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Advances in Hot Side SO₃ Mitigation Technology

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ABSTRACT

Historically sorbent based mitigation of SO₃ has been implemented in association with the plant's electrostatic precipitator, either hot side or cold side. As the positive benefits of reduced SO₃ on SCR performance, air heater performance and downstream duct corrosion are recognized, more plants are evaluating sorbent injection at the SCR outlet or the economizer outlet. Of additional interest is the optimized process evaluation where plant operating conditions are combined into a predictive algorithm that controls the sorbent injection rate in closed loop with bias adjustment provided from the Breen condensable measurement system. The result is immediate understanding of true sorbent performance and sorbent process cost. This presentation will report on results from several sorbent based projects implemented at these hot side locations. Sorbents used include magnesium, calcium and sodium compounds.

INTRODUCTION

Much has been written and presented about the negative effects of sulfuric acid and ammonium bisulfate vapor in the flue gas stream from the economizer outlet to its eventual gas discharge from the stack. As the installed base of Selective Catalytic Reactors (SCR) and Wet Scrubbers (FGD) increases, and as plants subsequently move to higher sulfur coal for economic value, these problems have become increasingly evident.

As of this writing 134 electric generating units are equipped with both SCRs and some form of wet FGD. Of those 134 units, 55 are equipped with some form of acid mist mitigation system. Those systems include:

- Magnesium Oxide and Hydroxide injection in the furnace,
- Wet or dry Sodium injection (generally Trona or Sodium Carbonate)
- Hydrated Lime injection
- Ammonia Injection ahead of the cold side ESP

Of those 55 systems, only 6 of the non-magnesium systems are placed ahead of the air heater (this reference includes any area ahead of the Air Heater, including ahead of the SCR). With the exception of the 2 most recent installs, all are located in close coordination with the ESP.

During 2009 and the first half of 2010, several extended demonstration programs were executed to explore the benefits and issues associated with injection of a mitigating sorbent ahead of the air heater. These tests included both sodium and calcium based sorbents and injection locations ahead of and behind the SCR.

The data presented here is meant to briefly recap the 2009 programs and cover in more depth two programs executed in early 2010. Both of these programs employed hydrated lime injection at a location between the SCR and the Air heater.

Lastly, all of the data presented here comes from the Breen condensables monitoring process. For background purposes a brief description of that process is included.

ON-LINE SO₃ CONDENSABLES MEASUREMENT

The AbSensor - Condensables measurement device uses a kinetic algorithm to detect condensables related temperatures. These temperatures are labeled as Formation Temperature and Evaporation Temperature as seen in the figure below.

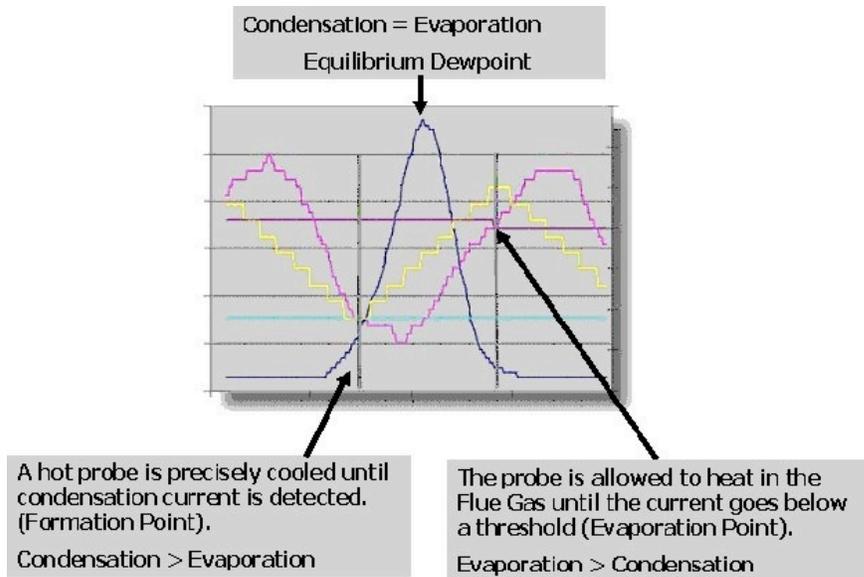


Figure 1 - Condensables Instrument Process Cycle

The Breen Energy AbSensor - Condensables measurement device consists of a highly polished glass surface with electrodes embedded therein. The kinetic algorithm then

