaluate the effect of the following variables:

- Flue gas flowrate – 14,000 acfm vs. 19,000 acfm. Corresponds to an air-to-cloth ratio of 3.7 and 5.15.
- Flue gas temperature – 280°F and 343°F
- Different cleaning intervals and modes (Pressure settings vs. time settings)
- Effect of Powdered Activated Carbon Injection (to further increase mercury capture beyond what can be accomplished by fly ash alone)

Results and Discussion

Figures 42, 43, and 44 shows some of the results at various conditions of gas flow rate, cleaning modes, and flue gas temperatures. The average level of mercury in the flue gas stream incoming to the baghouse was 10.3 µg/m^3. The speciation was 80% elemental and 20% oxidized. As noted earlier, the SCR was kept out of service for the entire duration of testing. Without the SCR, this level of mercury speciation is consistent with historic data from MRC facility.

Figure 41 provides a more comprehensive summary of the capture rates of mercury under various combinations of variables.

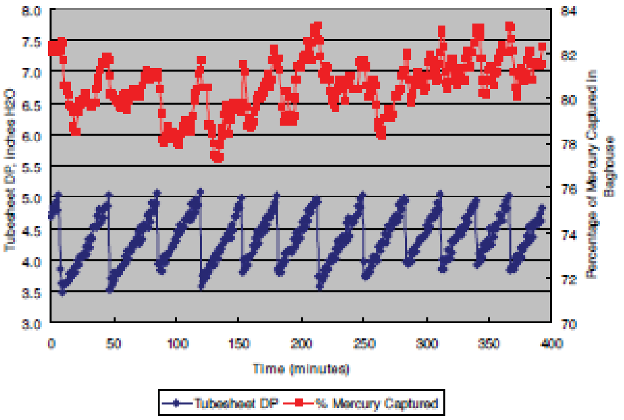
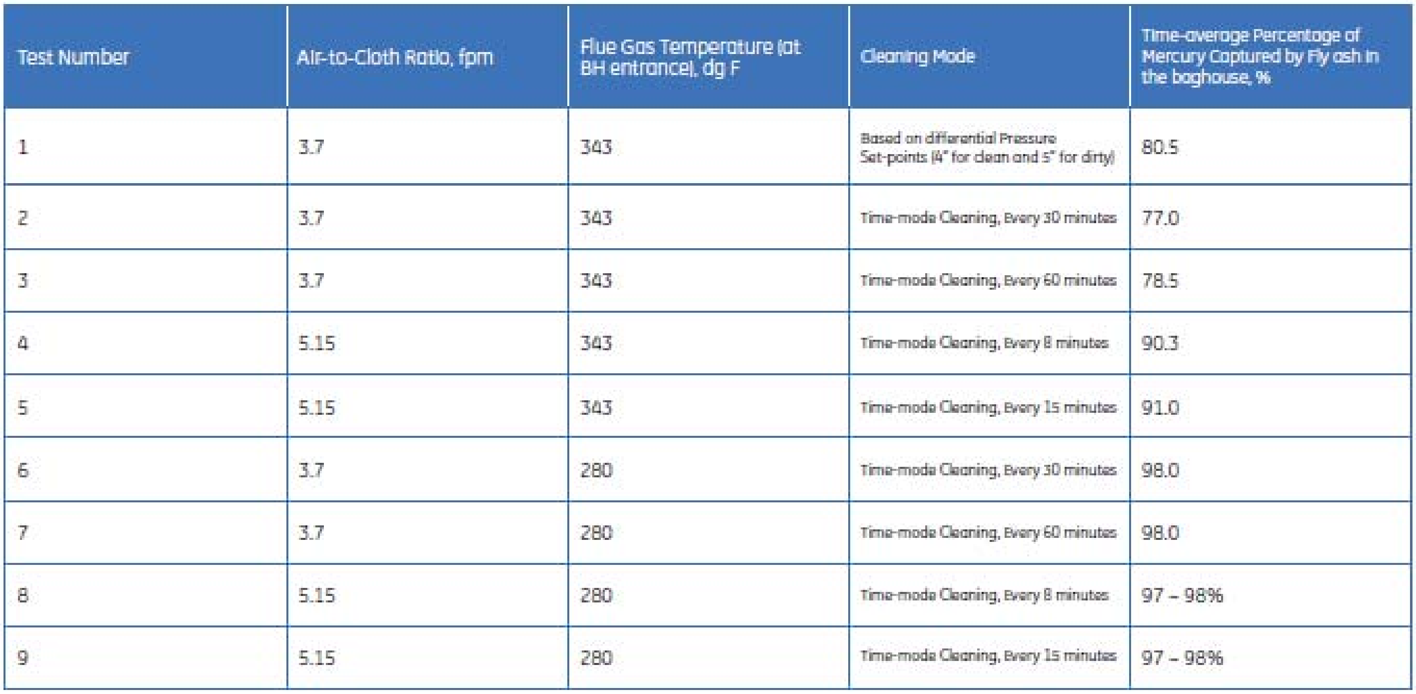


