



# CONTROLLING SO<sub>3</sub> IN COAL AND OIL FIRED UTILITY BOILERS: TECHNOLOGY AND EXPERIENCE

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## INTRODUCTION

This paper discusses two variations of SO<sub>3</sub> mitigation technology used in coal and oil fired utility and industrial boilers. This paper examines results from field testing in-duct combustion gases for SO<sub>3</sub> and ash pH on boilers using TDI™ Targeted Duct Injection™ technology, TIFI™ Targeted In-Furnace Injection™ technology or a combination of the two technologies.

Test results for a 1% solution of ash pH using a Storm Technologies hyperkinetic ash sampler and SO<sub>3</sub> measurements using a modified controlled condensation method and equipment from Clean Air Engineering were used to obtain SO<sub>3</sub> data from different sites for this project.

Test results, observations and interpretation of mechanisms of function are also discussed based on testing and analysis of baseline and treated conditions.

## HISTORY & BACKGROUND

### *Historical Overview of TIFI™ Targeted In-Furnace Injection™ Technology*

The TIFI program was originally designed as a slag and fouling control program that involves targeting areas of the radiant and convection sections of a boiler with chemicals designed to control slag and fouling. By targeting the problem areas of the furnace instead of targeting the fuel, performance and cost effectiveness were significantly improved.

Recent developments involve the use of this technology to control SO<sub>3</sub>, blue plume, stack opacity (caused by sulfuric acid) and air

pre-heater fouling caused by these conditions.

Chemicals are mixed with air and water and then injected into the flue gas stream. The areas that are “targeted” are based on Computational Fluid Dynamics (CFD) to ensure maximum coverage where the problem areas are known to exist. This has allowed excellent slag, fouling or SO<sub>3</sub> abatement performance previously thought to be resistant to chemical programs, including utility and other boilers firing coal, pet coke, residual oil and other fuels.

With the chemical being added to the flue gas and “aimed” at either the problem heat transfer surfaces or at chemical reactions (SO<sub>3</sub> mitigation) later in the system, greater than 90% of the injected material goes to the problem areas. This causes the additive to react with slag as it is forming and penetrate existing deposits to affect its physical crystal characteristics in areas where this is required. It is also what gives the technology its strong SO<sub>3</sub> abatement performance.

## PROCESS DESCRIPTION

TIFI technology involves using two different forms of fluid dynamics modeling and a virtual reality engine. Together, these create a running duplicate of a given furnace with injection overlays and dosage maps to predict where the chemical is going and to ensure as close as possible to 100% coverage of the targeted zones.

The most common application of TIFI technology utilizes magnesium hydroxide slurry diluted with water and then

atomized with air. This mixture is sprayed into the furnace at computer-determined ports that allow for complete coverage of the problem areas. In order to understand how this is done, it is necessary to look at the injection process itself.

The injectors are set up to feed the required air, water and chemical as determined by modeling. The injectors produce a range of droplets that the computer program has calculated and/or taken into account. The smallest droplets evaporate very close to the injection point. The chemical activates, and thus covers the zones nearest the injectors.

Each successively larger set of droplets goes deeper and deeper into the furnace before evaporation is completed and chemical is activated. This provides coverage successively further into the furnace until all the droplets have been evaporated and all chemical has been activated.

The program overlays all injection calculations on the fluid dynamics model. The result is chemical distribution calculations that merge into a map of how much chemical goes where; i.e., a dosage map of the targeted areas in the furnace. This targeted area can be as small as a dedicated problem heat exchanger or as broad as the furnace water walls, the convection sections and the platen areas combined.

TDI Targeted Duct Injection functions in a similar fashion. Injection of the reagent occurs in the duct. Distribution and activation occur at duct temperatures prior to the air pre-heater. Droplet sizes and velocities are modified to account for this.

### **CFD Modeling & Virtual Reality Visualization**

Process Design Modeling, in effect, involves simulating the operation of a particular duct or furnace in a high performance computer and then testing various “what if” problems and solution scenarios at various power

settings. A great deal of detail goes into running this “plug flow” model.

All size and design dimensions, fuel and heat rates, fuel chemistry details, details of air usage and boiler or duct geometry as appropriate are programmed into the model.