varies the cooling flow rate to the back of this glass tip to change the temperature of the glass surface which sits in the flue gas. At the beginning of a measurement cycle the tip temperature is high enough to not cause any material to condense. The tip temperature is then varied at a controlled rate creating a temperature dynamic similar to the metal plates in the Air Heater. When the temperature of the tip is sufficiently low, material begins to condense on the tip and a current is recorded by the device. This temperature is noted as the **Formation Temperature**. The cooling air to the tip is then reduced in a controlled fashion and the tip temperature begins to rise.

As long as the tip temperature is below the equilibrium dewpoint, more material continues to condense on the tip thereby increasing the current as measured by the device. As the tip temperature crosses the equilibrium dewpoint, the material starts to vaporize faster than it condenses and the total material on the tip begins to go down. This results in the current going down until it goes to 0. The temperature at which the current goes back to 0 is noted as the **Evaporation Temperature**.

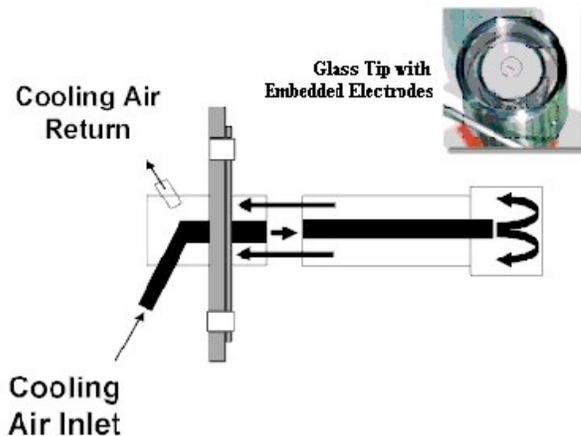


Figure 2 - Condensables Instrument Graphic Representation

PAST PLANT OPERATING DATA

The following data summarizes four demonstrations conducted during 2009. Two use hydrated lime as the sorbent and two use sodium compounds. Both of the sodium based demonstrations were conducted with reagent application ahead of the SCR. One of the lime demonstrations is ahead of the SCR and one is between the SCR and the AH.

Hydrated Lime Injection – Pre SCR



Figure 3 - Results of Pre-SCR Hydrated Lime Injection

This test, run later in 2009 shows the instrument feedback to introduction of hydrated lime at a location ahead of the SCR. For reference purposes the load was essentially constant during the reporting period.

As can be seen, the initial SO₃ level as measured at the AH Inlet was roughly 24 ppm (uncorrected for gas temperature). Introduction of the lime at the SCR inlet resulted in a drop of measured SO₃ to a level below 8 ppm. The spike in SO₃ at roughly 19:00 is the result of an intentional stoppage of lime flow to see the system response.

The lessons to be learned from this demonstration are:

1. Hydrated Lime is effective in capturing SO₃ even at temperature levels present at the economizer outlet,
2. The apparent level of reduction (75%) is net of the SO₃ created in the catalyst. This suggests that the actual level of reduction ahead of the AH may be even larger,