Figure 42. Mercury Capture Data at Flue gas flow rate of 14,000 acfm (air:cloth ratio of 3.7); Temperature 343°F; Cleaning in pressure mode with set points of 4" and 5" for clean and dirty conditions



Test Number	Air-to-Cloth Ratio, fpm	Flue Gas Temperature (at BH entrance), dg F	Cleaning Mode	Time-average Percentage of Mercury Captured by Fly ash in the baghouse, %
1	3.7	343	Based on differential Pressure Set-points (4" for clean and 5" for dirty)	80.5
2	3.7	343	Time-mode Cleaning, Every 30 minutes	77.0
3	3.7	343	Time-mode Cleaning, Every 60 minutes	78.5
4	5.15	343	Time-mode Cleaning, Every 8 minutes	90.3
5	5.15	343	Time-mode Cleaning, Every 15 minutes	91.0
6	3.7	280	Time-mode Cleaning, Every 30 minutes	98.0
7	3.7	280	Time-mode Cleaning, Every 60 minutes	98.0
8	5.15	280	Time-mode Cleaning, Every 8 minutes	97 – 98%
9	5.15	280	Time-mode Cleaning, Every 15 minutes	97 – 98%

Figure 41: Summary of Mercury Capture across baghouse at various conditions of air-to-cloth ratio, flue gas temperatures, and cleaning modes. The average level of Mercury in the flue gas stream incoming to the baghouse was 10.3 µg/m^3. The speciation in the inlet flue gas was 80% elemental and 20% oxidized.

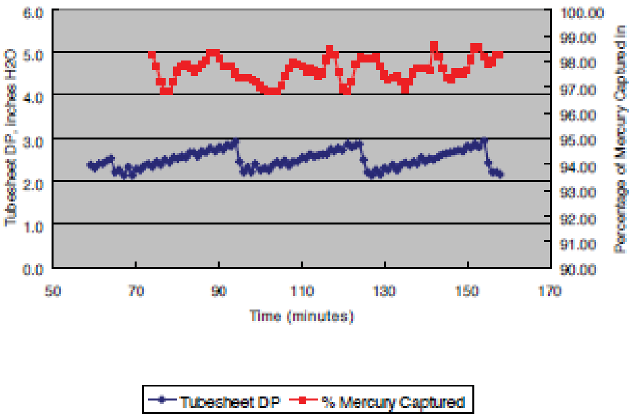


Figure 43. Mercury Capture for Flue gas flow rate of 14,000 acfm (air:cloth ratio of 3.7); Temperature 280°F; Cleaning in Time Mode every 30 minutes – Snapshot of data through 3 cleaning cycles

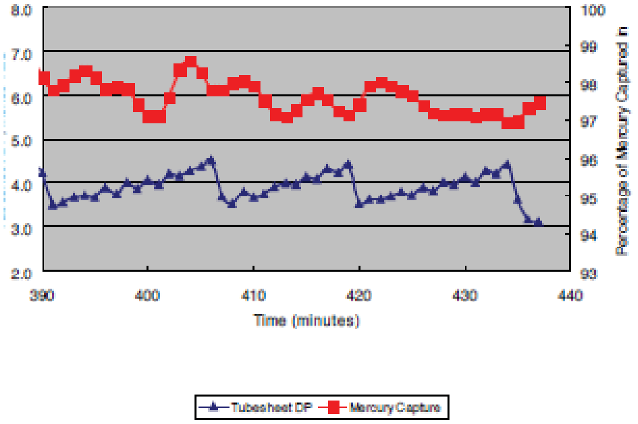


Figure 44. Mercury Capture for Flue gas flow rate of 19,000 acfm (air:cloth ratio of 5.15); Temperature 280°F; Cleaning in Time Mode every 15 minutes – Snapshot of data through 3 cleaning cycles