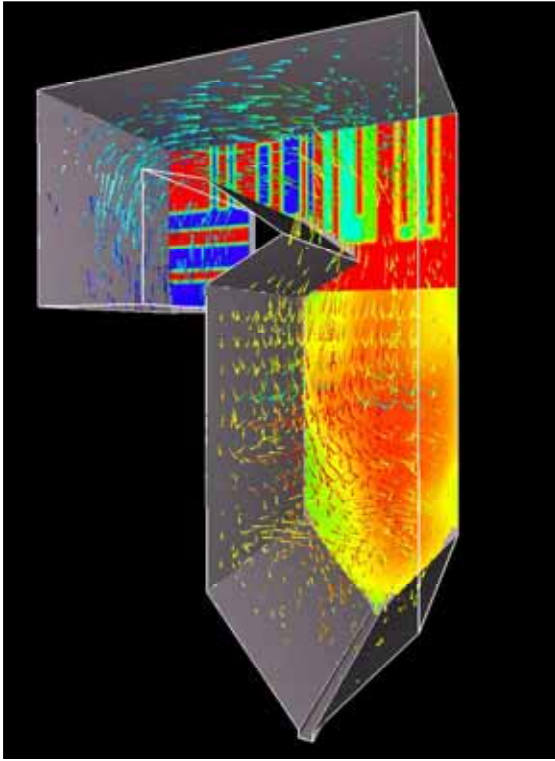
The data set output from this model is complex and difficult to visualize. Recent advances with virtual reality visualization techniques, coupled with fluid dynamics modeling, have yielded new insights into how complex dynamic systems like coal and oil burning utility boilers and other furnaces, behave in real time.

The TDI Targeted Duct Injection process functions in a similar fashion. After all of this data is programmed, a temperature and gas velocity gradient is calculated for the entire furnace or duct. In furnace applications, the results generally show small imbalances in heat release and gas flow pattern, which is normal. If the variations were excessive, a notation would be made in the report indicating that the abnormal condition exists, along with some recommendations on how to deal with it.

Treatment programs can then be designed for the specific boiler or duct application. A customized injection scenario is then built inside the computer and tested under varying program conditions, and results are calculated.

For example, complexities that present challenges to operating and maintaining the furnace/convection section can be highlighted and accounted for or minimized through this visualization technique.

Figure A details the gas flow fluid dynamics using flying vector arrows that are coded for velocity (length), temperature (color) and direction.



**Figure A**

Understanding is enhanced by looking at one-half real time models running in the virtual reality environment. Eddy currents, dead spots and high gas flow areas are all highlighted and can be avoided or used to carry the chemical to desired areas. This depends on the strategy chosen and the requirements of the program.

The next phase of the model deals with setting up the injectors and their predicted performance within the model. How well the various injector scenarios perform at covering the targeted critical gas path is calculated.

Figure B shows how the boiler gas path from the radiant section through the superheaters and the reheaters is targeted for chemical application by adjusting the number of injectors, placement, design and performance settings.

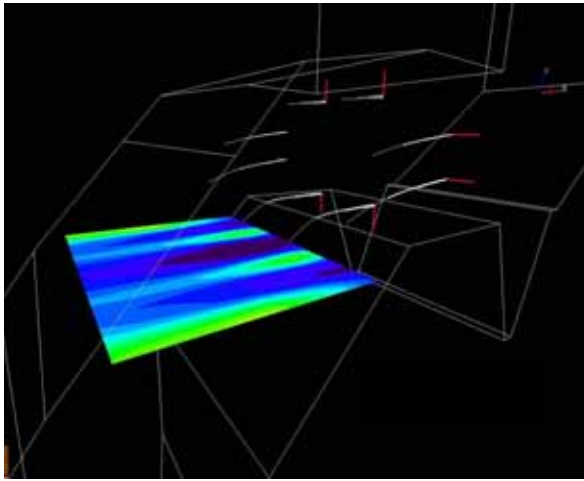
This technology makes it possible to have high chemical activity in several places at the same time.

This process continues until the result is judged satisfactory for solving the problem. A custom feed and control system is engineered and constructed, based on these results.

In this manner, the treatment covers all the areas that need the most attention. The program uses this sophisticated “aiming” ability to ensure that the correct dosage is applied everywhere it is required.

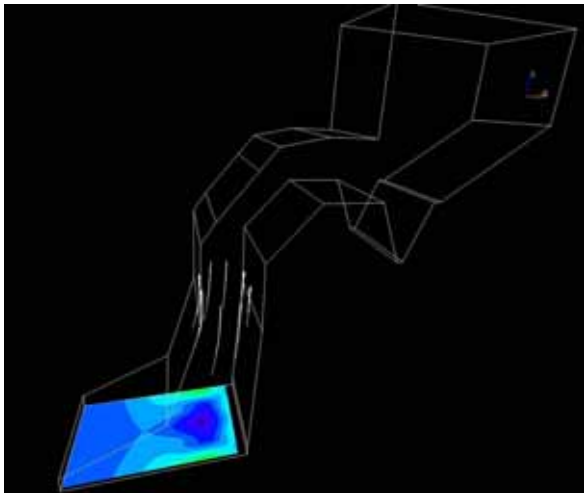
### **TDI APPLICATIONS**

Figure C depicts a TDI duct application after a SCR in the duct and prior to the air pre-heater. The diagram shows how the injectors behave and reveals the merged mapping of chemical activity, color coded by concentration. In this case, the dosage, the number of injectors in the array, the injector settings and the placement of the injector array yield an excellent solution, as evidenced by the blue and green coverage on the map surface. This indicates good activity and distribution of the reagent.



