Next Generation Wet Electrostatic Precipitators

Hardik G Shah, Applications (Mechanical) Engineer, Southern Environmental, Inc., 6690 West Nine Mile Road, Pensacola, FL 32526

John C Caine, General Sales Manager, Southern Environmental, Inc., 6690 West Nine Mile Road, Pensacola, FL 32526

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 1). 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.

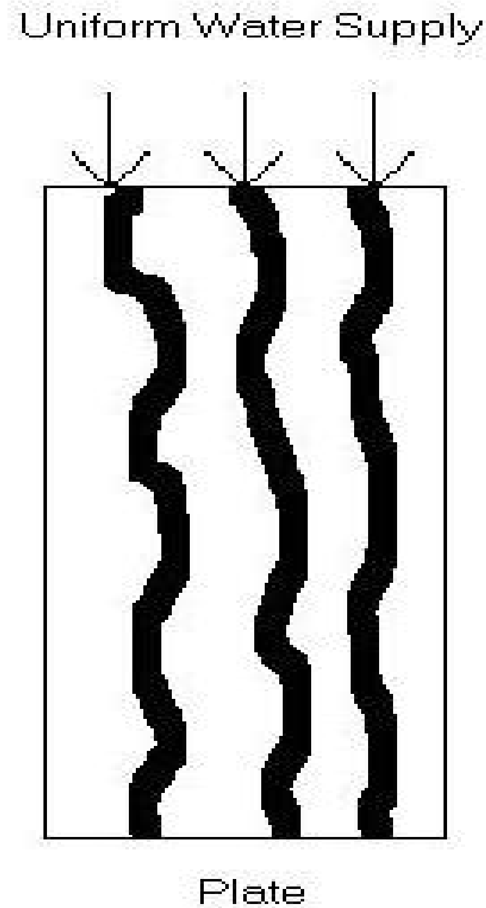


Figure 1: Water Flow in Conventional Metal Plate WESP

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 2). 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.

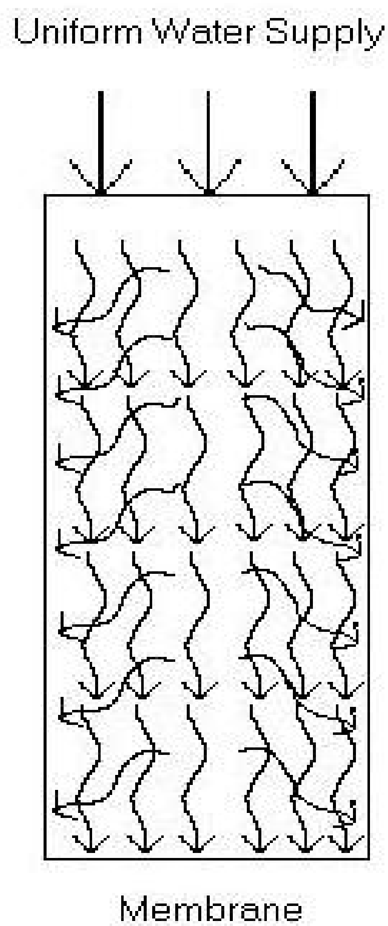


Figure 2: Water Flow in Membrane WESP

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. C*apillary 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.

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 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. ^oF	125^0 F	125^0F	125^0 F	125^0F
SCA	91	48	76	41
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

Table 1: Performance Comparisons of Bruce Mansfield Pilot

Mercury Removal

We also tested Hg removal with the Bruce Mansfield Pilot (results in Table 2 below). 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% each, 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} = 93%.

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.

Species	%	Scrubber Inlet (µg/ dsm^3)	WESP Inlet/Scrubber Outlet (µg/ dsm^3)	Scrubber Eff. % wt.	WESP Outlet (µg/ dsm^3)	WESP Eff. % wt.
Ash Hg	33	4.5	0.8	82%	0.2	72%
Hg+2	44	5.8	1.8	69%	0.5	72%
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) = 93%**						

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

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 3, 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.

Figure 3: Picture of Membrane Build-up Test

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 4, 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 the goal of this wet unit was to remove fine particulate and SO_3 mist after an existing sodium hydroxide scrubber.

Figure 4: Picture of SSCC Stevenson Membrane WESP

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
H_2SO_4 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 48,000 ACFM to 625,000 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 5) The design parameters are:

Gas Volume	48,000 ACFM
Gas Temp	100^0 F Saturated
H_2SO_4 inlet loading	180 PPMV
H_2SO_4 outlet loading (from 2nd stage)	8 PPMV
Irrigating Liquid	10% H_2SO_4 solution

MATERIALS OF CONSTRUCTION

Casing	FRP
Membrane	Polypropylene
Discharge Electrode	C276 Hastalloy

Figure 5: Two-Stage Membrane WESP Modules at Climax Acid Plant

ADVANTAGES OF CONDENSING MEMBRANE WESP OPERATION

- **<u>The membrane Wet ESP can operate in a condensing Wet ESP mode</u>** - By creating a temperature difference of 30^0 - 40^0 F between the saturated gas stream and the cooled membrane irrigation water, the unit can easily reduce the saturated gas temperature by 5^0 to 10^0 F. This reduction in saturated gas temperature will condense water droplets out of gas stream. As seen in figure 6, this has been demonstrated for the last five years in the commercial unit at Stevenson, Alabama.

