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Executive Summary

WFGD System Upgrades for Reduced Emissions and Improved Reliability

By Albert Moretti and Barry Tielsch, Babcock & Wilcox

Electric utilities must find a way to balance and manage (1) new and more stringent environmental regulations, (2) the economic desire to increase the duration between unit outages, and (3) ways to reduce operating and maintenance costs. Older WFGD (Wet Flue Gas Desulfurization) systems were not designed for new regulations, such as the anticipated Utility Boiler MACT (U-MACT), the Clean Air Transport Rule (CATR), a lower standard for ambient sulfur dioxide (SO_2) (NAAQS), and Coal Combustion Residue (CCR) regulation. As a result, existing FGD systems will be pressed for greater removal and higher reliability.

New WFGD systems are typically designed for SO_2 removal levels of 98% and reliability of 99%+. Fortunately, the technological improvements that have been incorporated into the newest WFGD systems can be adapted for retrofit into older WFGD systems. The upgraded WFGD systems allow for the elimination of any WFGD flue gas bypass without the need to add an absorber module. These technological improvements include the installation of improved gas-liquid contacting devices, redesigned spray headers, spray nozzles and spray nozzle patterns, upgraded mist eliminators and mist eliminator wash systems, conversion from natural or inhibited oxidation to in-situ forced oxidation, and improved limestone preparation systems and byproduct dewatering systems. ***Full Story….***

Next Generation Wet Electrostatic Precipitators

By Hardik G. Shah and John Caine, Southern Environmental Inc.

Multi-pollutant control technologies will become more important in the future. This new membrane wet electrostatic precipitator (WESP) system is ideally suited to, and very cost effective for, removing $PM_{2.5}$, SO_3 and Hg^{+2} after limestone wet flue gas desulphurization (WFGD) scrubbers in the utility industry.

Several coal-fired utilities have been experiencing increased SO_3 emissions from their existing WFGD scrubbers, especially after installing a Selective Catalytic Reduction (SCR) for NOx Control. Achieving co-benefits of Hg removal by installing SCR's and WFGD systems is already becoming a key strategy for reducing mercury levels after coal fired power plants. ***Full Story….***

Reduce Harmful Emissions

By Joseph McCarney, Johnson Matthey

Noxious gases thrown into the atmosphere by cruise liners are highly reactive and risk the disruption and destruction of sensitive marine environments. As the industry seeks to curb its emissions, the following article explains how selective catalytic reduction can help.

Despite a greater focus on environmental concerns, shipping remains a very polluting industry in terms of the exhaust emissions it pumps into the atmosphere. Marine exhaust gases contain high levels of NOx, SOx, particulate matter, carbon monoxide and unburned fuel. However, looming regulations and a greater interest in clean transportation are persuading ship owners, shipyards and operators that it is time to take action. ***Full Story….***

How to Grade Your ESP

By John Knapik, B&W Power Generation Group

….This leads us to….How to grade each section of your precipitator and get a better overview! Here is a four step by step procedure. Apply the above rating system after applying each step. ***Full Story….***

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WORLDWIDE POLLUTION CONTROL ASSOCIATION

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By Albert Moretti and Barry Tielsch (brtielsch@babcock.com)

Introduction

Electric utilities must find a way to balance and manage:

1. **New and more stringent environmental regulations;**
2. **The economic desire to increase the duration between unit outages;**
3. **Ways to reduce operating and maintenance costs.**

Older WFGD (Wet Flue Gas Desulfurization) systems were not designed for new regulations, such as the anticipated Utility Boiler MACT (U-MACT), the Clean Air Transport Rule (CATR), a lower standard for ambient sulfur dioxide (SO_2) (NAAQS), and Coal Combustion Residue (CCR) regulation. As a result, existing FGD systems will be pressed for greater removal and higher reliability.

New WFGD systems are typically designed for SO_2 removal levels of 98% and reliability of 99%+. Fortunately, the technological improvements that have

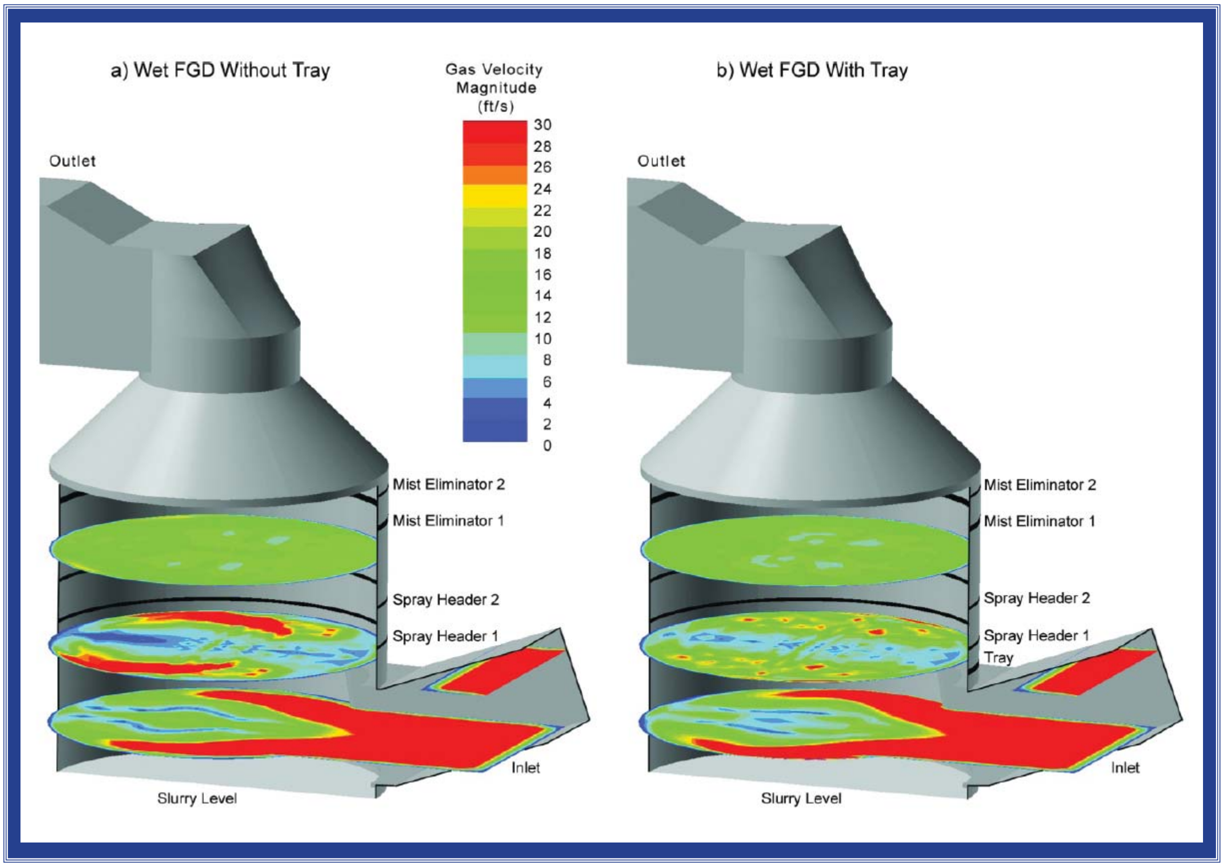

Figure 1: Gas velocity profiles of the flue gas at the spray levels in an open spray tower compared to an absorber tower with a tray.

been incorporated into the newest WFGD systems can be adapted for retrofit into older WFGD systems. The upgraded WFGD systems allow for the elimination of any WFGD flue gas bypass without the need to add an absorber module. These technological improvements include the installation of improved gas-liquid contracting devices, redesigned spray headers, spray nozzles and spray nozzle patterns, upgraded mist eliminators and mist eliminator wash systems, conversion from natural or inhibited oxidation to in-situ forced oxidation, and improved limestone preparation systems and byproduct dewatering systems.

Upgrading an existing WFGD system may be an effective way to improve SO_2 removal, allow the use of lower cost higher sulfur coals, reduce power consumption, eliminate high pressure drop packing, allow the conversion to a forced oxidized system, allow for the use of an alternate reagent, and improve the reliability of the system while reducing the operating and maintenance costs.

Absorber Gas-Liquid Contact Device

The most common type of WFGD absorber is the spray tower. Many spray towers were built in a completely "open" tower configuration with a horizontal gas entry into a vertical open cylindrical vessel with multiple levels of spray headers. Problems associated with the totally open configuration were gas maldistribution across the cross section caused by the high velocity of gas entry and gas sneakage due to the tendency of the gas to hug the walls of the absorber.

The SO_2 removal efficiency of a spray tower of the open type can be upgraded by adding wall rings or an absorber tray. Wall rings serve to significantly reduce the gas sneakage as well as kicking out any slurry running down the walls. The structural aspects of adding wall rings or an absorber tray must be considered in any such retrofit.

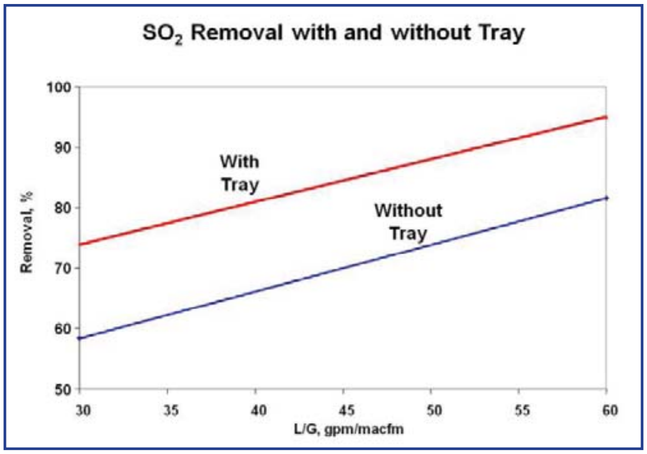

Figure 2: SO_2 removal efficiency increase in the same absorber tower with and without an absorber tray

The retrofit of an absorber tray into an open spray tower is an efficient way to increase the contact between the flue gas and the slurry spray. The tray creates more contact between the gas and the slurry due to the violent frothing action that occurs on the tray. The absorber tray also evenly distributes the flue gas flow across the absorber cross-section, promoting optimum contact as the flue gas passes through the absorber spray levels. Figure 1 *(shown on page 1)* shows the gas velocity profiles of the flue gas at the spray levels in an open spray tower compared to an absorber tower with a tray.

When upgrading an existing WFGD system, both capital and operating costs benefits are realized. The additional fan power required due to the increased gas side system pressure drop of the tray is typically offset by a reduction in pumping power associated with the lower L/G required to achieve a given SO_2 removal efficiency. The retrofit of an absorber tray can eliminate the requirement for the addition of a spray level to the absorber. For moderate SO_2 removal improvements, the absorber tray retrofit can allow the plant to use one less spray level and spray pump per absorber. This results in decreased operating and maintenance costs.

Full-scale field tests have shown the benefit of adding an absorber tray to an open spray tower. Figure 2 shows an SO_2 removal efficiency increase in the same absorber tower with and without an absorber tray. Depending upon the target removal efficiency and configuration of the existing WFGD module, a dual tray may also be considered as a means to achieve the most optimized upgrade to the system.