*Figure C*

Figure D represents an alternative TDI solution selected by the customer to account for the proximity of grating and safety stanchions to allow access to the injector array for routine maintenance. This injector array resulted in as good or better reagent distribution as the array depicted in Figure C.



*Figure D*

### **REAGENT CHEMISTRY**

The reagent is a special chemical slurry with high reactive ability owing to its large surface area per unit weight ratio (approximately 530,000 sq.ft./cu.ft.). This high activity results in better performance at recommended treatment dosages while its high stability eliminates many of the

handling and feeding problems associated with unstabilized compounds.

The levels required for good performance are based on chemical reactions in the combustion gases as  $\text{SO}_3$  forms and condensation of sulfuric acid vapor occurs and adheres to air pre-heater basket and duct surfaces. (Refer to Figure I.) When properly treated, deposition from acid and ash reactions is significantly reduced, allowing the air pre-heater to remain clean and free of corrosive deposits.

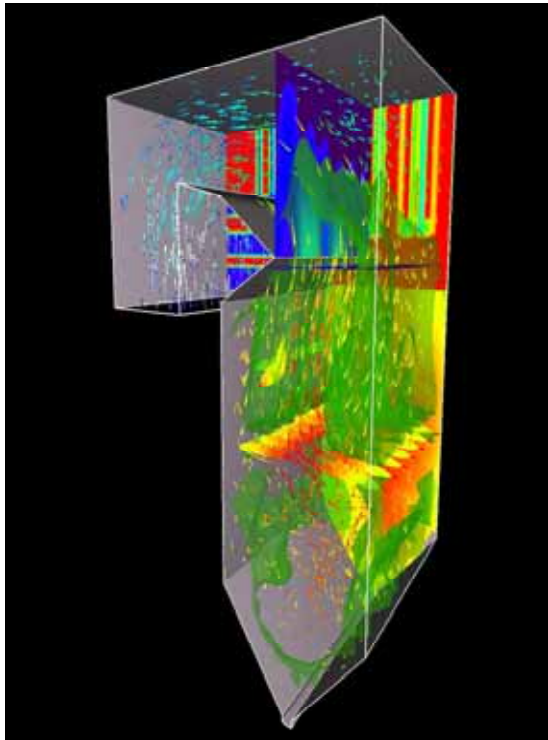
Left untreated, the increased resistance to gas flow will ultimately dictate that the boiler has to be taken offline for air pre-heater cleaning. If this occurs during ozone attainment season, the resulting downtime can be very expensive.

Based on tests and operating results, chemical feed rates for  $\text{SO}_3$  related problems are usually slightly above laboratory stoichiometric requirements with NSRs (Normalized Stoichiometric Ratio) in the region of 1.7 to 2.0.

While TIFI and TDI technologies use modeling to aim the reagent and sophisticated engineering to execute the feed requirements, there are some things that occur after the reagent is fed into the furnace (TIFI) and duct (TDI) environments.

It is both physical and chemistry reactions, including crystal morphology, that do the work of controlling the slag, fouling and acid-base neutralization reactions. Together these control sulfuric acid levels, which results from  $\text{SO}_3$ , and attendant plume, opacity and pre-heater fouling.

The chemical reagent arrives at the customer site in the form of a suspended slurry of 5–8 micron sized particles. Atomization takes place in accordance with the model output.



**Figure E**

Figure E depicts a unique capability for users of this technology. The model can calculate iso-contours of temperature, such that any spot at a given temperature in the boiler can be visualized and linked to form a surface of the same temperature. In this example, the translucent green shape represents 2,150 degrees Fahrenheit. This, in itself, is not unique. However, when matched to the ash fusion temperature for the fuel being burned in the subject boiler, it becomes an accurate predictor of the slag and fouling front. It essentially shows the operator where the slag and fouling are likely to first show up.

When targeted with the chemical injection, a unique and powerful tool is formed that can be used to control the slagging and fouling to a degree not possible before.

### **Nanotechnology and Fractal Geometry**

Here, the physical aspects of the chemical reactions that control slag, fouling and SO<sub>3</sub> problems are accomplished.

The reagent actually reacts chemically to alter the crystal structure of the slag and fouling that originates in the boiler fuel as

ash, and is entrained in the flue gas of the upper furnace. This technology changes the molten slag to a more friable material that does not adhere as tenaciously to the tube surfaces and is therefore easier to remove during sootblowing.

This is also important for control of air pre-heater fouling when ash and sulfuric acid combine to form tenacious and corrosive deposits.

Until recently, the exact mechanism of how this was accomplished was not well understood. Recent research results have revealed some striking new ways to explain what the mechanism of function now appears to be.

Current theory suggests that nanotechnology is at work in the way the TIFI program functions. For the use of the term “nano” in this discussion, it is defined as “the ability to synthesize, manipulate and characterize matter at the sub-100nm level.” To simplify, 100 nm = 0.1 um.