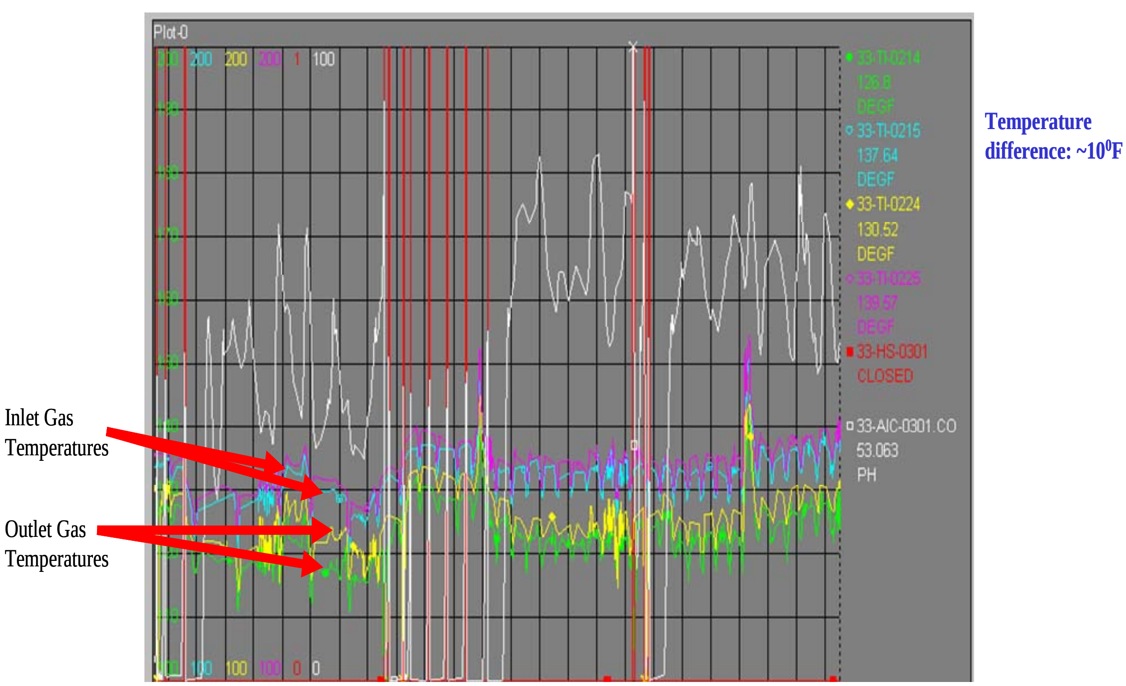
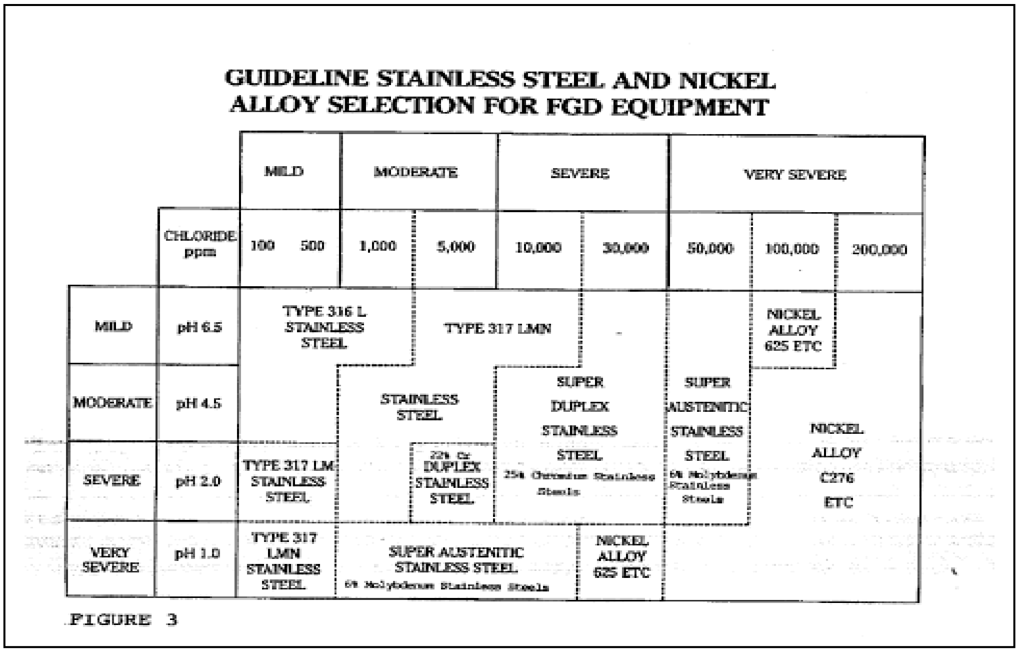


Figure 6: 24-hour PI chart of two-module membrane WESP at SSCC, Stevenson, AL

- ## 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 blow-down 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^{0}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 5^0 F, the recycle loop could be operated with no more than 100 PPM chlorides. As seen in Figure 7, 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.



Source: "Selection of alloys for air pollution control equipment" by William L. Mathay

Figure 7: 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 TEMPEATURE 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 5-10^0 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.

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