Absorber Spray Headers

Many older WFGD absorber modules were designed with spray patterns that do not provide efficient contact of the flue gas with the slurry spray. Gaps or openings in the spray pattern of older designs allow flue gas to travel through the spray zones without having contact with the slurry. Many of these gaps are seen on the outside of the absorber near the absorber walls, which provide a direct path for the flue gas to bypass the slurry spray. Figure 3 (*shown on page 3*) shows an example of an original spray pattern compared to an upgraded spray pattern design in the same absorber.

The spray header modifications shown in Figure 3 involved replacement of the spray headers and nozzles. Modifications to the absorber pumps and absorber discharge pumping were not necessary to realize the benefit of the spray pattern redesign.

Many of the older spray header designs have a support system that routinely breaks, causing header sections to break off and fall to the bottom of the absorber. The most modern WFGD systems now employ self-supporting spray headers with up to 60 foot spans. These headers can be fabricated from either FRP or alloy material.

Mist Eliminators and Mist Eliminator Wash System

Older WFGD systems use a variety of mist eliminators (ME) and mist eliminator wash systems. A common design was the use of a bulk entrainment separator followed by two levels of "tee-pee"-style mist eliminators. Other designs use two levels of flat chevron style MEs that do not incorporate the design improvement of the latest chevron MEs.

In new WFGD systems, the lower MEs capture the large particles and the upper MEs capture the remaining wash water droplets and finer particles. Typical modern mist eliminators are shown in Figure 4 (*shown on page 3*).

In many cases, the old ME wash system did not effectively wash all the surfaces of the MEs that are typically washed in modern designs. Fixed grid ME wash headers can be installed to replace retractable lance-style wash systems or fixed grids that were ineffective in washing the ME surfaces.

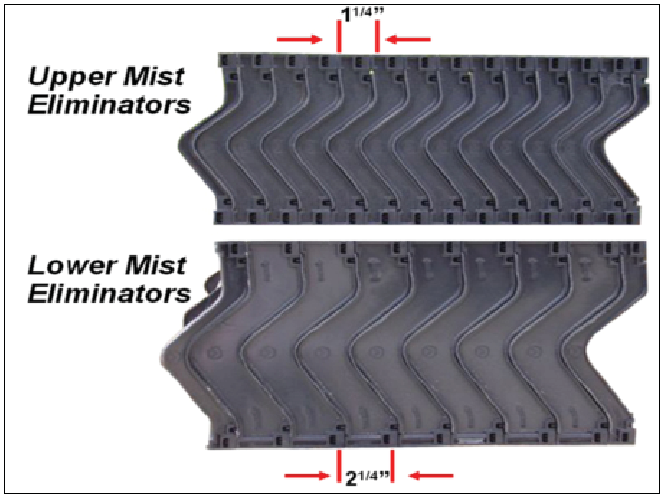

Figure 4: Typical modern day mist eliminator

Forced Oxidation

As SO_2 emission limits are decreased and higher sulfur coals are burned, the amount of WFGD byproduct will increase. WFGD systems that utilize natural oxidation will be affect-

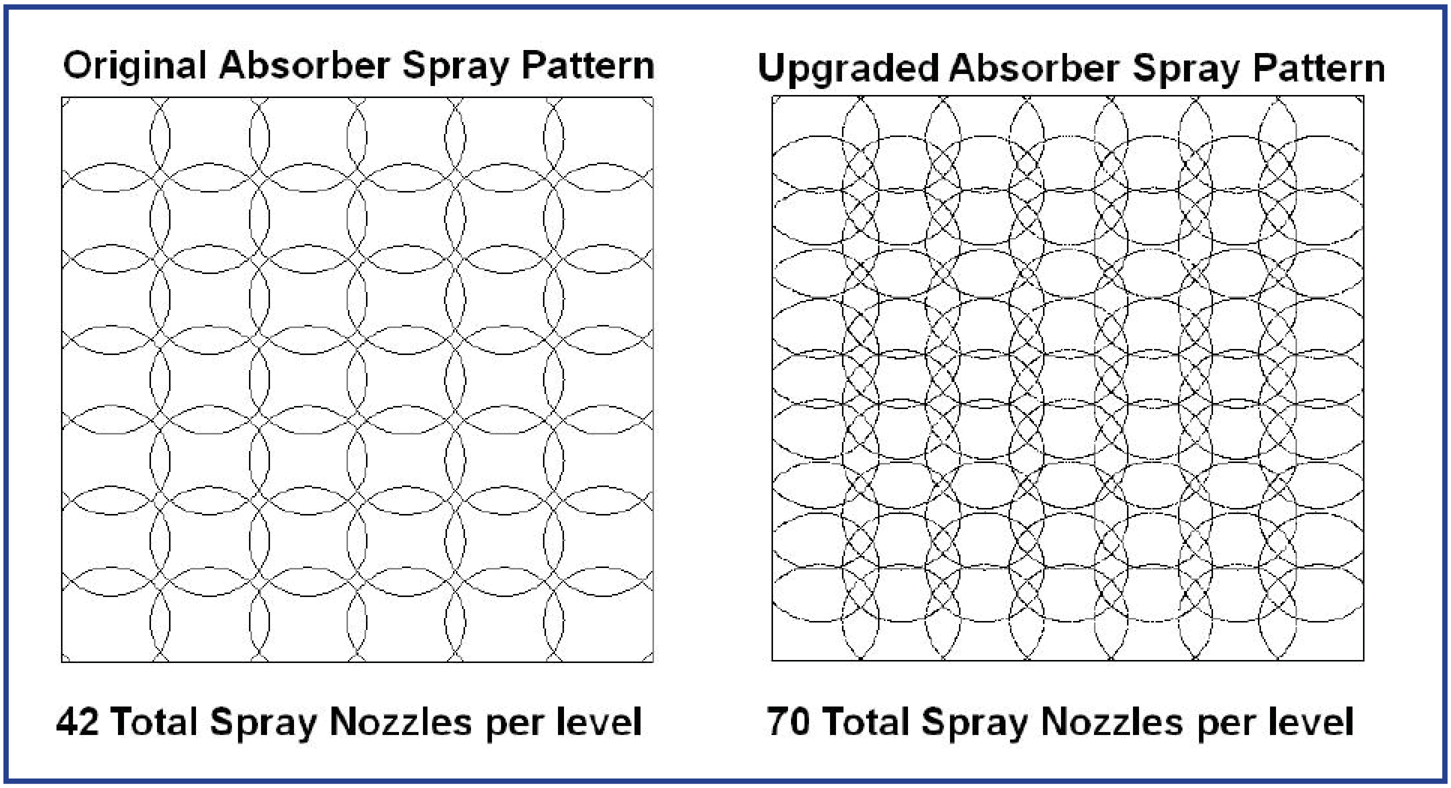

Figure 3: Original spray pattern compared to an upgraded spray pattern design in the same absorber

ed because the use of disposal ponds will likely no longer be allowed by regulations and would be more quickly filled to capacity if the current WFGD is upgraded to improve performance. The Limestone Forced Oxidized System (LSFO) WFGD is the most common system in use today. The LSFO system produces a stable gypsum byproduct that is typically sold for use in the manufacture of wallboard or to the cement industry. In some cases, a disposable gypsum product is produced for landfill if there are no wallboard or cement plants within a reasonable distance. The differences between gypsum products depend on the amount of impurities or the degree of dewatering. In addition, the LSFO system is less prone to scaling compared to a natural oxidization system.

The LSFO WFGD process incorporates air injection to ensure a fully oxidized gypsum product. The method chosen for the introduction of oxidation air has an influence on plant costs and system operating requirements. Air sparge grids and air lances with mechanical agitators are the two generally applied methods of introducing oxidation air into the process. The sparge grid is a multiple air header arrangement with near even spacing of bubble stations across the vessel plan area. The lance system consists of air pipes directed to a region in the liquid jet created by side entry mixers. See Figure 5.

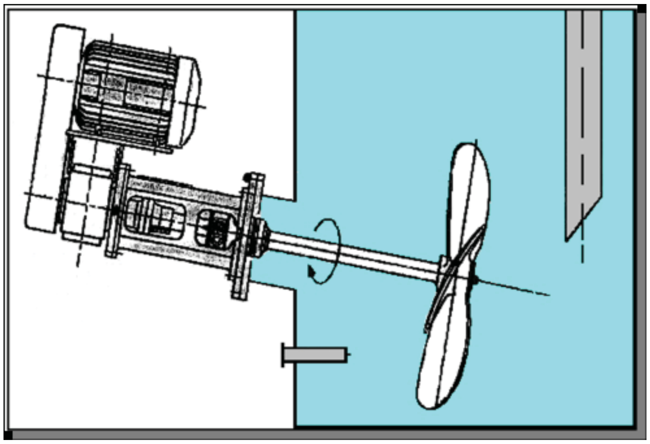

Figure 5: The lance system consists of air pipes directed to a region in the liquid jet created by side entry mixers

The performance of the lance system is influenced by the energy of the fluid jet (mixer power) and the submergence depth (air blower power). The performance of the sparge grid is less dependent on the mixer power and is, to a much greater degree, influenced by submergence depth.

When upgrading an existing WFGD, a general review of the capacity available in the existing absorber recirculation tank is required. In some cases a sparge grid or lance system can be retrofit into the existing tank. If there is not enough residence time available, an external oxidation air tank may be required.

Reagent Preparation and Dewatering

Many older WFGD systems were designed with reagent preparation and dewatering systems that are undersized if limestone consumption must be increased to improve SO_2 removal. Many times, higher SO_2 removal requires a finer grind than the systems were originally designed to achieve. The standard grind on modern WFGD systems is 95% less than 325 mesh. It is possible to upgrade the components of some existing milling systems to handle the new quantity and grinding requirements. Optimizing the grind of the limestone milling system can have a significant positive impact on limestone utilization.

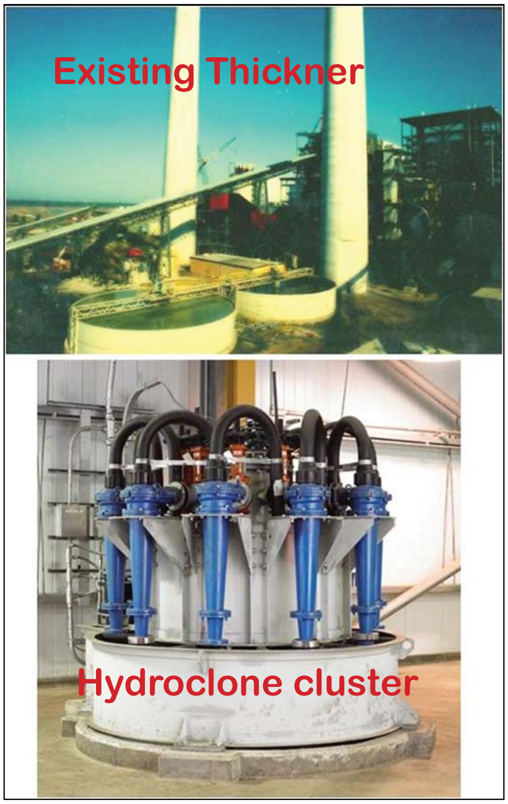

Figure 6: Hydroclones require substantially less real estate compared to a Thickner

Older WFGD systems were designed with thickeners for primary dewatering and rotary drum filters for secondary dewatering. In modern WFGD systems, thickeners have been replaced with hydroclones. Hydroclones can achieve up to 55% moisture removal, while thickeners typically achieved 35-45% and required a substantial amount of plant real estate. Greater moisture removal from the hydroclones can reduce the required size of the vacuum filters. Also, thickeners have been known to cause maintenance problems with stuck rakes and the large mechanical equipment is expensive to maintain or replace. Additionally, a forced oxidation conversion can make thickeners difficult to operate due to the rapid settling of gypsum in the center well of the thickener. Hydroclone maintenance is minimal and downtime is almost eliminated due to the use of spare cyclones. The use of hydroclones in forced oxidized systems is proven technology. See Figure 6 (shown on page 4).