In order to comprehend what was happening to the magnesium hydroxide particles after they were injected into the combustion gas, an indirect measurement method had to be devised to test the theory that the nominal 5 - 8 um particles had to become much smaller. This was surmised because performance of the technology suggested that far smaller particles had to be at work to explain the activity observed in real life conditions.

The experiment selected consisted of a Dean Stark distillation apparatus which would be used to synthesize an organo-metallic magnesium compound using a solvent based sulfonation method.

This scenario was selected because in the synthesis of this material, several things would happen:

- The temperature at which things happened could be measured

- The reaction process produces about 10% soluble material, and the rest remains as particles.
- The size of these particles in suspension could be accurately measured and a distribution established.
- If a change in particle size and distribution were to occur, it could all be accurately measured, even well down into the nano-particle range. Other methods were more complex, costly and did not increase accuracy over this set-up.
- The soluble material generated was deemed within the margin of error and acceptable, due to the difficulty of trying to measure these things in-vitro.

Tests were conducted on a number of magnesium sources to determine which ones were the most suitable for TIFI and TDI technologies.

Scanning electron microscopy photos of different parent magnesium hydroxides showed observable differences in crystal structure that could account for differences in reactivity and performance.

Crystal structures that prevented the venting of steam caused by the water of hydration being heated until it flashed to steam appeared to have higher reactivity than crystal structures that were open and allowed steam to escape without disrupting the particle structure.

Particles in the sub-100 nm level, in effect, behave like a gas and have properties of gases. The property of Brownian motion is important for penetration deeper into the boiler and the ability to penetrate existing slag and fouling deposits, loosening them and enabling removal of preexisting deposits.

Recall that the TIFI process operates by using droplets of varying size ranges to

allow particles to travel to varying depths in the furnace and convection section, dependent on the initial droplet size. When the water evaporates, there is a brief period of travel as the 5.0 micron particles heat up to about 325 degrees Celsius. At this point, the particles explode into varying sizes from 0.03 to 0.3 microns.

This is significant, because this testing proved that TIFI technology is, in fact, an in-situ nano-technology. That is, TIFI technology becomes nano-technology inside an operating furnace. These two events, TIFI/TDI technology, and the in-vitro creation of nano-particles of high reactivity and performance are unique.

### **Chemistry and Rheology**

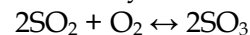
Sulfur oxides (SO<sub>x</sub>) formation is dependent on numerous factors. Furthermore, the reactivity and/or the state of SO<sub>x</sub> are highly dependent on factors of the combustion environment. Kinetics, temperature, fuel sulfur content, ash composition and excess air level all play a major role in SO<sub>x</sub> formation, reactivity and/or molecular state.

In the ordinary combustion environment sulfur may exist in various forms as SO<sub>2</sub> or SO<sub>3</sub> and in the backend as H<sub>2</sub>SO<sub>4</sub>. The oxidation of SO<sub>2</sub> to SO<sub>3</sub> is thought to be brought on by three mechanisms.

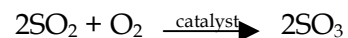
1. Oxidation of SO<sub>2</sub> in flame by atomic oxygen.



2. Oxidation of SO<sub>2</sub> by molecular oxygen.



3. Catalytic oxidation via molecular oxygen.



Mechanism number 3 is the result of catalytic oxidation of SO<sub>2</sub> to SO<sub>3</sub> by contact with ash particles, metal heat transfer surfaces, or contact with the SCR bed. Iron

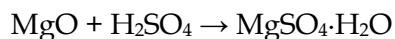
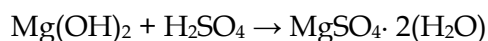
oxides present on the metal surfaces provide the catalyst for the conversion of SO<sub>2</sub> to SO<sub>3</sub>. Metal surfaces that are clean are a factor in mitigating SO<sub>3</sub> formation in this mechanism.

Air pre-heaters (APH) are used to transfer heat from the flue gas exiting the economizer to combustion air flowing into the boiler. Typical air temperatures going into the APH are 600° to 700° F and 300° to 400° F when exiting. This is significant because SO<sub>3</sub> is hygroscopic and has a tendency to absorb moisture at temperatures well above its dew point to form H<sub>2</sub>SO<sub>4</sub>.

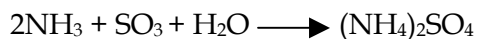
As the flue gas temperature drops, the SO<sub>3</sub> hygroscopicity increases and the conversion to H<sub>2</sub>SO<sub>4</sub> significantly increases. In short, as the flue gas temperature drops the concentration of H<sub>2</sub>SO<sub>4</sub> increases and SO<sub>3</sub> decreases.



The same environment that causes the formation of sulfuric acid also allows for a classic acid - base reaction between magnesium hydroxide and/or magnesium oxide with sulfuric acid.