Dry Sodium Injection – Pre SCR

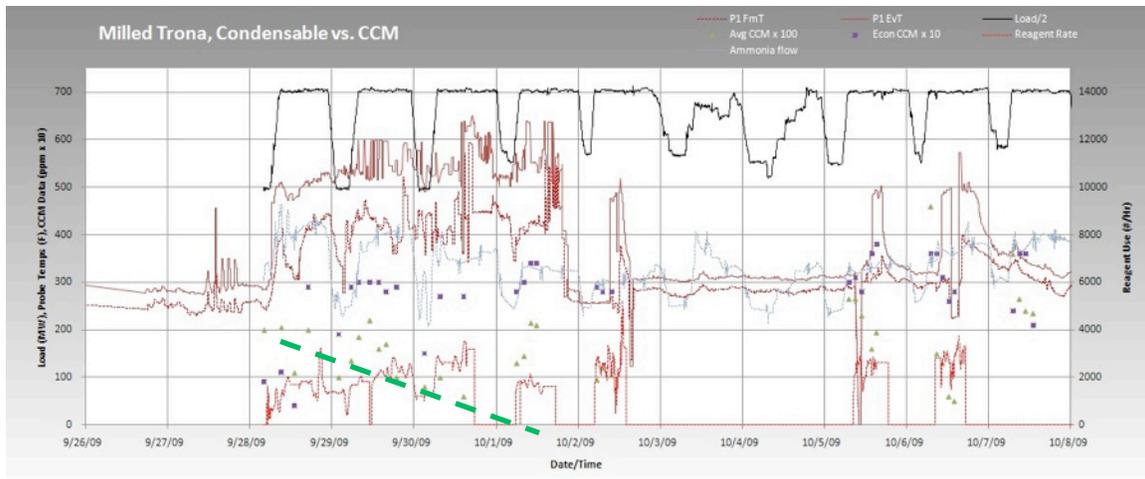


Figure 4 - Results of Pre-SCR Trona Injection

This last example demonstration was executed in the fall of 2009 with milled and unmilled trona being injected at a location ahead of the SCR. The formation and evaporation temperatures observed by the condensable measurement instrument are shown in darker red (upper part of the graph) with the relative level of trona injection shown in red at the bottom of the graph. Blue is the ammonia injection rate and the dashed green line is the trend line for a number of CCM readings taken during the testing.

The lessons to be learned from this demonstration are:

1. Increasing the level of trona fed, resulted in a clear reduction in the level of free condensable as measured by traditional wet chemistry methods,
2. Open loop injection of sodium material at this temperature can lead to formation of higher level condensables. The material evaporating at 600F on 9/29 is expected to be sodium bisulfate. The material evaporating closer to 500F may be some combined form of sodium ammonium bisulfate. No laboratory analyses were conducted in an attempt to isolate either material.
3. What is clear is that the level of condensable varied with both the level of sodium injection and the level of ammonia injection.

Balance of Plant Effects

Injection of sorbent ahead of the Air Heater provides three benefits to injection of the same material downstream of the air heater. These benefits are:

- Increased residence time of the sorbent in the flue gas stream.
- Improved mixing of the sorbent with the flue gas due to the turbulence created in the air heater, and

- Reduction in air heater fouling potential due to removal of some (or all) of the condensable matter prior to the air heater outlet.

What must be further considered, though, are the potential negative effects of the mitigation process on the Electrostatic Precipitator when it is located downstream of the Air Heater (the most common US configuration).

Side Effect 1 – Sodium Bisulfate Deposition: As can be seen from Figure 4 there may be a condensable component in the flue gas with formation temperatures above 350°F. This sodium bisulfate, or sodium ammonium bisulfate, condensable may be present when the molar ratio of the sodium is sub-stoichiometric when compared to the free SO₃ vapor. This condensable can cause air heater deposition issues and can additionally cause deposition on ESP perf plates and internal when the ESP gas temperatures exceed 350°F.

This suggests that when a sodium material is selected for injection ahead of the air heater, close attention must be paid to closed loop control of the feed rates to assure that the injection rate remains above the bisulfate formation point and that gas temperatures into the ESP remain comfortably below 350°F.