Many older FGD systems have rotary drum filters that may be undersized to handle increased SO_2 removal and subsequently greater byproduct from the absorber. Existing rotary drum filters must be examined for the possibility of increased usage - more hours per day of operation. Many worn parts of the system may need to be replaced to ensure adequate reliability. In some case, replacement of the existing drum filters may be required. A majority of new WFGD systems use vacuum belt filters to reach moisture levels of less than 10%. See Figure 7 (Shown on page 5). New rotary drum filter technology can also achieve levels of 10% moisture or better. Decreased gypsum moisture levels can allow for gypsum sales to wallboard and cement companies or as a minimum, decrease landfill transportation costs.

Figure 7: Picture of a Rotary Drum Filter and Vacuum Belt Filter

Conclusion

With advancements in technology, utilities have many ways to upgrade their existing WFGD systems to meet the latest stringent regulations, increase the length of time between outages for maintenance, reduce forced outage occurrences to near zero, and reduce operating and maintenance costs. These technologies include:

- Addition of an absorber tray for increased liquid to gas contact resulting in greater SO_2 removal;
- Redesigned spray headers and spray nozzle patterns for improved flue gas contact with the slurry in the absorbers;
- Redesigned mist eliminators and mist eliminator wash systems to handle higher absorber velocities;
- Forced oxidation conversion to eliminate the need for disposal ponds, creating a saleable byproduct which will decrease disposal costs;
- Improved reagent preparation and dewatering equipment for greater system capacities and increased reliability.

Whether the plant's goal is to comply with the latest regulations, reduce outages (scheduled or forced), minimize operating and maintenance costs, or all of the above, upgrading an existing WFGD may be the method of choice for applying proven technology while minimizing capital costs.

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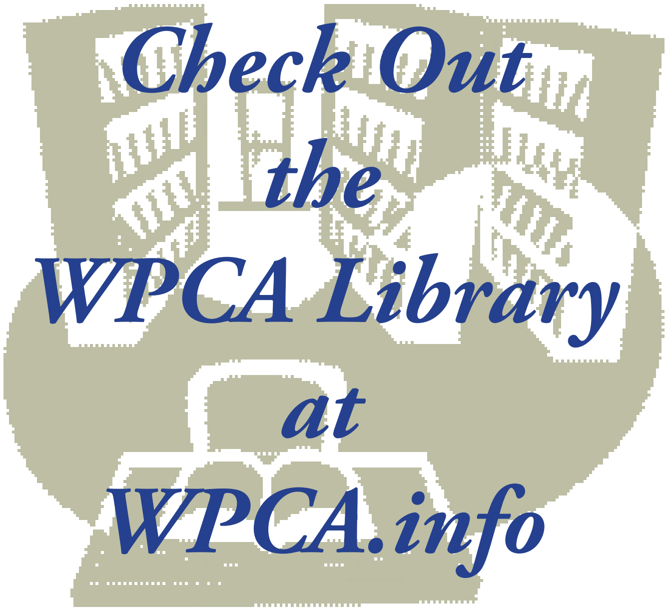


Next Generation Wet Electrostatic Precipitators

By Hardik G Shah, and John C Caine, SEI

Abstract

Multi-pollutant control technologies will become more important in the future. This new membrane wet electrostatic precipitator (WESP) system is ideally suited to, and very cost effective for, removing $PM_{2.5}$, SO_3 and Hg^{+2} after limestone wet flue gas desulphurization (WFGD) scrubbers in the utility industry.

Several coal-fired utilities have been experiencing increased SO_3 emissions from their existing WFGD scrubbers, especially after installing a Selective Catalytic Reduction (SCR) for NOx Control. Achieving co-benefits of Hg removal by installing SCR's and WFGD systems is already becoming a key strategy for reducing mercury levels after coal fired power plants.

In the future CO_2 removal from flue gas may be necessary. For a CO_2 absorption to operate effectively very low loadings of PM, SO_2 & SO_3 are required (deep cleaning). A WESP offers the most cost effective technology to achieve deep cleaning.

A WESP can readily collect acid aerosol and fine particulate due to greater corona power and virtually no re-entrainment. The WESP can also enhance collection of Hg (Hg ash & Hg^{+2}). The main historical limitation associated with wet precipitators has been the higher cost of special alloys and stainless steel material used in their manufacture. This new technology WESP, based on fabric membrane for the collecting electrodes, dramatically reduces weight and cost, compared to conventional, metallic WESPs.

Operation of several pilot units using the membrane technology has demonstrated excellent PM removal efficiency. The first commercial-size unit, collecting fine particulate and sulfuric acid mist emitted from two boilers firing No.6 oil with 4% sulfur, shows high SO_3 removal as well. The operation and performance of this 5 year old unit, will be described.

The benefits of being able to operate the unit as a condensing WESP will also be described.

Introduction

Fine particulate, $PM_{2.5}$ and pseudo particulate (H_2SO_4 mist) is of concern to coal-fired utilities because it effectively scatters light, leading to increased stack opacity. Soot, or condensed hydrocarbons and acid aerosols, are capable of causing significant opacity problems at concentrations as low as 10 ppmv. Acid aerosols form when an acid (notably sulfuric acid) condenses, providing excellent condensation nuclei for water accumulation, eventually creating aerosol particles 1-2 μm in diameter.

Sulfuric acid condensation nuclei are prevalent when SO_3 concentrations are high, either because of burning high sulfur coal or when selective catalytic reduction (SCR – used for NOx control) catalyst beds oxidize significant amounts of SO_2 to SO_3. SCR's are increasingly being used in coal-fired power plants for NOx control, especially in the Midwest. Most states limit opacity at the stack/scrubber outlet to around 10%.

Advantages of Wet Electrostatic Precipitators: Wet precipitators are excellent for controlling fine particulates, & sulfuric acid mist. In wet precipitators, re-entrainment is virtually nonexistent due to adhesion between the water and collected particulate. WESPs can achieve up to several times the typical corona power levels of dry precipitators, greatly enhancing collection of submicron particles [1&2..] Also the gas stream temperature is lowered to the saturation temperature, promoting condensation, and enhancing the collection of soluble acid aerosols.

Discussion

Problems with Existing Wet Electrostatic Precipitators

In most wet precipitators, both tubular and flat-plate, the collection surface normally has the form of a plain, solid, continuous sheet of metal or plastic. Therefore, the flushing liquid (water) passing over the surface tends to "bead" due to both surface tension effects as well as the initial geometric surface imperfections ("hills and valleys") (Figure 8 shown on page 7).

Because the flushing liquid cannot be uniformly distributed over the surface, this beading can lead to channeling and formation of "dry spots" of collected particles. The resulting build-up of collected material causes the precipitator electrical performance to degrade. As a result, current flow is inhibited, which results in increased emissions from that section of the electrostatic precipitator.

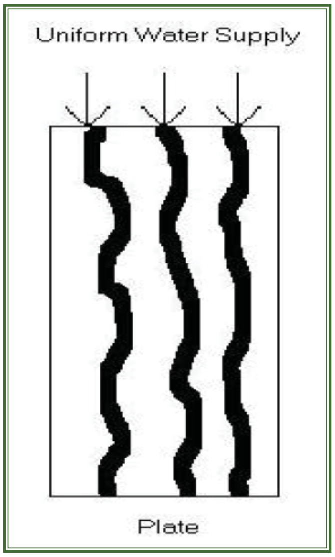


Figure 8: Water Flow in Conventional Metal Plate WESP

Most “old-design” wet precipitators employ atomization or spraying to more uniformly distribute liquid over the surface. However, any spraying into the gas stream will produce aqueous mist droplets which are highly conductive. As a result, the high voltage electric field will have a conductive path to ground, shorting out the field. To avoid this grounding, called sparkover, the field voltage is usually reduced or switched off during intermittent spraying for collector plate cleaning.

Corrosion is also a big concern of metal plate wet precipitators, so the internals must be made of expensive alloys.

Membrane Wet Electrostatic Precipitator Design Solves These Problems: Developed over the last eight years, a new type of wet precipitator, in which fabric membranes replace traditional metal collecting electrodes, solves these problems. Tests indicate that membranes made from materials that transport liquid (primarily water) by capillary action are effective collection electrodes. Capillary flow promotes well-distributed water flow both vertically and horizontally which is necessary for particle collection, removal and transport (Figure 9).

This solves a major historical problem in wet electrostatic precipitators, both of the wet upflow and wet horizontal flow types, which is to keep the collecting electrodes continuously clean.

The flushing liquid can be delivered to the membrane in a number of ways. The most important design aspect is that the water is “dripped”, not sprayed, over the collecting surface. Capillary action of the membrane material, along with an assist from gravity, delivers the water throughout the membrane eliminating splashing or spraying. The amount of water delivered and the resulting thickness of the surface liquid film can be controlled. Tests indicate that adequate flushing of collected material can be achieved with only 0.5 – 0.75 GPM per 1,000 ACFM of saturated gas.

Several Membrane Materials Can be Used: Because the liquid film is also the collecting surface (i.e. it conducts electricity), the membranes can be made from corrosion resistant, nonconductive materials like Polypropylene, or PPS. These materials essentially eliminate problems of corrosion, while offering a much lower cost alternative to stainless steels and expensive alloys.

In addition, the cost of installation and transportation are significantly lower compared to metal plate type WESP’s. The membrane collecting electrode can be kept very flat with a small amount of tension.