The data shown in figure 41 came as a great surprise to the team. The data showed that by using native fly ash alone, mercury capture of 98% can be achieved in the baghouse with BHA pleated elements if the flue gas inlet temperature can be reduced to 280°F. This is true in spite of the mercury being predominantly in the elemental state. For a more conventional flue gas temperature of around 343°F, the capture percentage of between 75% to 80% can be achieved. These numbers are surprising, as the historic data from MRC shows that with traditional round non-membrane bags, the expected capture percentage is around 30%.

The data also shows that there is some benefit to operating the process in a pressure-based cleaning mode (compare results from Tests 1 and 2). There is some advantage to increasing the time between cleaning (compare the results from Tests 2 and 3).

At higher flue gas temperature (343°F), the data further showed that operating at higher air-to-cloth ratio could actually be better for mercury capture. This came as another counter-intuitive observation.

Confirmatory Tests on the Validity of Data

Since the observed mercury capture percentages were significantly higher than traditional round bags, a few confirmatory tests were run to rule out any equipment error or anything unusual with flue gas chemistry.

In order to confirm that the mercury analyzers were reading correctly, we ran the following two confirmatory tests.

- The flue gas duct was reconfigured to bypass the baghouse. On bypassing the baghouse, the outlet mercury analyzer read within 2% of the inlet analyzer.
- During steady state operation with baghouse in service, mercury samples were also collected with carbon traps. These carbon traps were sent to an outside test lab. The data from these carbon traps matched the inline Thermos data very closely.
  - Average of two traps 0.90 µg/m^3 at 3% O_2 (ran for 111 minutes)
  - Average of Thermo Total Hg over the 111 minutes 0.88 µg/m^3 at 3% O_2

Based on these two tests, any concerns with mercury analyzers were ruled out.

The second concern was whether there was some temporary fluctuation in the plant operation that is leading to unusual gas stream chemistry or unusually high affinity of fly ash for mercury. In order to confirm that this was not the case, we collected mercury capture data across ESP alone. The rationale was that since amount of mercury capture by ESP in a typical power plant is very well documented, by collecting the baseline data with ESP, any unusual issues with this particular gas stream chemistry or fly ash composition can be ruled out. The four-field ESP was operated at the standard operating conditions (50KV on each field).

ESP was operated at temperature 340°F. The flue gas flow rate was 14,000 acfm. At these conditions, the percentage of mercury captured across ESP was around 35%. This level of capture of mercury across ESP is consistent with documented studies, and historical data from MRC. Hence, anything unusual about this fly ash or gas chemistry can be ruled out.

Testing with Injection of Powdered Activated Carbon

Since injection of powdered activated carbon is accepted as a well-accepted method for mercury control, we hypothesized that by using BHA's ThermoPleat® elements the amount of carbon needed by an utility can be substantially reduced.

Testing was conducted with Darco® Hg-LH powdered activated carbon supplied by Norit. This is impregnated activated carbon, and is designed for flue gas streams having high percentage of elemental mercury.

Figure 45 shows the parametric curve with various levels of activated carbon injection rates. The activated carbon studies showed that with BHA ThermoPleat® element, a capture rate of 92% plus can be achieved by carbon injection rate of 0.6 lbs/MM Acf. This compares to typical injection rate of 4.0 lbs/MM Acf reported in literature for standard non-membrane bags[2].

Summary of Key Findings

1. Mercury capture of 98% can be achieved in the baghouse with QR811 elements, if the flue gas inlet temperature can be lowered to 280°F. This is true in spite of the mercury being predominantly in elemental state.

2. Mercury capture of 75% to 80% can be achieved in the baghouse with QR 811 pleated elements, if the flue gas temperature is kept at typical set-up of around 345°F.