Side Effect 2 – SO₃ Stratification at the Air Heater Outlet: It is well known that Cold Side ESPs need a certain level of sulfuric acid vapor to condition the fly ash and lower the resistivity. Proper SO₃ management vs. SO₃ mitigation would utilize one of the dry reagents (generally hydrated lime for this application) to remove only the SO₃ levels that are over-conditioning the ash layer in the ESP or resulting in a visible plume at the stack. This requires both a solid understanding of the ash resistivity dynamics of the generating units as well as a solid, controllable, closed loop system to explicitly manage the SO₃ vapor to a specific level.

The problem faced here is that partial removal of the SO₃ ahead of the air heater, by intention, leaves some level of acid still free during the AH gas transition.

As flue gas containing condensable matter passes through the air heater temperature stratification results from the physical cold to hot rotation of the wheel. This temperature stratification has the effect of concentrating the free acid vapor leaving an acid depleted zone in the cold gas side of the outlet duct and an acid enriched zone in the hot gas side of the outlet duct.

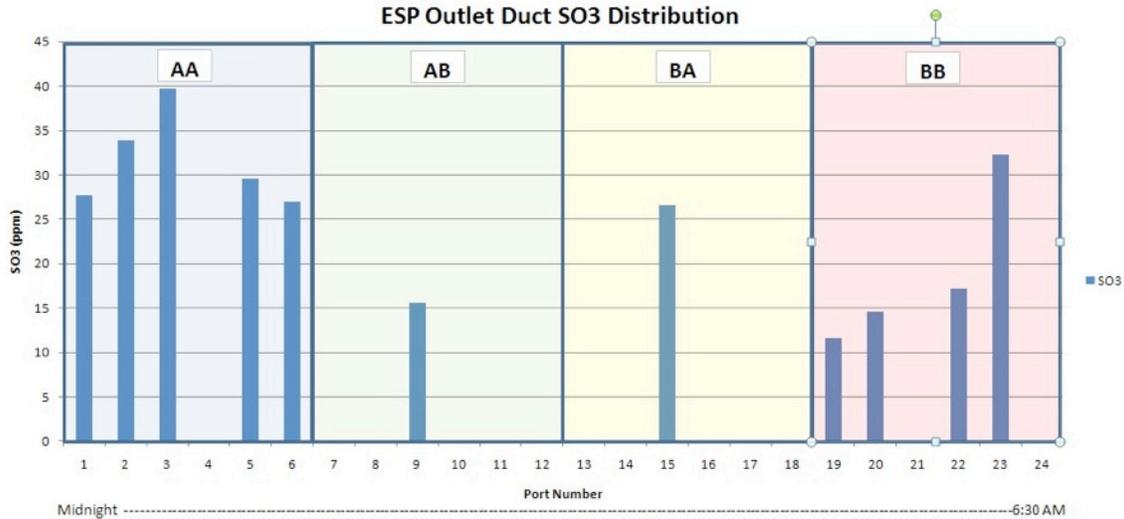


Figure 5 - SO₃ Stratification Profile at the AH Outlet

Figure 5 shows a typical stratification curve for a unit with two air heater and each air heater outlet being immediately split into two duct. The rotation is typically mirrored so that the hot gas side of the “B” air heater shows up in the BB duct and the hot gas side of the “A” air heater shows up in the AA duct. Not all of the ports were capable of being opened so the data set is not fully complete.

What is clear is that there is a high concentration of Acid vapor on the AA side of the “A” air heater and a trend toward a higher concentration on the BB side of the “B” air heater.

With full removal of all SO₃ prior to the air heater, there was insufficient fly ash conditioning and the plant experienced particulate emissions issues.

With pre-air heater-only partial conditioning, the plant also experienced particulate emissions issues due to the high levels of over-conditioning on the outboard ducts.

The final solution required a primary injection of hydrated lime ahead of the air heater to relieve air heater fouling issues and a secondary injection of hydrated lime after the air heater and asymmetrically distributed to reduce the stratified SO₃ but leaving the small levels (approximately 15 ppm pre-ESP) required in all four ESP ducts.