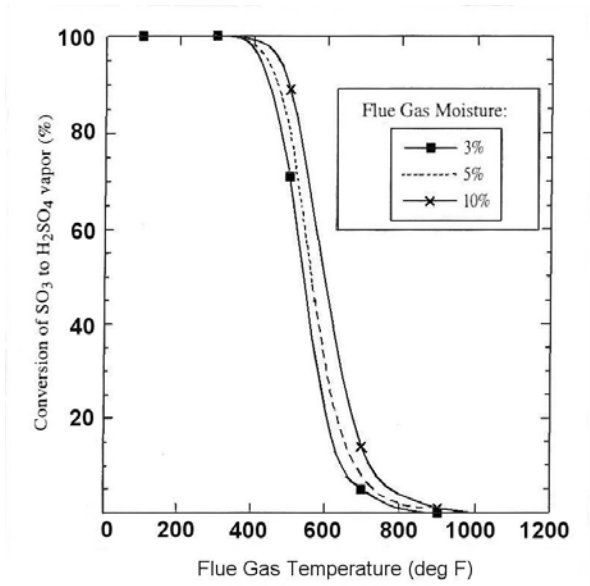
Ammonia slip (residual NH<sub>3</sub>) in units equipped with SCRs (Selective Catalytic Reduction) for NO<sub>x</sub> is a costly problem for coal-fired utilities. Residual NH<sub>3</sub> reacts with SO<sub>3</sub> to produce ammonium bisulfate at APH operating temperatures (approx. 400°F).



Ammonium bisulfate deposits are sticky and difficult to remove, accelerate corrosion and create significant air heater fouling.

## Results and Observations

There are several observations that seem to be common for utility operators that are having trouble controlling SO<sub>3</sub> emissions. A good example is acid blue plume emissions. Often this blue plume is most notable during power ramp up. Although this is a common observation, the underlying mechanisms, the best control strategies and the best measurement criteria are not easily devised. Inspection of the air heater, although accurate, is an after-the-fact observation. It makes more sense to devise a preventative solution to the problems before they occur.



**Figure F**

Figure F is a graph of SO<sub>3</sub> species vs. H<sub>2</sub>SO<sub>4</sub> species as a function of temperature and combustion gas moisture, compiled by the Electric Power Research Institute (EPRI).

This graph is helpful in understanding some of the phenomena occurring in the cold end of a utility boiler system. For instance, SO<sub>3</sub> conversion to H<sub>2</sub>SO<sub>4</sub> at 700°F is only about 5%. Just 100°F lower, at 600°F, H<sub>2</sub>SO<sub>4</sub> conversion leaps to 60% at a 5% moisture level.

Factor in that these temperatures are bracketed by the operation of the SCR, and it's easy to see why so much SO<sub>3</sub> gets captured by the SCR at low loads. (See Figure M.)



*Figure G*

Figure G is a classic example of a stack with detached blue plume. Note for the first several stack diameters, the plume color is white. Then the pale blue color typical of sulfuric acid mist appears. While this is typical of blue plumes (sulfuric acid mist), not all stacks exhibit this behavior.

Figure H is a stack plume of a U.S. utility that was experiencing blue plume problems that were exacerbated during ozone attainment season due to a SCR (Selective Catalytic Reduction) for NO<sub>x</sub> control. The plume in this case is slightly detached, but not nearly as much as in Figure G.

Problems associated with blue plume are not limited to visible plumes. Figure I is a picture of an air pre-heater taken out of service during a downturn where blue plume and sulfuric acid misting were a problem. Note the black sticky appearance of deposits. Inspection of this air heater where a blue plume was visible indicated severe fouling.

Fly ash pH 1% solution (ASTM) measurements show an inverse relationship to both air heater fouling and correlating blue plume. When the fly ash pH is low (acidic), even up to neutral, the blue plume is visible and the correlating air heater fouled.

These deposits are black due to the iron sulfate corrosion deposits, and are mixed with condensed sulfuric acid on the baskets. This combination is a problem for a number of reasons.

First, these deposits are corrosive and will significantly degrade the baskets through oxidation. Second, sulfuric acid is sticky and will cause corrosion products and ash to form a hard crusty deposit that fouls the baskets and limits gas flow through the air pre-heater.

During ozone attainment season, ammonium bisulfate deposits from SCR operations make the matter worse and can cause unscheduled outages during ozone attainment season when the cost of replacement power is at its highest.

Clean up for an air heater in this condition is difficult and costly.

When magnesium hydroxide is injected using TIFI and/or TDI technologies, the results are dramatic but not necessarily immediate. It takes some time and initially a relatively high dosage plan to condition and remove sulfuric acid deposition from duct and pre-heater surfaces.

When the pH of a 1% solution of ash reached pH 9 and higher, no blue plume was observed and the air heater was clean and free of deposits, including ammonium bisulfate in a SCR equipped unit.