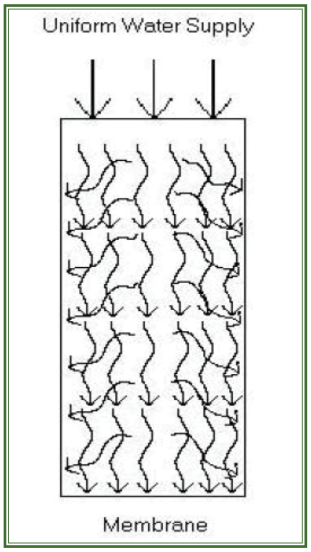


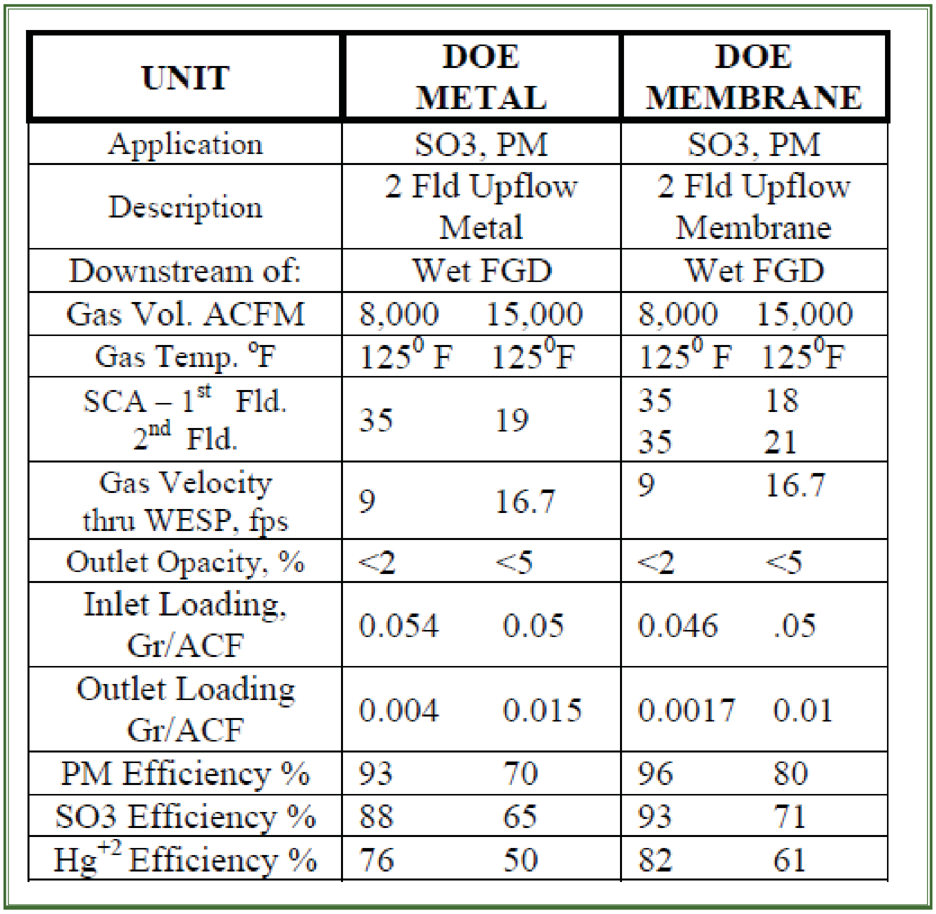
Figure 9: Water Flow in Membrane WESP

Pilot Scale Testing

Utility Pilot Plant: After two previous pilot Projects proved very successful, under partial sponsorship from the U.S. Dept. of Energy (Instrument Number: DE-FC26-02NT41592), a third pilot membrane WESP after an existing wet FGD system was built at First Energy’s Bruce Mansfield Station in Shippingport, PA.

The goal of this project was to compare the performance of the membrane design to a “conventional” metal, tubular

WESP. Under all conditions the membrane unit performed somewhat better than the metal tubular unit as seen below in Table 1.



UNIT	DOE METAL		DOE MEMBRANE	
Application	SO3, PM		SO3, PM	
Description	2 Fld Upflow Metal		2 Fld Upflow Membrane	
Downstream of:	Wet FGD		Wet FGD	
Gas Vol. ACFM	8,000	15,000	8,000	15,000
Gas Temp. °F	125^0 F	125^0F	125^0 F	125^0F
SCA – 1^{st} Fld. 2^{nd} Fld.	35	19	35 35	18 21
Gas Velocity thru WESP, fps	9	16.7	9	16.7
Outlet Opacity, %	<2	<5	<2	<5
Inlet Loading, Gr/ACF	0.054	0.05	0.046	.05
Outlet Loading Gr/ACF	0.004	0.015	0.0017	0.01
PM Efficiency %	93	70	96	80
SO3 Efficiency %	88	65	93	71
Hg^{+2} Efficiency %	76	50	82	61

Table 1: Performance Comparisons of Bruce Mansfield Pilot

Mercury Removal: We also tested Hg removal with the Bruce Mansfield Pilot (results in Table 2 shown on page 9). Tests were conducted across the existing wet scrubber and across the membrane WESP. In this plant, there is no dry precipitator, only a wet scrubber installed after the boiler for both particulate and SO_2 control. The SCR was installed, but not operating during these tests.

The higher level of elemental Hg was somewhat surprising, we see that removal efficiency across the scrubber was 82% for ash Hg and 69% for Hg^{+2}, and, of course, no collection on elemental mercury. The interesting thing, though, is that the membrane WESP achieved significant additional collection efficiency on both the ash and oxidized mercury, 72% and 78% respectively, across just the WESP. This suggests that the membrane WESP is not only effective in both Hg ash and Hg^{+2} removal, but augments and increases the overall mercury removal across a scrubber/WESP combination. In fact, as shown in the last line of the table, the overall scrubber/WESP removal efficiency on Hg ash plus Hg^{+2} = 94%.

These results also indicate that, to the extent the Hg^0 can be converted to Hg^{+2}, with $CaBr_2$ or some other additive, the combination scrubber/WESP should be able to remove 80%-90% of the total mercury in the gas stream.

Membrane Build-up Test

After these tests, which clearly demonstrated the membrane WESP's high performance efficiency in removing PM, SO_3 and Hg^{+2}, we decided to search for the ultimate test as far as membrane buildup was concerned. In 1995 we had installed a two-field, metal plate, up-flow WESP at Excel Energy's Sherbourne, Minnesota Station. This unit suffers from chronic calcium sulfate $CaSO_4$ buildup and is forced every six months to take the modules off-line to remove the accumulated calcium sulfate using high pressure water, and to clean the electrodes in the first field.

The experiment consisted of "draping" the membranes over the metal plates, which are 4' long in direction of gas flow, and irrigating the membranes continuously with water. After six months of continuous operation, as you can see in Figure 10, the metal plates exhibited their typical build-up to the point where neither the collecting plates nor the discharge electrodes are effective. By comparison, the eighteen "membrane" tubes in this compartment, although subjected to identical operating conditions as the metal plates, were totally free of build up after the six-month period. We believe this conclusively proves that as long as the membranes can be kept wet there will be no build up.

First Commercial Installation

The first commercial application of the membrane WESP technology is at Smurfit Stone Container Corporation's, Stevenson, AL Plant. This system, shown in Figure 11, is a two-module, upflow, single field, membrane WESP installed on two boilers burning No. 6 fuel oil with 4% sulfur content. The vanadium in the oil converts a significant portion of the SO_2 to SO_3 (about 20 PPM inlet to the WESP) so

Species	%	Scrubber Inlet (μg/ m^3)	WESP Inlet/Scrubber Outlet (μg/ m^3)	Scrubber Eff. % wt.	WESP Outlet (μg/ m^3)	WESP Eff. % wt.
Ash Hg	33	4.5	0.8	82%	0.2	72%
Hg+2	44	5.8	1.8	69%	0.4	78%
Hg0	23	3	3	0%	2.7	10%
Combined		13.3	5.6	58%	3.3	41%
Scrubber Efficiency (Ash Hg + Hg+2) = 75% **Scrubber+WESP Efficiency: (Ash Hg + Hg+2) = 94%**						

Table 2: Scrubber/Membrane WESP – Mercury Removal Ontario Hydro Method

Figure 10: Picture of Membrane Build-up Test

Figure 11
Picture of SSCC
Stevenson Membrane
WESP

this wet unit was to remove fine particulate and SO$_3$ mist after an existing sodium hydroxide scrubber.

The design parameters of this system are as shown below. Started up in March 2005, the membrane WESP has achieved the 0.05 lbs mm/BTU particulate and sulfuric acid (combined), outlet emission requirement at volumes slightly lower than the design volume of 125,000 ACFM. Problems which developed during early operation have been solved and the unit now has operated essentially trouble free for the last 4.5 years.

Design Parameters for New Installation

2 Boilers - WESP downstream of Na scrubber
- Gas Volume to WESP, ACFM 105,000
- Gas Temperature, oF 135
- Fuel Type, Oil #6 Bunker C
- Fuel Sulfur Content Max. 4% wt.
- Inlet loading to WESP, lb./MMBtu 0.13
- Inlet loading, lb./hr 60
- H2SO4 inlet concentration, ppmv 20 approx.
- Outlet Emission Rate, lb./MMBtu 0.05
- Outlet Emission Rate, lb./hr 22
- Outlet Emission, Gr/ACF 0.02
- Removal Efficiency (PM & H2SO4) 62%

Materials of Construction: The WESP casing is fabricated using 1/8th" thick 316L Stainless Steel with 304 Stainless Steel stiffeners. The support system for the discharge electrode is 904L and the discharge electrodes themselves are Hasteloy C2000 (at the customer's request). The membranes are felted polypropylene.

Commercial Units

To date six commercial-size Membrane WESPs are in operation ranging in size from 50,000 ACFM to 650,000 ACFM. The most recent installation consists of two-membrane modules in series collecting H_2SO_4 acid mist in a Non-Ferrous Metals Plant. (Figure 12) The design parameters are:

Gas Volume 50,000 ACFM
Gas Temp 1000 F Saturated
H_2SO_4 inlet loading 180 PPMV
H_2SO_4 outlet loading 8 PPMV
(from 2nd stage)
Irrigating Liquid 10% H_2SO_4 solution

Material of Construction

Casing	FRP
Membrane	Polypropylene
Discharge Electrode	C276 Hastalloy

Figure 12: Two-Stage Membrane WESP Modules at Climax Acid Plant

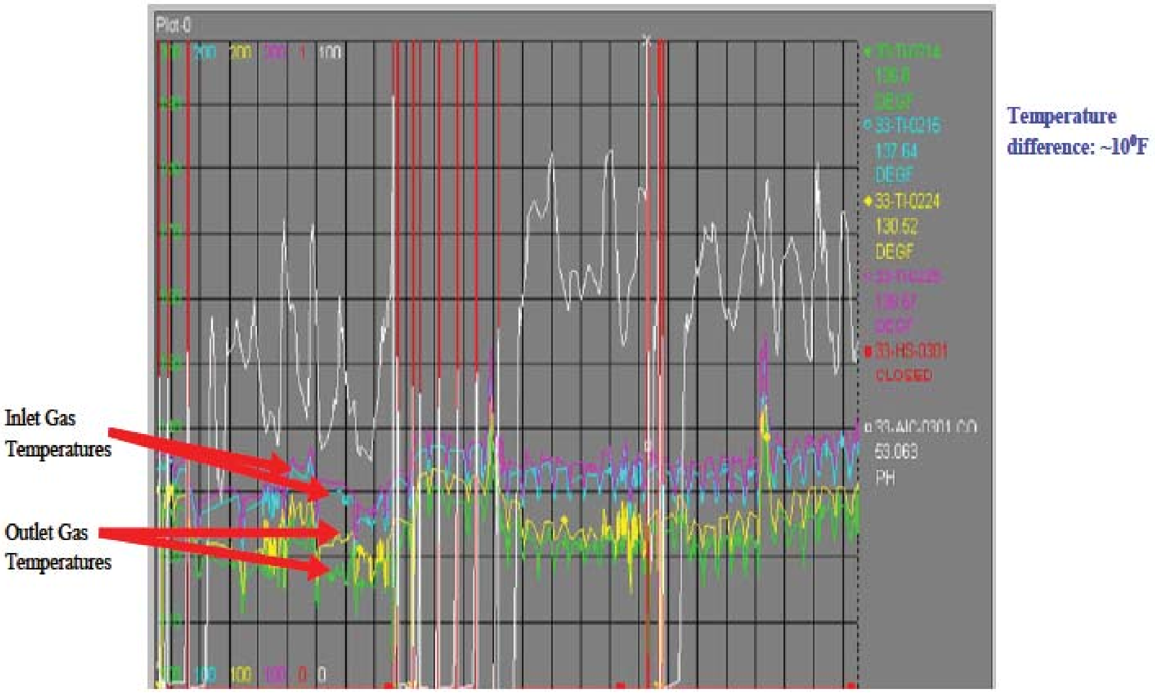


Figure 13: 24-hour PI chart of two-module membrane WESP at SSCC, Stevenson, AL

Advantages of Condensing Membrane WESP Operation

- **The membrane Wet ESP can operate in a condensing Wet ESP mode** - By creating a temperature difference of 300 - 400 deg. F between the saturated gas stream and the cooled membrane irrigation water, the unit can easily reduce the saturated gas temperature by 50 to 100 deg. F. This reduction in saturated gas temperature will condense water droplets out of gas stream. As seen in Figure 13, this has been demonstrated for the last five years in the commercial unit at Stevenson, Alabama