3. Further increase to mercury capture can be achieved at the higher temperature settings (343°F) by activated carbon injection. Capture rate can be increased to 92% plus by carbon injection rate of 0.6 lbs/MM Acf. This compares to typical injection rate of 4.0 lbs/MM Acf reported in literature for standard non-membrane bags.

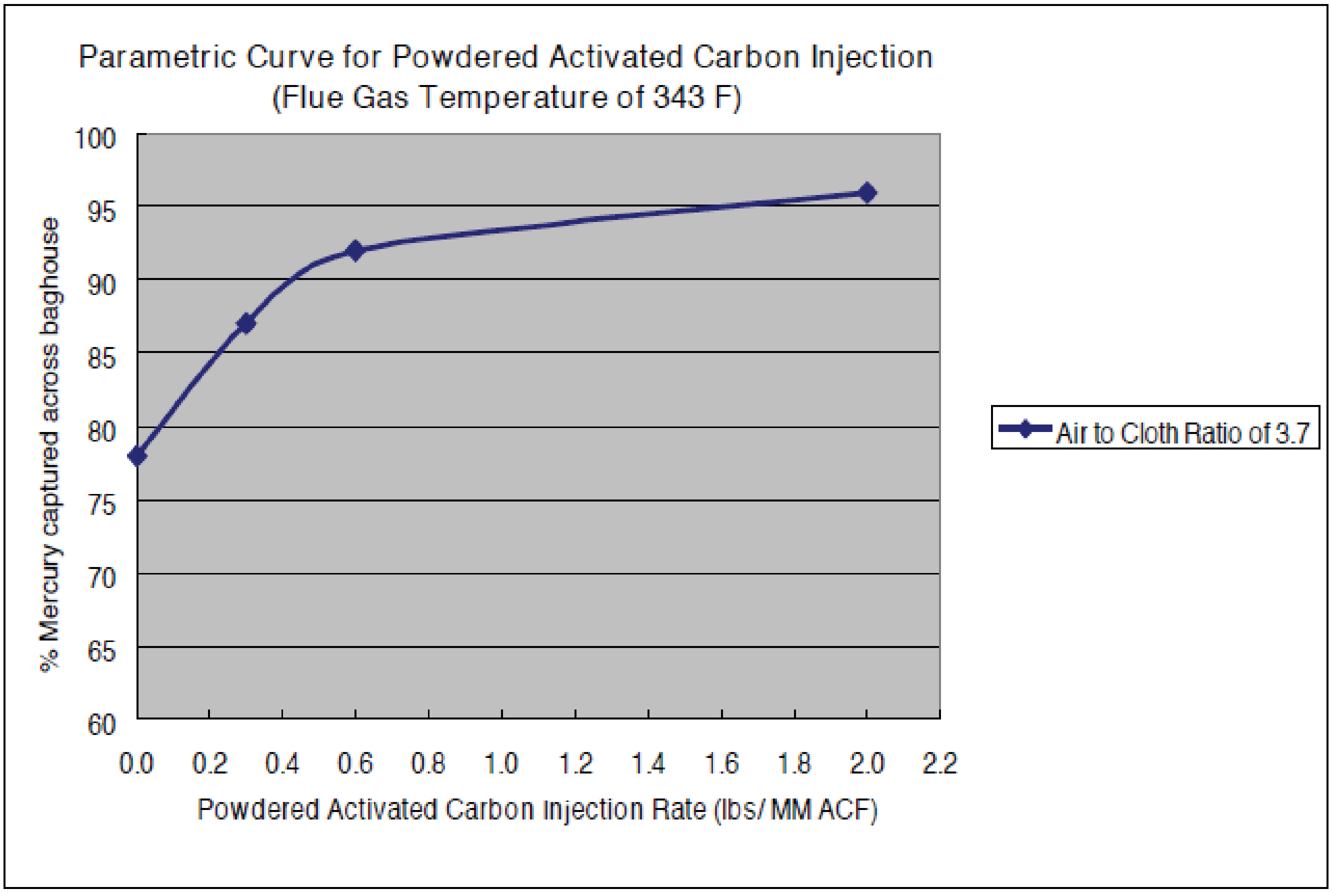


Figure 45: Percentage of Mercury captured with the injection of powdered activated carbon. Flugas flow rate of 14,000 acfm (air-to-cloth ratio of 3.7)

Proposed Mechanism

The exact mechanism for these unexpected findings is still being investigated. An initial hypothesis of mechanism is discussed below.