**Figure H**



**Figure J - Treated (TDI)**



**Figure I - (Untreated)**



**Figure K - (Treated)**

One of the goals in dealing with  $\text{SO}_3$  mitigation, then, would be to do no further harm to operations during ozone attainment season. TIFI/TDI injection technology is designed with that objective in mind.

Figure J is a photo of the same boiler stack as in Figure H, taken after operating for a period of time on the TDI program. The blue plume is now absent and opacity is considerably lower.

The air pre-heater shown in Figure I was no longer fouled and corroded as indicated in

Figure K. This photo shows a clean set of air baskets, free of ash, fouling and corrosion.

Figure L is a graph of  $\text{SO}_3$  readings taken while using Targeted Duct Injection technology in the duct of the boiler discussed above. The chemical, injected in the ductwork just down stream of the SCR outlet, produced the  $\text{SO}_3$  numbers seen in Figure L.

Baseline readings at full power on the boiler are in blue on the left. Stack readings, taken after the air pre-heater, are in red on the right.

Baseline SO<sub>3</sub> numbers averaged 13-14 ppmv and stack SO<sub>3</sub> readings averaged around 5 ppmv.

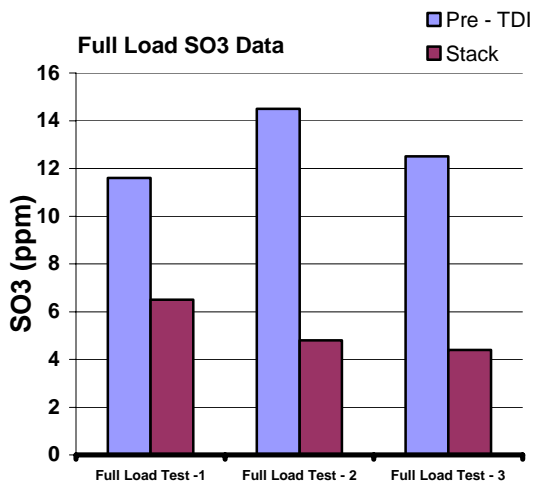


Figure L

Figure M contains data summarizing SO<sub>3</sub> testing done at low loads on the boiler described above.

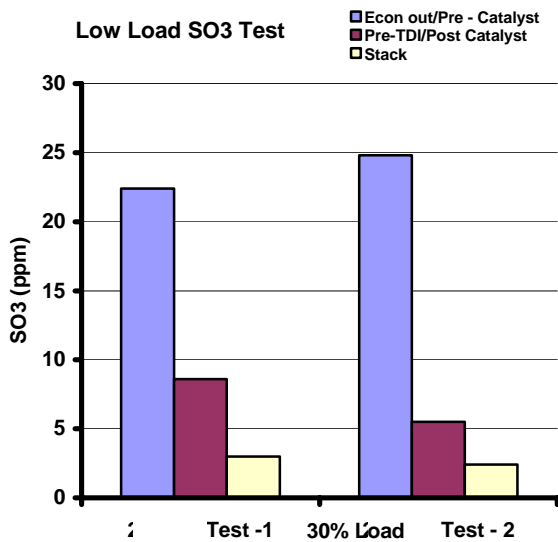


Figure M

The decision was made to take SO<sub>3</sub> readings at the economizer outlet, the SCR outlet and the stack, in order to determine what might be going on with SO<sub>3</sub> hideout, if anything, during low power operations.

SO<sub>3</sub> readings exiting the economizer were in the mid 20's, on average, which is fairly typical of low loads. Readings taken after the SCR, were surprisingly low, averaging 7-8 ppmv SO<sub>3</sub>. SO<sub>3</sub> readings taken at the stack showed a further drop, but not nearly as dramatic as the drop observed between the economizer exit and the SCR exit.

SO<sub>3</sub> values exiting the stack were quite low and in line with expectations for eliminating the blue plume.

Figure N represents a graph of a series of SO<sub>3</sub> tests conducted at another U.S. utility boiler that has had problems with visible acid plume generation. This unit does not have a SCR on the back end.

The TIFI technology was chosen to deal with the plume problem. This in-furnace injection of Mg(OH)<sub>2</sub> was able to drive baseline SO<sub>3</sub> levels from a high of 12 ppmv to a low of about 2 ppmv.

While the generally accepted SO<sub>3</sub> levels required to remain plume free are about 5 ppmv or so, there is no guarantee that the plume will continue to remain absent at these SO<sub>3</sub> levels unless other factors are taken into consideration.