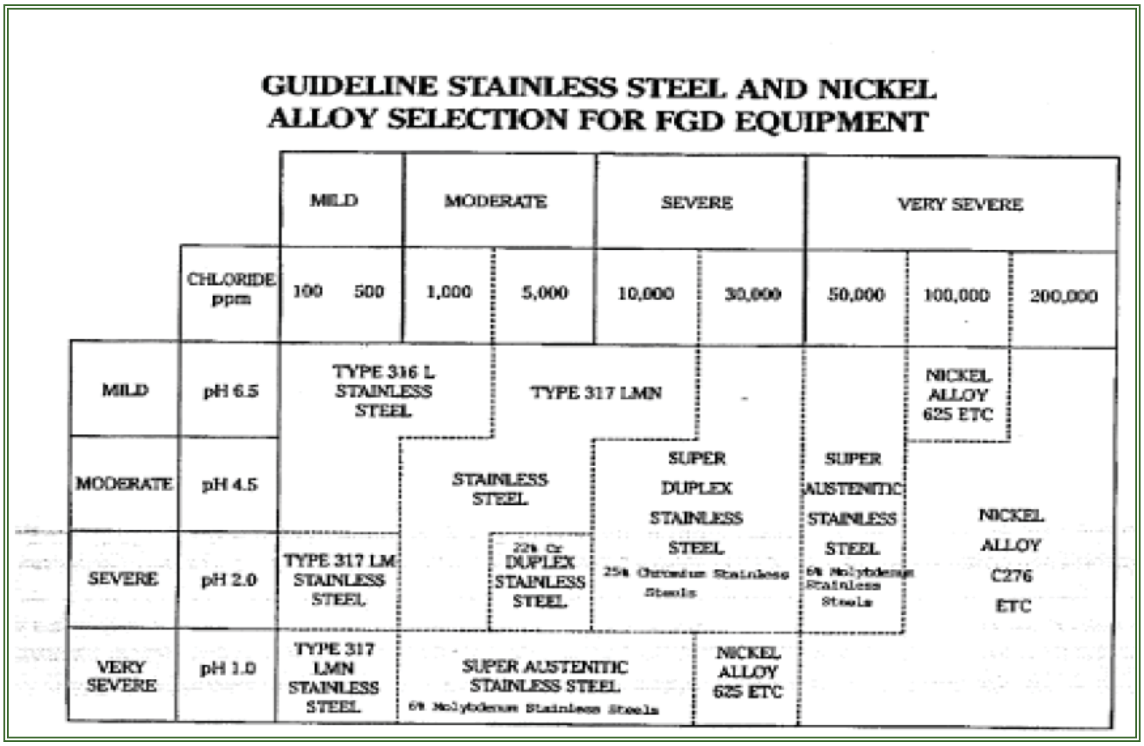
- **Benefits of reducing saturated gas temperature of gas stream**

☐ **Particulate collection efficiency is enhanced** – Like raindrops, the condensing water droplets form around the dust particle and H_2SO_4 mist nuclei making them larger, therefore easier to collect.

- **Supports lower cost materials of construction** – A "raining" precipitator allows lower cost materials of construction for the casing. A 1991 patent (No. 5,039,318) by Harry Johansson, describes how a "...condensing Wet Precip... cools the inner surfaces of the (metal) collector electrodes. This condensation of water from the gas stream essentially dilutes any acid build-up and effectively results in a lower concentration of corrosive substances in the condensate. This enables the collector electrodes to be made of steel which has relatively low alloy content." Since the Membrane Wet ESP lowers the saturated gas temperature and condenses water out of the gas stream, this "washing/dilution" phenomenon occurs "naturally." In the absence of chlorides, this can significantly reduce the rate of corrosion. We have seen for example at the Unit in Stevenson (shown in figure-4), handling ~ 20 PPM H_2SO_4 mist, that after 5 years of continuous operation, there is no detectable corrosion on the 316L SS metal casing.

- **No make-up water necessary** – A WESP system generally requires blow-down to get rid of suspended solids, and minimize any potential build-up of solids within the system. The blowdown requires an addition of make-up to maintain the system water balance. If make-up water comes from the plant, then it brings with it the down side of possibly adding chlorides to the system, which would then require costly alloys for construction of the WESP. The unique operation of the Membrane Wet ESP has demonstrated that by maintaining a temperature difference of 30-40 deg.F between the saturated gas stream and the irrigation water, the saturated gas stream can be cooled. Therefore, sufficient make-up water can easily be condensed out of the saturated gas stream to operate the WESP.

In a full size utility unit this could have quite a beneficial effect. By eliminating the need for plant make-up water; the only chlorides would be those coming over from the scrubber, which are estimated to be no more than 1 to 4 PPM, by saturated gas volume. This means that by reducing the saturated gas temperature by only 50 deg.F, the recycle loop could be operated with no more than 100 PPM chlorides. As seen in Figure 14, this suggests that for chlorides less than 100 PPM, 316 L SS can confidently be used as the material for casing fabrication. The membrane irrigation liquid pH will be around 6-7. The savings, compared to say 317 LMN stainless steel alloy for an 800 MW unit, could exceed $2,000,000.



GUIDELINE STAINLESS STEEL AND NICKEL ALLOY SELECTION FOR FGD EQUIPMENT

		MILD		MODERATE		SEVERE		VERY SEVERE		
	CHLORIDE ppm	100	500	1,000	5,000	10,000	30,000	50,000	100,000	200,000
MILD	pH 6.5	TYPE 316 L STAINLESS STEEL			TYPE 317 LMN		-		NICKEL ALLOY 625 ETC	
MODERATE	pH 4.5				STAINLESS STEEL	SUPER DUPLEX STAINLESS STEEL 25% Chromium Stainless Steels		SUPER AUSTENITIC STAINLESS STEEL 6% Molybdenum Stainless Steels	NICKEL ALLOY C276 ETC	
SEVERE	pH 2.0	TYPE 317 LM STAINLESS STEEL			22% Cr DUPLEX STAINLESS STEEL					
VERY SEVERE	pH 1.0	TYPE 317 LMN STAINLESS STEEL		SUPER AUSTENITIC STAINLESS STEEL 6% Molybdenum Stainless Steels			NICKEL ALLOY 625 ETC			

Source: "Selection of alloys for air pollution control equipment" by William L. Mathay
Figure 14: Guidelines for selection of Material in a corrosive environment
(316L SS is adequate for system that has <500 ppm chlorides and >4.5pH)

Lower Gas Temperature ahead of a CO_2 Absorption System

Most CO_2 absorption systems benefit by having a lower inlet gas temperature. As shown above the Membrane WESP design can easily/cheaply achieve a 5-10 deg.F reduction in gas temperature. This might be considered as a "fringe benefit" of the Membrane design.

Potential Applications of membrane WESP

The main applications envisioned for the membrane WESP are to collect fine particulate and acid aerosols, after scrubbers:

- After WFGD scrubbers in the utility industry.
- After upstream particulate scrubbers in industrial applications.

Conclusions and Recommendations

The operational advantages and cost savings outlined above truly change the perception of wet electrostatic precipitators to the point where they can be considered a cost effective emissions control device for $PM_{2.5}$, SO_3 & Hg^{+2} .

Continuing tests will help refine the capability and lower cost of this improvement in WESP technology.

For further information go to
www.sei-group.com

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In Memory of John Caine

B.S. Chemistry – Auburn University
1963–1965 - US Army 1st Lt.
1965–1972 - Shell Chemical Company
Industrial Sales
1972-1988 – Wheelabrator APC Div. Sales Engineer,
Regional Sales Manager,
Product Mgr (FF & Dry FGD)
1988-1991 - Regenerative Environmental Equipment Co.
Sales Manager
1991-1993 - Procedair/Air Science Technologies
Product Director
1993-1996 – Fuller-Kovako Corp.
Marketing Manager APC.
1996-2010 – Southern Environmental, Inc.
General Manager, General Sales Manager

John Caine passed away on Sunday, September 19, 2010. It was while pursuing his love of the outdoors at his farm in Stafford, AL that an untimely accident occurred. He will be missed very much by his family, friends and an industry that he passionately supported for over 45 years.

Contributions in his memory may be made to:

- VFW (Veteran of Foreign Wars of United States)
  National Headquarters, 406 W. 34th Street
  Kansas MO 64111

- Paralyzed Veterans of the America
  801 18th Street NW, Washington DC 20006-3517

- Defenders of Wildlife
  1130 17th Street NW, Washington DC 20036

- Population Connection
  2120 L Street, NW Suite 500, Washington DC 20037

All cards should be sent to SEI

Removing NOx on the High Seas

By Joseph McCarney, Johnson Matthey

Noxious gases thrown into the atmosphere by cruise liners are highly reactive and risk the disruption and destruction of sensitive marine environments. As the industry seeks to curb its emissions, the following article explains how selective catalytic reduction can help.

Despite a greater focus on environmental concerns, shipping remains a very polluting industry in terms of the exhaust emissions it pumps into the atmosphere. Marine exhaust gases contain high levels of NOx, SOx, particulate matter, carbon monoxide and unburned fuel. However, looming regulations and a greater interest in clean transportation are persuading ship owners, shipyards and operators that it is time to take action.

The first pollutant on the hit list is NOx, generated in the heat of a ship's engine. These acidic gases are highly reactive, hazardous to human health and contribute to environmental damage.

Reducing NOx

Shipping is responsible for about 30% of global emissions of NOx and, in an attempt to reduce the industry's impact, recently approved updates to Marpol Annex VI will require dramatic reductions in emissions. Ships built after 1 January 2016 and operating in emission control areas (ECA) will have to reduce NOx output by 80%.

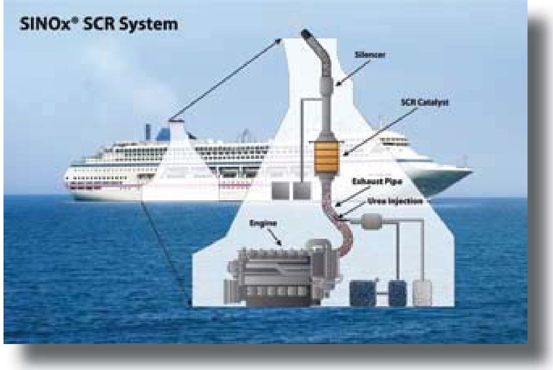


Figure 15: Using an SCR system a ship can run at optimum power while neutralizing NOx in the tailpipe by up to 90%.

Two ECAs exist in the Baltic and North Seas. The growth in the number and extent of ECAs, such as those of the US and Canadian coastline extending 200 nautical miles out to sea, will require major changes in the shipping industry and the way it deals with its exhaust emissions. The reduction can be accomplished by altering conditions in the engine so that less NOx is created during combustion or by selectively neutralizing NOx in the exhaust using a catalytic converter. Joseph McCarney, business development manager for stationary and marine emission control at catalyst developer Johnson Matthey, explains that while both methods have a role to play there are limitations to what can be achieved using the former method.