First a recap of the known facts,

- Pleated elements with membrane are leading to very high rate of mercury capture, compared to literature-reported values with traditional non-membrane round bags.
- Air-to-cloth ratio appear to have weak effect.
- Interval between cleaning does appear to have some effect (lengthening it increases the capture).
- Temperature of flue gas has the strongest effect.
- There appears to be something inherently unique about pleated elements and membrane that is leading to high capture. The mechanism cannot be explained by cleaning interval and air-to-cloth ratio alone.

In order to ascertain that the high rate of mercury capture across pleated elements is related to fly ash, an experiment was conducted in which the fly ash was removed from the equation. An experiment was conducted in which ESP and baghouse were operated in series. ESP was operated at its standard conditions with all four fields operational. At these conditions, this ESP is believed to remove 99.5%+ of the fly ash, per MRC (no opacity measurement available). Gas flow rate was 14,000 acfm, and temperature was 340°F.

The results are summarized in figure 46.

When operating under these conditions, it was found that the baghouse provided no significant further mercury capture beyond what was achieved by ESP alone. This leads us to conclude that the key mode of mercury removal across the pleated elements relies on the fly ash.

However, in the above set-up, what came as a surprise was that while the baghouse provided no additional mercury removal (when operated in series downstream of ESP), it continued to oxidize mercury (even in absence of fly ash). Based on this observation, the proposed mechanism for the high amount of mercury capture by membrane pleated elements is as follows:

- High capture requires membrane AND pleats in the filter element.
- High surface area of membrane (nodes and fibril structure on surface) provides collection surface for Hydrochloric acid (HCl) in the gas stream to collect on and to oxidize the elemental mercury in flue gas to mercuric chloride.
- With pleated elements, there is always some fly ash collected in the valleys that captures this mercuric chloride. This fly ash does not contribute to filter pressure drop, as it is not actually on the filtration surface, but located in close vicinity of filtration surface.
- In case of round bags, there is very little fly ash that remains in vicinity of filtration surface (the cleaning pulse being directed at 90 degree angle from the bag would push out all the fly ash).

In the proposed model, the membrane facilitates mercury oxidation, and the pleats facilitate capture of oxidized mercury. Need to have both to get high total capture.

Explanation of Observed Results by Proposed Mechanism

No additional capture of mercury by baghouse when ESP is in service

- Without fly ash in the flue gas stream, the HCl build-up on the membrane nodes and fibrils would still take place. This would still oxidize the elemental mercury to chloride form. Experimental data shows that as well.

- However, without any fly ash to capture this mercuric chloride, it would simply go through the baghouse as gas (at these concentrations dew point of mercury in gas is below zero dg C).

Upstream of ESP		Downstream of ESP / Upstream of Baghouse		Downstream of Baghouse	
Total Mercury, $\mu g/m^3$	Percentage Elemental (%)	Total Mercury, $\mu g/m^3$	Percentage Elemental (%)	Total Mercury, $\mu g/m^3$	Percentage Elemental (%)
9.49	81	6.36	50	6.07	15

Figure 46: Process with ESP and Baghouse operated in series. Total levels of Mercury and speciation at various stages of the process.

Substantial increased capture of mercury on reducing the flue gas temperature from 343^{o}F to 280^{o}F.

At lower temperatures, the surface precipitation of HCl on the membrane surface would be even higher, explaining increased oxidation of mercury and hence greater capture.

Somewhat increased capture of mercury at higher gas flow rate (19,000 acfm vs. 14,000 acfm).

At higher flue gas flow rates, the cleaning pulse would not be able to push off the cake from the filtration surface that far, and there will be increased collection within the valleys of the filter. This increased collection of ash in the valleys would help with mercury capture.

Overall Summary

In summary, this demonstration proved that QR811 pleated elements are an effective replacement for standard cloth bags on wire cages and require much less physical space to achieve functionality. Mercury removals of >95% across the baghouse were achieved with only the LOI in the fly ash, which averaged about 4.3%. When supplemented with activated carbon, much higher removals were achieved. Lower temperature operation increased removal as did reducing the cleaning frequency which led to thicker filter cakes on the bags.