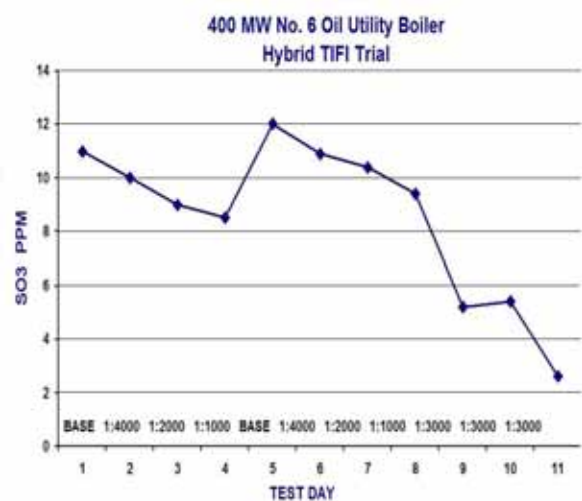


Figure N

Chief among these, testing has confirmed, is pH of a 1% solution of ash, taken with a hyperkinetic ash sampler in the duct immediately ahead of the air pre-heater.

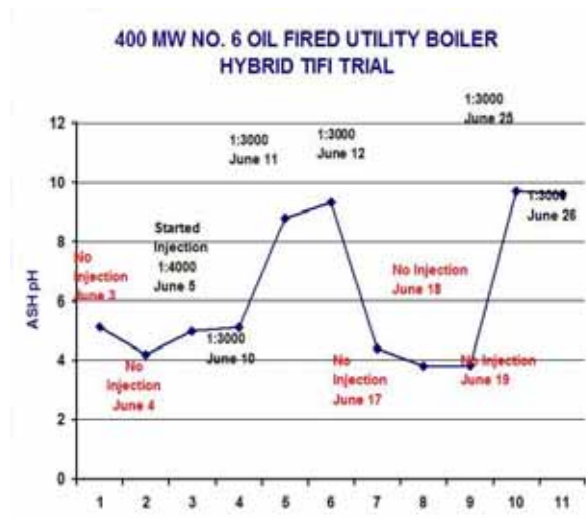


Figure O

Figure O is a graph of various pH tests that were run on the same unit as in Figure N. pH readings were run on ash solutions without treatment and with the TIFI treatment turned on.

The graph shows a good correlation to high pH in the duct necessary to keep the blue plume from forming and feeding or lack of feeding the TIFI reagent.

This type of measurement is again confirmed on another utility boiler having a blue plume condition.

Figure P is a graph of several pH's that were run from the start up of a TIFI installation. After the technology was installed and started, pH readings in the duct ahead of the pre-heater started out low, around 4.0, but gradually rose to a pH of 9.0 over time.

Even during ramp up and ramp down, pH remained relatively steady and the blue plume disappeared.

Figure Q is a graph of a unit that was tested using TIFI injection technology to control an existing blue plume condition.

The graph shows the correlation of pH's greater than 9.0 to low APH fouling factors until pH went below 9.0. At this point, fouling factor began to rise slowly and APH pressure differential also began to rise as well.

All of these observations correlated to the presence and absence of the blue plume. At pH 9.0 or greater, there was no plume. At pH's less than 9.0, the plume returned and the other observations were made.

Figure R is an air heater delta P of a utility boiler operating with a SCR installed. On this particular unit, TIFI technology was in use on both air pre-heaters.

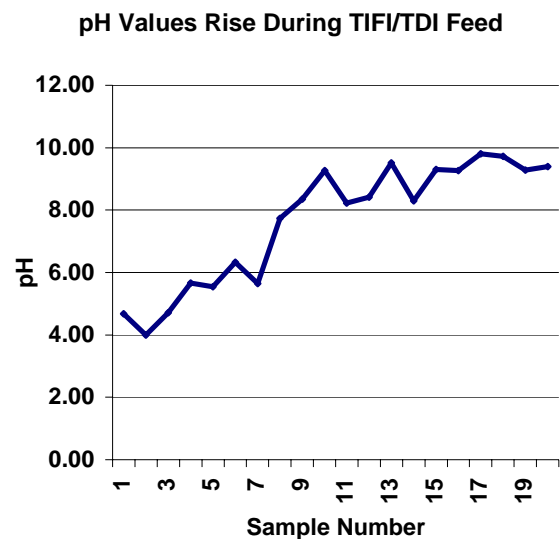


Figure P

After a successful run with the TIFI process, it was decided to try the TDI process on only one duct and one air pre-heater. The unit was run in this fashion so one air pre-heater (APH) was treated with the TIFI process only and the other APH was effectively treated with both TIFI and TDI processes.

In all trials it was observed that the air pre-heater had a tendency to foul until ash pH reached a level of 9 and higher. During the trials the dosage was decreased to ascertain if the air pre-heater fouling would stabilize at lower pH readings.