"When you modify the internal workings of an engine you risk introducing inefficiencies to the combustion process and that leads to more fuel being burned and more CO_2 emitted," he says. "When you consider the total cost of owning and running a cruise vessel the most significant cost is that of the fuel, so fuel efficiency is of critical concern."

Using selective catalytic reduction (SCR) the engine can still run under optimum, fuel-efficient conditions with up to 90% NOx being neutralized in the tailpipe. The process works by injecting urea into the hot exhaust gas, which then breaks down into ammonia and, as it passes over the catalyst, combines with nitrogen oxides to create nitrogen and water. Shipyards often take the decision to install SCR, but McCarney has seen greater interest from owners in the application of the technology.

"That's a reflection of the fact that it will be standard in the next five years and they want to learn more about it," he says. "Owners and operators want to understand how it works."

Growing industry support

Building on its experience in the automotive and stationary engine markets, Johnson Matthey has 160 SCR systems running in marine applications. McCarney estimates that there are 500 ships fitted with similar devices, but that this number will increase dramatically as the new regulations come into force.

"It's a small number of vessels, mostly driven by local needs, he says. "But as we approach 2014-15 more ships will have emission control installed and, by 2016, any vessel that operates in an ECA will likely be using after treatment such as SCR."

While SCR technology is proven in the marine environment, McCarney acknowledges that there is potential for significant improvements in terms of effectiveness and cost. This plays to one of Johnson Matthey's key strengths – its innovative R&D effort where scientists and engineers constantly innovate to respond to industry and customer needs.

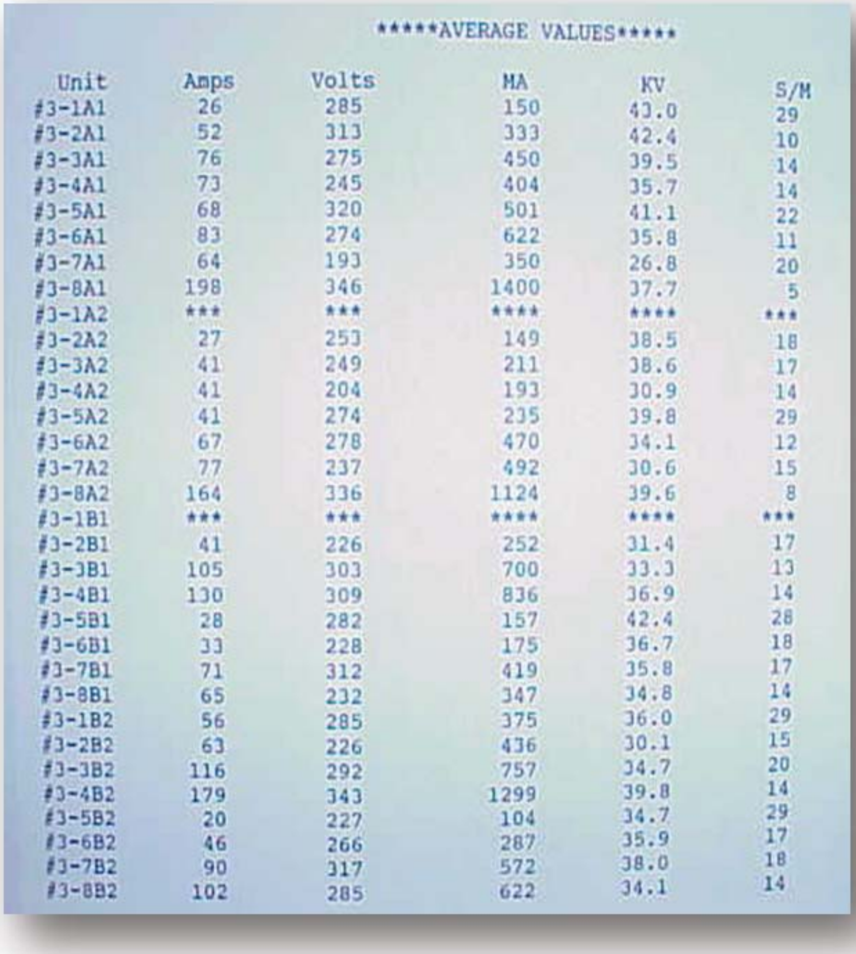
The company sees the potential for other after-treatment technology. Oxidization catalysts and filters – similar to those used in cars – can be developed for ships, reducing emissions of carbon monoxide, unburned fuel and carbon particulates. The presence of SOx in the exhaust makes this technically difficult but, with the IMO looking at restrictions on sulfur, operators could begin to use low-sulfur fuel in the coming decade.

There is the will in the industry to protect the environment, and IMO expectations and requirements are high. Tighter regulation presents new challenges for shipyards, owners and operators. Collaboration with technology providers such as Johnson Matthey offers a cost-effective way of removing harmful gases from exhaust emissions – helping the world to 'breathe easy'.

Further information contact
Wilson Chu at wilson.chu@jmusa.com
Johnson Matthey www.matthey.com

How to Grade Your ESP

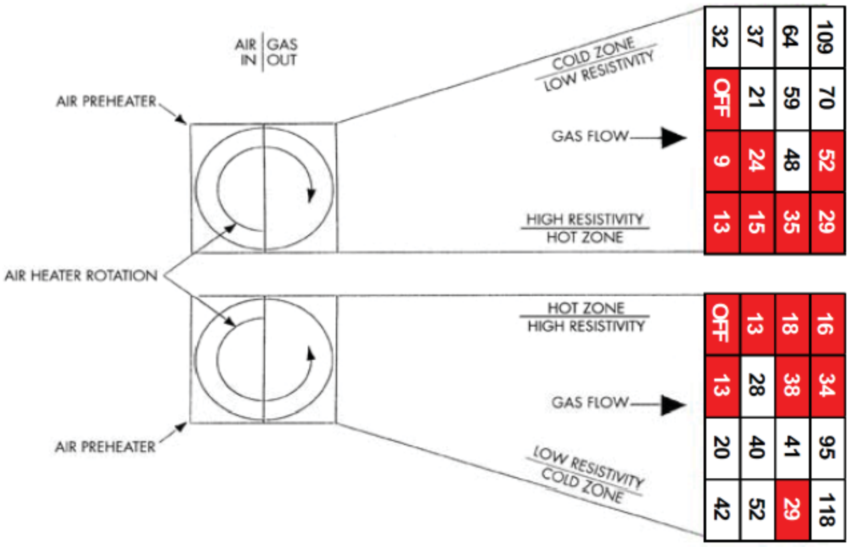
By John Knapik, Application Engineer, B&W Power Generation Group



```
                        *****AVERAGE VALUES*****

  Unit      Amps     Volts        MA        KV       S/M
#3-1A1       26       285        150      43.0        29
#3-2A1       52       313        333      42.4        10
#3-3A1       76       275        450      39.5        14
#3-4A1       73       245        404      35.7        14
#3-5A1       68       320        501      41.1        22
#3-6A1       83       274        622      35.8        11
#3-7A1       64       193        350      26.8        20
#3-8A1      198       346       1400      37.7         5
#3-1A2      ***       ***       ****      ****       ***
#3-2A2       27       253        149      38.5        18
#3-3A2       41       249        211      38.6        17
#3-4A2       41       204        193      30.9        14
#3-5A2       41       274        235      39.8        29
#3-6A2       67       278        470      34.1        12
#3-7A2       77       237        492      30.6        15
#3-8A2      164       336       1124      39.6         8
#3-1B1      ***       ***       ****      ****       ***
#3-2B1       41       226        252      31.4        17
#3-3B1      105       303        700      33.3        13
#3-4B1      130       309        836      36.9        14
#3-5B1       28       282        157      42.4        28
#3-6B1       33       228        175      36.7        18
#3-7B1       71       312        419      35.8        17
#3-8B1       65       232        347      34.8        14
#3-1B2       56       285        375      36.0        29
#3-2B2       63       226        436      30.1        15
#3-3B2      116       292        757      34.7        20
#3-4B2      179       343       1299      39.8        14
#3-5B2       20       227        104      34.7        29
#3-6B2       46       266        287      35.9        17
#3-7B2       90       317        572      38.0        18
#3-8B2      102       285        622      34.1        14
```

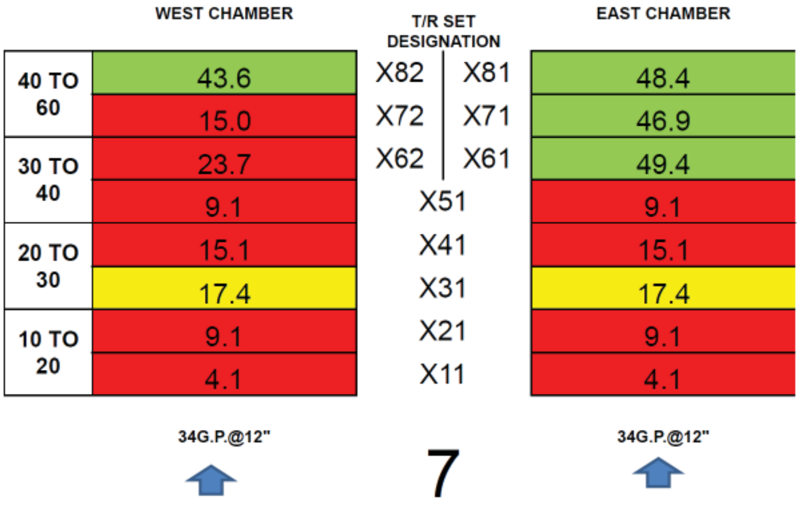
If you were handed this list of AVC readings, does this ESP have a problem?



How about when you look at that same ESP and each control this way?

AVC	AMPS	VOLTS	mA	KV1	KV2	SPM
711	38	292	134	64.2	52.0	64
721	59	327	296	51.1	40.8	29
731	122	340	569	45.9	50.3	59
741	99	324	494	45.0	37.0	2
751	52	241	296	36.3	32.2	55
761	129	404	806	53.0	X	0
762	79	330	387	43.7	X	30
771	125	393	766	50.8	X	0
772	56	262	245	29.1	X	37
781	134	376	790	44.1	X	0
782	128	353	711	45.6	X	0

What about this ESP?
Does this one have a problem?



	WEST CHAMBER	T/R SET DESIGNATION		EAST CHAMBER
40 TO 60	🟩 43.6	X82	X81	🟩 48.4
	🟥 15.0	X72	X71	🟩 46.9
30 TO 40	🟥 23.7	X62	X61	🟩 49.4
	🟥 9.1	X51		🟥 9.1
20 TO 30	🟥 15.1	X41		🟥 15.1
	🟨 17.4	X31		🟨 17.4
10 TO 20	🟥 9.1	X21		🟥 9.1
	🟥 4.1	X11		🟥 4.1

How about when you look at it this way?

This leads us to….How to grade each section of your precipitator and get a better overview!

Very Good	🟩
Marginal	🟨
Poor	🟥

Here is a four step by step procedure.
Apply the above rating system after applying each step.