MODIFICATIONS TO TRADITIONAL INJECTION EQUIPMENT DESIGN

In light of the encouraging data seen when injecting either sorbent at a pre-AH location, a program was developed at Progress Energy to further explore the impacts of pre-AH injection with a low dust SCR. This program was executed by Breen Energy and ADA Environmental Solutions.

Progress Energy's objective for the program was to inject hydrated lime at the Air Heater inlet and observe the balance of plant impacts (if any) in the absence of post injection precipitator collection.

Breen/ADA's objective for the program was to explore an alternative approach to dry sorbent injection in an attempt to reduce the calcium carbonate buildup often observed in hydrated lime injection systems.

The project was executed between November of 2009 and February of 2010.



Figure 6 - The Equipment Installation at Site

The design philosophy was based on four drivers:

1. Positive control of actual transport air temperature,
2. Positive control of actual transport air humidity, and
3. Positive control of material transport energy
4. Increase system availability and reliability to greater than 95%.

Temperature, moisture and energy were determined, from the myriad industry reports on the presence and formation of calcium carbonate scaling in existing systems, to be the critical elements affecting the chemical feed system. In all cases CO_2 reacts with the hydrated lime to form calcium carbonate and contributes to a growing scale buildup at intersections, splitters, wyes, injector nozzles and other locations with high temperature or incidental high impact velocity. On a practical level, the carbonate reaction is

currently unavoidable. However, the mechanisms affecting carbonate formation can be effectively and positive managed.

Existing blower based, hydrated lime feed systems have attempted to control both humidity and temperature using dehumidifiers and pre-coolers and the success has been questionable. In fact, industry papers often conflict on whether pre-coolers help or hurt the scaling problem.

It is well supported that scaling is accelerated by an increase in temperature. The actual “temperature” in the transport air is a product of the physical temperature of the gas and the latent heat (or moisture) in the gas. Self-heating of the fluid through transport and the localized heat generated by particle impacts during transport act to compound the scaling problem. Positive control of these parameters has shown improved reliability in transport of hydrated lime. The design implemented at the Progress project incorporates an expanded compressed air source (rather than the traditional blower) which allows for massive improvements in transport air quality.

Secondly, the transport piping and distribution system was engineered to minimize the changes in linear particle momentum. This includes proprietary changes to the rotary air lock feed system, piping and routing of the main transport piping, patented modifications to wye intersections and elimination of “splitters” in favor of partitioning headers. The system endeavors to maintain material transport in the super critical laminar condition to preclude saltation and unwanted boundary friction.



Figure 7 - A typical Header

The results of the departure from industry accepted practice were very positive:

1. System availability during the extended run was 99%
2. Total maintenance time spent on the system amounted to two 10-minute routine inspections and maintenance checks each day,
3. At the end of a 38 day continuous run there was zero buildup at the rotary gate outlet, or at any of the partitioning points.



Figure 8 - Outlet of the Transition Chute below the Feeder after 38 days of operation

4. System feed accuracy was controlled via Loss in Weight techniques to $\pm 3\%$ of set point
5. Additionally, no balance-of-plant problems were experienced during the run and, in fact, the air heater back pressure declined during the entire period.

FURTHER WORK AND NEXT STEPS

Further demonstration programs are currently underway or planned at several different utility sites. The main next steps to be explored there include:

1. Development of an initial predictive feed rate algorithm based on actual measured condensables baseline data taken prior to injection start and incorporating the stratification effects of the air heater,
2. Operation of multiple injection lines from a common expanded compressed air source to multiple injection locations. This will significantly reduce the overall

system cost and allow for injection of different sorbents from the same main plant (i.e., activated carbon and hydrated lime, hydrated lime and trona, etc.)

3. Exploration of the effectiveness of multiple injection sites, or multiple chemicals to provide guaranteed, closed loop, compliance with the current BACT specifications (0.005#/mmBTU SO₃ at the stack)