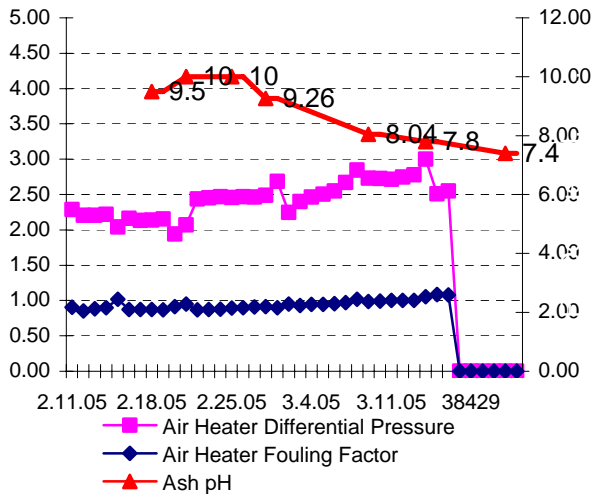


Figure Q

### Controlling Airheater Pressure dP Increase

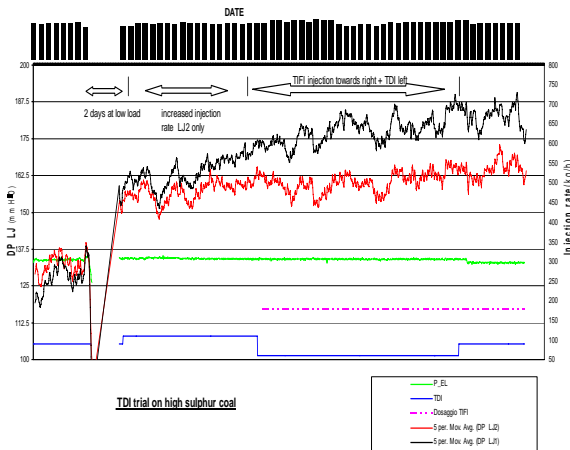


Figure R

The resulting graphs of APH delta P show that the red line on Figure R, which represents the APH treated with both the TIFI and TDI technologies had lower

fouling rates than the APH treated with the TIFI technology alone.

This either represents the combination of the TIFI and TDI processes as being superior to the TIFI application alone or an indirect way of showing that increased feed rate resulted in better performance. The combination may also do a better job of addressing ammonium bisulfate fouling in the air pre-heater. Further testing will be required to answer this question.

Figure S represents stacks of two adjacent boilers, one treated with in-fuel SO<sub>3</sub> treatment only (left) and one unit treated with both an in-fuel treatment and a TIFI array (right stack).

The stack on the right with both treatment regimens is clearly cleaner with no trace of the acid/blue plume seen on the stack on the left.



Figure S

### Conclusions

Acid blue plume emissions, opacity and air pre-heater fouling are common and costly problems for the utility community with SCRs retrofitted burning medium to high sulfur fuels and over-controlling NO<sub>x</sub> and experiencing high levels of SO<sub>3</sub>.

The conversion of  $\text{SO}_3$  to  $\text{H}_2\text{SO}_4$  is a significant phenomenon that is highly dependent on the environment. Temperature is a major factor in this conversion. A  $100^\circ\text{F}$  swing in temperature from  $700^\circ\text{F}$  to  $600^\circ\text{F}$  has a dramatic effect on the conversion from  $\text{SO}_3$  to  $\text{H}_2\text{SO}_4$ . (from 5% to 60% conversion)

Very little  $\text{SO}_2$  to  $\text{SO}_3$  conversion was observed across the SCRs tested for this paper. More testing at additional sites is needed to characterize this situation better.

There is most likely a  $\text{SO}_3/\text{H}_2\text{SO}_4$  hideout phenomenon occurring in utility boiler back end systems. In units equipped with an SCR, the presence of this piece of equipment appears to be a significant storage device for a mixture of gaseous  $\text{SO}_3$  and  $\text{H}_2\text{SO}_4$  during low power operations.

In non-SCR equipped units, the air pre-heater appears to perform this function. The TIFI/TDI technologies discussed in this paper appear to work on sulfuric acid mist or sulfuric acid droplets, rather than on  $\text{SO}_3$  or gaseous  $\text{H}_2\text{SO}_4$ .

Evidence of this is seen in the action of pH behavior in a 1% solution of ash. When pH of a 1% solution of ash, taken ahead of the air pre-heater in the duct, stayed at or above 9.0, APH fouling, visible acid mists and acid fallout all disappeared.

In the case of this technology, acid-base neutralization is clearly important to the process.

Blue plume, APH fouling, opacity and ground level acid fall out are the key significant problems that can be avoided by interrupting the mechanism that causes these problems.

$\text{SO}_3$  by itself, cannot be used to quantify or control these problems. Driving the fly ash pH to a level of 9 or higher, in conjunction with low  $\text{SO}_3$  levels is capable of controlling these problems.

The most effective and efficient way of raising the pH level to 9 or higher is by combining the effects of TDI Targeted Duct Injection and TIFI Targeted In-Furnace Injection technologies. The TIFI process alone or the TDI process alone was not as effective as the combination of the two for these particular trials.

It appears that the combination of the TIFI/TDI approach had a greater affect on ammonium bisulfate deposits on the APH than either the TIFI or TDI approach alone. This requires further testing and analysis.

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