Step 1:

If a T/R set is not sparking, then its AVC should be pushing that T/R set to one of its pre-set, **healthy** limits (volts, amps, KV, ma, or firing angle). What is meant by "Healthy Limts?" Primary or secondary current limit is not healthy when accompanied by a primary voltage level < 90 VAC or a secondary level < 12 KV. It usually indicates a short circuit. Secondary voltage limit is not healthy when there is very little secondary current. It usually indicates an open circuit. Neither condition is aiding in particle capture. (Remember: know the ratings of the T/R sets on the ESP being reviewed. Walk up to the roof of the ESP and look at the nameplate on the T/R set.)

The AVC has two jobs to execute (1) control the amount of sparking in the ESP and (2) in the absence of sparking, push the T/R set to its limit(s).

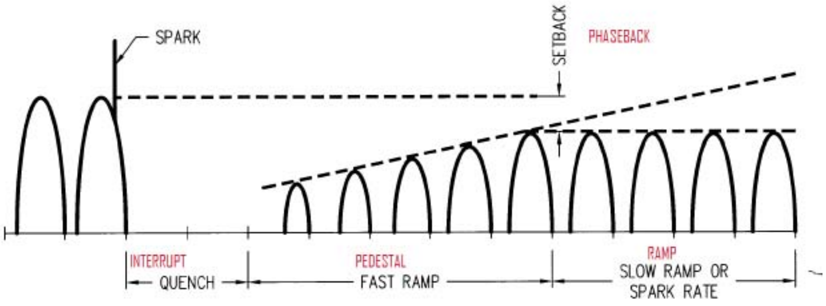


Figure 16 : AVC Spark response

Step 2:

Each succeeding field of a precipitator should have the same or higher precipitator current (mA), or better put, current density then the preceding field.

Figure 17: AVC spark Limited – doing its job. The actual T-R set rating is shown on top and the actual ESP operating values are in the green.

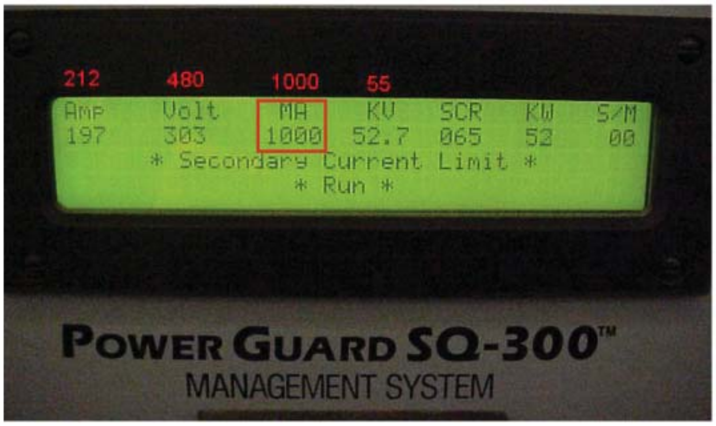


Figure 18: T/R current limits without sparking. The actual T-R rating is in red above the display. The actual ESP operating values is in the green display.

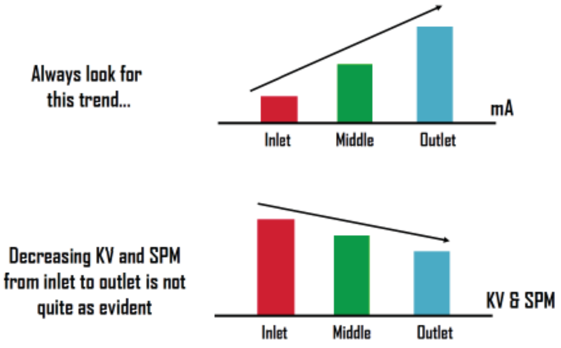


Figure 19: Space charge effects on meters

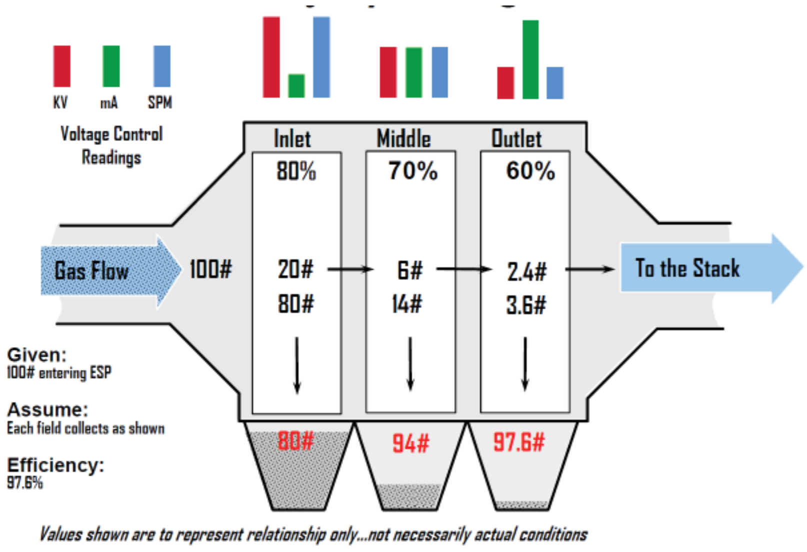


Figure 20: Incremental collection efficiency and secondary operating conditions.

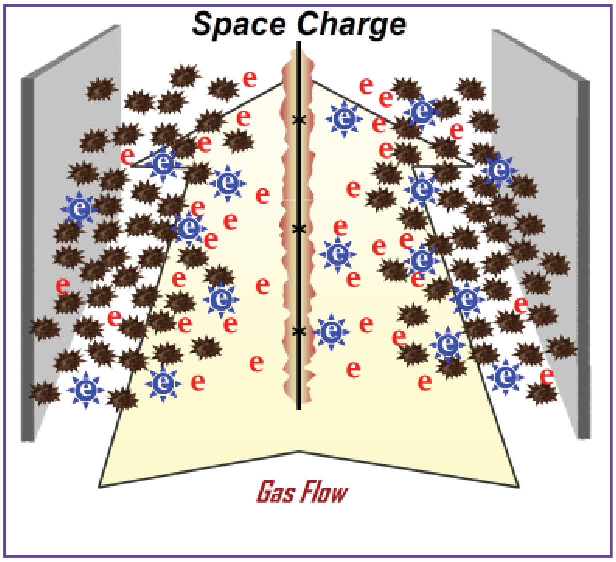


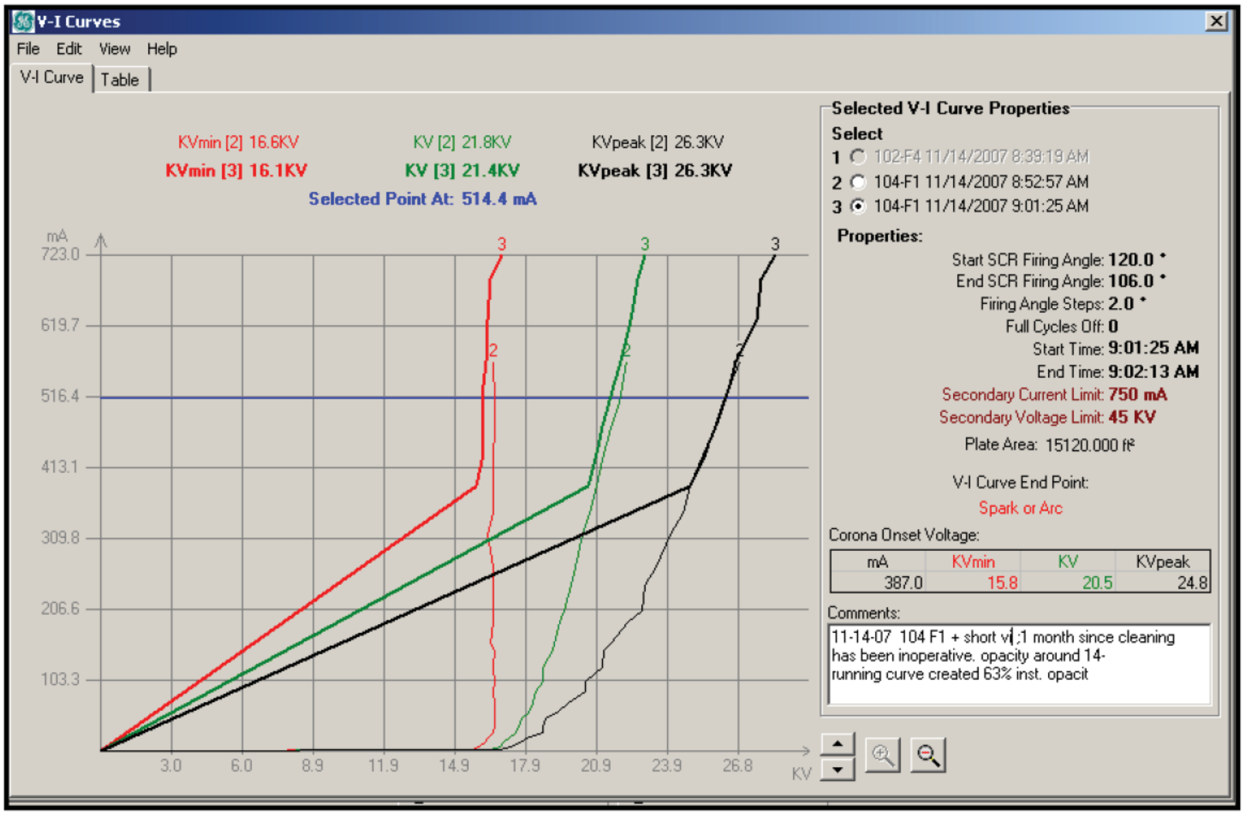
Figure 21 : Space charge / gas flow
The current carriers are (1) free electrons (2) negative gas ions and (3) charged dust particles

Step 3:

If the dust is not highly resistive, then outlet fields usually run at full current and little or no sparking. It would not hurt to run a couple of quick V-I curves. These are quick tests for resistivity. A full curve may be prohibitive because of opacity spiking caused by backing a set down to corona onset. Be careful!! In the diagram below curve 2 is the full VI curve; Curve 3 is a “Quick-Curve”**.**

Step 4:

Current densities are the best tool to check for dust resistivity and to **GRADE** successive fields’ ESP current (mA) values.