In this short-term test it was shown that the pleated bags can achieve very high levels of mercury removal without imposing any detrimental effect on unit operation.

A model for potential mechanisms that result in such high degree of mercury capture has been proposed. While the exact mechanisms are not known, it is believed that the presence of ePTFE membrane as well as the filter geometry (pleated elements vs. round bags) are critical to achieve the high mercury capture.

References

[1] EPA-452/R-97-010, US EPA Mercury Study Report to Congress, Volume 8. An Evaluation of Mercury Control
Technologies and Costs
[2] McLellan, Debra etal, "Multi-Technology, Mercury Abatement Program Implementation and Performance at Nova Scotia Power", Power Plant Air Pollution Control Mega Symposium, Aug 30- Sep 2, 2010
[3] Internal Final Report submitted by PCT Inc.
to CLARCOR Industrial Air – Baghouse Operation and
Mercury Control using High Surface Area
QR811 Pleated Bags at the MRC- Plant Crist

Acknowledgements

All the data presented in this report was collected by PCT, Inc. at MRC Center located at Gulf Power's Plant Crist in Pensacola, FL. The final report submitted by PCT, Inc. forms the basis of much of the information in this paper.

The authors express gratitude to Ralph Altman and Charles Lindsey from PCT, Inc. for the work, report, and discussions about the data. The authors are also grateful to Norit Americas Inc. for supplying the powdered activated carbon for the trial.

For further information contact Tim Stark at
timothy.stark@clarcor.com

Vishal Bansal was born and grew up in India. He graduated from Indian Institute of Technology (IIT), Bombay with a Bachelors of Science in Chemical Engineering (1992), and then completed his Ph.D. in Chemical Engineering at the University of Oklahoma (1997). He also completed an Executive MBA from Virginia Commonwealth University in 2003.

Bansal is the Strategic Technology leader for Clarcor Industrial Air, located in Lee's Summit, MO. In this role, he identifies and leads the development of pipeline for long term technology initiatives.

Bansal joined GE Energy in 2004, as the Applications Engineering Manager for the Membrane Technology business. He was promoted to Principal Engineer in 2007. In 2012, he assumed his current responsibilities. He is a winner of GE's prestigious "Annual Engineering Award" in the field of Material and Process Engineering – a competition encompassing over 4,000 engineers.Before GE, Vishal worked for DuPont Nownwovens for seven years in Richmond, VA in a number of technology roles. The work at DuPont formed the basis for a $100 Million investment in a new plant.

Bansal's expertise is in the areas of polymeric materials, material processing technologies, structure-property relationships of polymers, filtration media, and filtration science. He has presented over 15 technology papers at international conferences, has been published in numerous trade journals, and has been awarded over 25 patents. He is well recognized as a filter media expert by our key customers, as well as our key vendor base which includes most filter media manufacturers.

CLARCOR Industrial Air | BHA

WPCA Corporate Sponsors

WPCA Chairman
Robert Hilton,
VP Power Tech for Gov. Affairs
Alstom
1409 Centerpoint Blvd., Knoxville, TN 37932
Email: robert.g.hilton@power.alstom.com

WPCA Secretary
Jason Horn, Dir. of Env. Controls
Stock Equipment Company
16490 Chillicothe Rd, Chagrin Falls, OH 44023
Email: jason.horn@stockequipment.com

WPCA Treasurer
Robert Mudry, President
Airflow Sciences Corporation
12190 Hubbard Street, Livonia, MI 48150 USA
Email: rmudry@airflowsciences.com

WPCA Vice President
Cindy Khalaf, Vice President
Johnson Matthey Catalysts LLC
1121 Alderman Dr. Ste 204, Alpharetta, GA 30005
Email: cindy.khalaf@jmusa.com

Greg Bielawski, Mgr. Env. Aftermarket;
Babcock & Wilcox
20 S. Van Buren Ave., Barberton, OH 44203 USA
Email: gtbielawski@babcock.com

Chetan Chothani, COO
Breen Energy Solutions
104 Broadway Street, Carnegie, PA 15106 USA
Email: cchothani@breenes.com