KVmin [2] 16.6KV KV [2] 21.8KV KVpeak [2] 26.3KV

KVmin [3] 16.1KV KV [3] 21.4KV KVpeak [3] 26.3KV

Selected Point At: 514.4 mA

Selected V-I Curve Properties

Select

1 ○ 102-F4 11/14/2007 8:39:19 AM
2 ○ 104-F1 11/14/2007 8:52:57 AM
3 ● 104-F1 11/14/2007 9:01:25 AM

Properties:

Start SCR Firing Angle: **120.0 °**
End SCR Firing Angle: **106.0 °**
Firing Angle Steps: **2.0 °**
Full Cycles Off: **0**
Start Time: **9:01:25 AM**
End Time: **9:02:13 AM**
Secondary Current Limit: **750 mA**
Secondary Voltage Limit: **45 KV**
Plate Area: 15120.000 ft²

V-I Curve End Point:
Spark or Arc

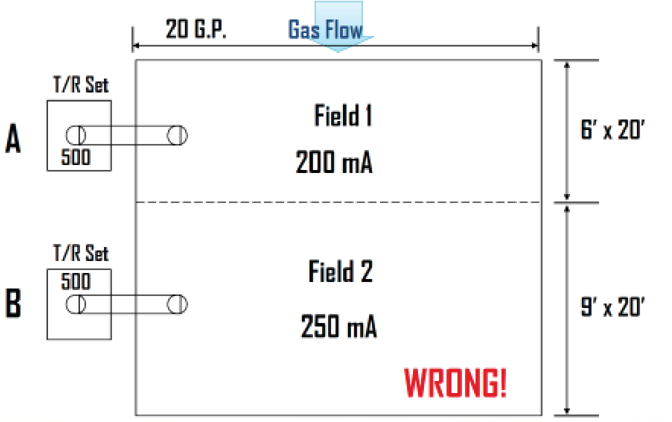
Corona Onset Voltage:

mA	KVmin	KV	KVpeak
387.0	15.8	20.5	24.8

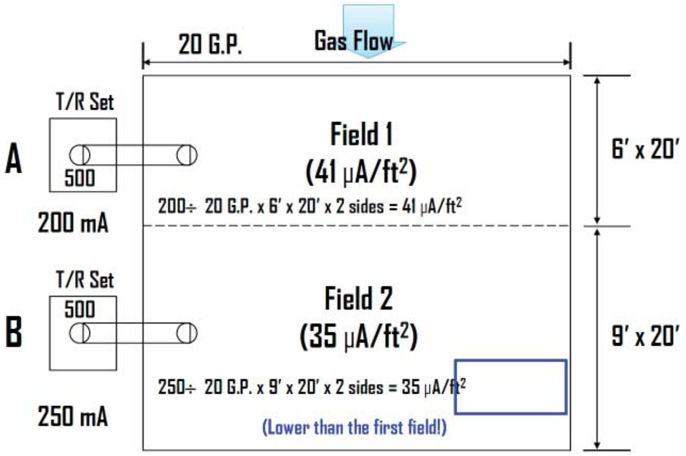
Comments:

11-14-07 104 F1 + short vi ;1 month since cleaning
has been inoperative. opacity around 14-
running curve created 63% inst. opacit

Based on what we have learned in Step 2, the ESP depicted in the reading below is OK. However that would be ……WRONG!!



The current density readings shows a different story…..



The current density enables a true comparison of ESP current for T/R sets not energizing the same square feet of collecting plates. Generally accepted values for low and high resistivity dust can aid in troubleshooting.

Current Densities

(for conductive dust)

In general, typical range of values for current density for a four field European ESP where T-R sets may not be sized to provide more than 40μA/ft²

Field Number	Current Density (μA/ft²)
1	10-20
2	20-30
3	30-40
4	30-40

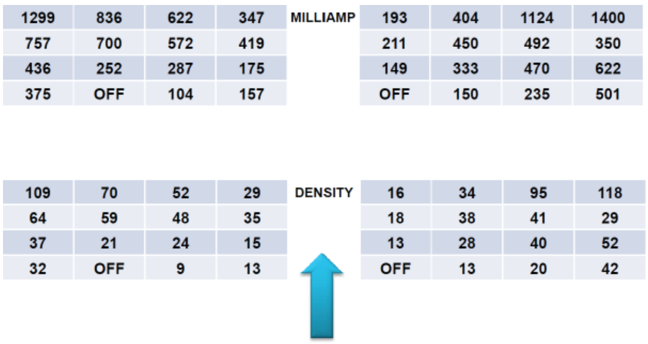
Current Densities

(for very conductive dust)

In general, typical range of values for current density for a four field American ESP.

Field Number	Current Density (μA/ft²)
1	10-20
2	20-30
3	30-50
4	50-70

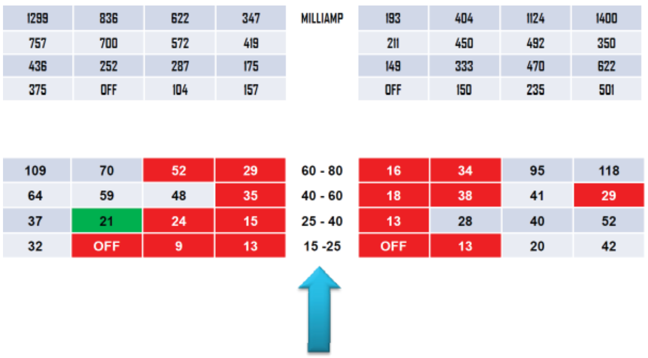
Converting to Densities We Get:



1299	836	622	347	MILLIAMP	193	404	1124	1400
757	700	572	419		211	450	492	350
436	252	287	175		149	333	470	622
375	OFF	104	157		OFF	150	235	501

109	70	52	29	DENSITY	16	34	95	118
64	59	48	35		18	38	41	29
37	21	24	15		13	28	40	52
32	OFF	9	13		OFF	13	20	42

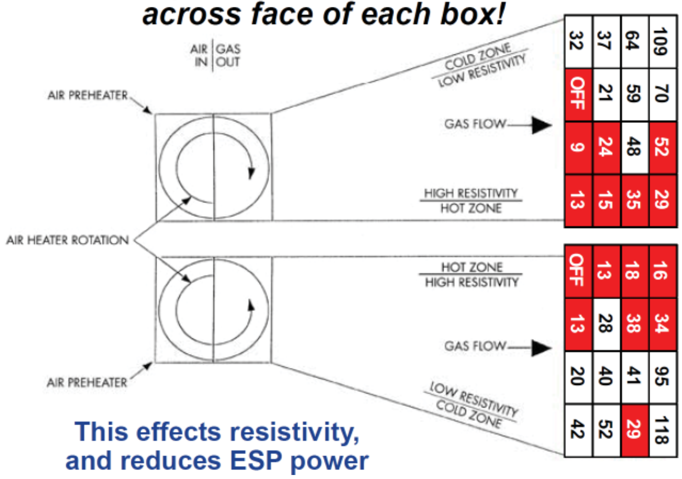
Evaluating Densities WE Get:



1299	836	622	347	MILLIAMP	193	404	1124	1400
757	700	572	419		211	450	492	350
436	252	287	175		149	333	470	622
375	OFF	104	157		OFF	150	235	501

109	70	52	29	60 - 80	16	34	95	118
64	59	48	35	40 - 60	18	38	41	29
37	21	24	15	25 - 40	13	28	40	52
32	OFF	9	13	15 -25	OFF	13	20	42

Air-Preheaters produce 60⁰ temperature difference across face of each box!



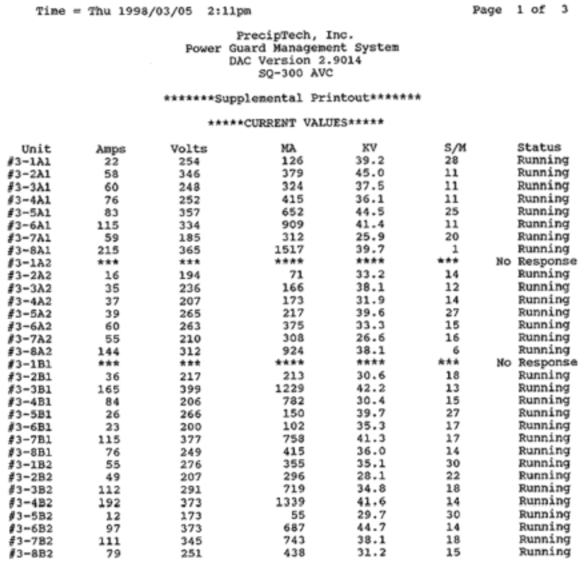
This effects resistivity, and reduces ESP power

There appears to be a pattern here. Why?

	WEST CHAMBER	T/R SET DESIGNATION		EAST CHAMBER
40 TO 60	🟩 43.6	X82	X81	🟩 48.4
	🟥 15.0	X72	X71	🟩 46.9
30 TO 40	🟥 23.7	X62	X61	🟩 49.4
	🟥 9.1	X51		🟥 9.1
20 TO 30	🟥 15.1	X41		🟥 15.1
	🟨 17.4	X31		🟨 17.4
10 TO 20	🟥 9.1	X21		🟥 9.1
	🟥 4.1	X11		🟥 4.1

34G.P.@12" 7 34G.P.@12"

What grade would you give this box?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   Time = Thu 1998/03/05  2:11pm                                    Page  1 of  3

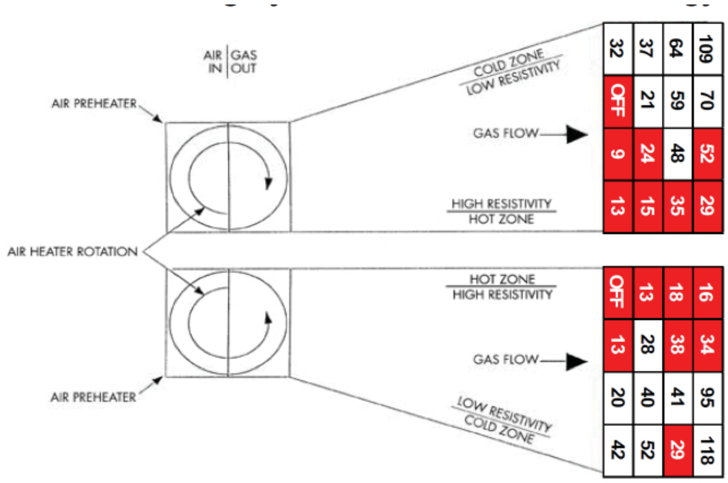
                                  PrecipTech, Inc.
                           Power Guard Management System
                                DAC Version 2.9014
                                    SQ-300 AVC

                          *******Supplemental Printout*******

                              *****CURRENT VALUES*****

   Unit        Amps       Volts          MA         KV          S/M        Status
 #3-1A1         22         254          126        39.2          28        Running
 #3-2A1         58         346          379        45.0          11        Running
 #3-3A1         60         248          324        37.5          11        Running
 #3-4A1         76         252          415        36.1          11        Running
 #3-5A1         83         357          652        44.5          25        Running
 #3-6A1        115         334          909        41.4          11        Running
 #3-7A1         59         185          312        25.9          20        Running
 #3-8A1        215         365         1517        39.7           1        Running
 #3-1A2        ***         ***         ****        ****         ***     No Response
 #3-2A2         16         194           71        33.2          14        Running
 #3-3A2         35         236          166        38.1          12        Running
 #3-4A2         37         207          173        31.9          14        Running
 #3-5A2         39         265          217        39.6          27        Running
 #3-6A2         60         263          375        33.3          15        Running
 #3-7A2         55         210          308        26.6          16        Running
 #3-8A2        144         312          924        38.1           6        Running
 #3-1B1        ***         ***         ****        ****         ***     No Response
 #3-2B1         36         217          213        30.6          18        Running
 #3-3B1        165         399         1229        42.2          13        Running
 #3-4B1         84         206          782        30.4          15        Running
 #3-5B1         26         266          150        39.7          27        Running
 #3-6B1         23         200          102        35.3          17        Running
 #3-7B1        115         377          758        41.3          17        Running
 #3-8B1         76         249          415        36.0          14        Running
 #3-1B2         55         276          355        35.1          30        Running
 #3-2B2         49         207          296        28.1          22        Running
 #3-3B2        112         291          719        34.8          18        Running
 #3-4B2        192         373         1339        41.6          14        Running
 #3-5B2         12         173           55        29.7          30        Running
 #3-6B2         97         373          687        44.7          14        Running
 #3-7B2        111         345          743        38.1          18        Running
 #3-8B2         79         251          438        31.2          15        Running
```

So with just numbers, we are somewhat clueless!



But with a grading system, we can plan a strategy.

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