Todd Clark, Business Dev. Mgr.
Babcock Power Inc.
5 Neponset Street, Worcester, MA 01606 USA
Email: tlicata@babcockpower.com

Allen Kephart, President
CleanAir Engineering
110 Technology Dr., Pittsburgh, PA 15275
Email: akephart@cleanair.com

Mark Ehrnschwender, VP Bus. Dev&Engr
Steag Energy Services LLC
304 Linwood Rd, Ste.102, Kings Mountain, NC
28086 USA
Email: mark.ehrnschwender@steag.us

Jean Bustard, COO
ADA-ES
9135 S. Ridgeline Blvd., Ste. 200,
Highlands Ranch, CO 80129
Email: jeanb@adaes.com

Tim Stark, Director
CLARCOR Industril Air
11501 Outlook St., Ste. 100,
Overland Park, KS 66211 USA
Email: timothy.stark@clarcor.com

Nate White, Dir. Business Development
Haldor Topsoe, Inc.
5510 Morris Hunt Dr., Fort Mill, SC 29708 USA
Email: tnw@topsoe.com

Richard Staehle, CEO
KC Cottrell, Inc.
8 Bartles Corner Rd., Ste 204,
Flemington, NJ 08822 USA
Email: rstaehle@kccottrell.us

Jerry VanDerWerff, Nat. Sales Manager
Sorb-N-Ject; Nol-Tec Systems, Inc.
425 Apollo Dr., Lino Lakes, MN 55014 USA
Email: JerryVanDerWerff@nol-tec.com

Ken Fairleigh, President & CEO
Paragon Airheater Technologies
23143 Temescal Canyon Rd., Ste. B,
Corona, CA 92083 USA
Email: kfairleigh@paragonairheater.com

Susan Reinhold, CEO
Reinhold Environmental Ltd.
3850 Bordeaux Drive, Northbrook, IL 60062 USA
Email: sreinhold@reinholdenvironmental.com

James Reynolds, VP Wet ESP Technology
Foster Wheeler
501 Grant Street, Pittsburgh, PA 15219-4429 USA
Email: james_reynolds@fwc.com

Michael Hatsfelt, General Manager
Southern Environmental, Inc.
6690 West Nine Mile Rd., Pensacola, FL 32526
Email: mhatsfelt@sei-group.com

Gordon Maller, Bus. Development Mgr.
URS Corporation
9400 Amberglen Blvd., Austin, TX 78729 USA
Email: gordon.maller@urs.com

Bill Hankins, VP Sales, U2A Systems
Wahlco
2722 South Fairview, Santa Ana, CA 92704 USA
Email: bhankins@wahlco.com

Tom Lugar, VP Product Development
MET
200 North 7th St., Lebanon, PA 17046 USA
Email: tlugar@met.net

Michael Atwell, Market Dev. Mgr.
SOLVAir Sol. Solvay Chemicals
3333 Richmond, Houston, TX 77098 USA
Email: michael.atwell@solvay.com

Jamie Fessenden, Bus. Mgr. Emission
Control Tech \ Cabot Norit Americas
3200 University Ave., Marshall, TX 75670 USA
Email: jfessenden@cabotcorp.com

Curt Biehn, Mgr., Mkt & Tech Services
Mississippi Lime
3870 S. Lindbergh Blvd., St. Louis, MO 63127
Email: crbiehn@mississippilime.com

Paul Ford, President
Redkoh Industries
300 Valley Road, Hillsborough, NJ 08844 USA
Email: paul.ford@redkoh.com

WPCA Officers

WPCA President
Joseph Hantz, Manager Environmental Services, Entergy
WPCA Vice President
Melissa Allen, FGD System Engineer TVA

WPCA Advisors

- **Greg Betenson, Principal Engineer, PacifiCorp**
- **Melanie McCoy, Superintendent Sebewaing Light & Power**
- **Michael Olive, Mgr, Major Project Integration, Progress Energy Florida**
- **Ebrahim Patel, Senior Consultant - APC, ESKOM-GTD**
- **Bruce Salisbury, Engineering Supervisor, Arizona Public Service**
- **John Walker, Senior Engineer - Station Electrical, Duke Energy**
- **Scott Williams, Senior Engineer, Duke Energy**