SO_3 Injector Fouling In Flue Gas Conditioning Systems

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SO_3 injection probe fouling is a major concern in the operation and maintenance of SO_3 flue gas fly ash conditioning systems. The source of the problem is moisture in the combustion air used by the sulfur burning SO_3 gas generator systems. Proper SO_3 injector probe operating temperature control and operation can alleviate many of the problems. The use of dry combustion air in combination with conventional SO_3 flue gas conditioning systems has the potential of reducing both the quantity of sulfuric acid generated and the dew point temperature of the sulfuric acid mist formed in the hot gas piping and SO_3 injection probes. The advantages of dry combustion air will be in reduced injector fouling - resulting in lower maintenance costs and improved fly ash conditioning performance. The lower sulfuric acid dew point temperature of the SO_3 gas will offset the additional operating costs associated with producing the dry combustion air and can also reduce the capital costs for new installations when combined with SO_3 gas flow splitting and biasing technology.

Introduction

Sulfur trioxide (SO_3) flue gas conditioning (FGC) is used in hundreds of coal burning power plants throughout the world. FGC systems control fly ash resistivity by controlling the amount of SO_3 in the flue gas entering the electrostatic precipitator (ESP). The resistivity of the fly ash can significantly impact the performance of the ESP and, ultimately, the stack opacity.

Most SO_3 FGC systems are based on sulfur burning processes that combust the sulfur in “wet” atmospheric air. The resulting sulfur dioxide (SO_2) is converted to SO_3 in a catalytic converter and injected into the flue gas ducting through multiple SO_3 injection probes. Prior to injection the SO_3 gas concentration is typically about 5% by volume.

The injection of SO_3 into the flue gas stream is generally expressed in parts per million (ppm). A 660 megawatt coal-fired boiler designed for 20 ppm of SO_3 injection would have a sulfur burning rate of approximately 165 lb/hr (76 kg/hr) and a combustion air flow rate of 790 SCFM (1,250 Nm3/hr). The following figure illustrates typical sulfur burning SO_3 flue gas conditioning system:

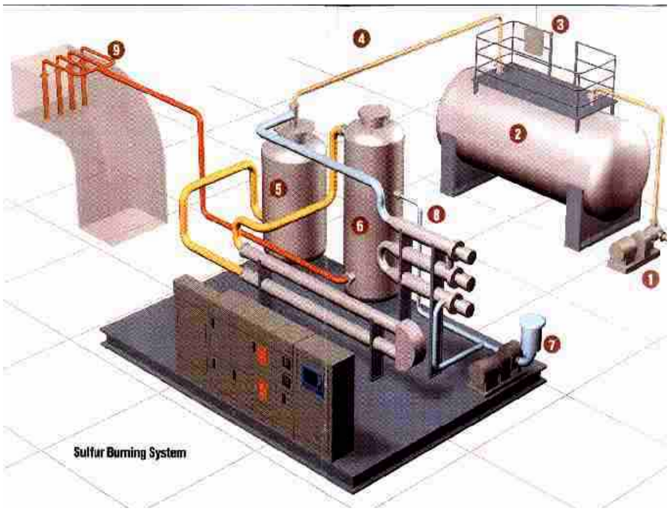

Figure 1: Typical Sulfur Burning SO_3 FGC System

Although the sulfur burning and SO_2-to-SO_3 conversion processes are exothermic, a combustion air heater is required in order to ignite the sulfur at startup. An air heater is also required, while operating at reduced sulfur rates, in order to maintain SO_2 and SO_3 gas temperatures throughout the system. The SO_2 gas temperature is controlled for optimum conversion in the catalytic converter and the SO_3 gas temperature must be kept above the sulfuric acid dew point to avoid fouling the SO_3 injection probes. The distance between the SO_3 gas generator and the SO_3 injection probes usually determines the size of the air heater.

The SO_3 gas stream leaving the gas generator system will contain a significant amount of moisture when using atmospheric combustion air. At elevated temperatures, the SO_3 and H_2O molecules remain disassociated. Sulfuric acid (H_2SO_4) is formed as the gas begins to cool. The amount of sulfuric acid formed is dependant upon the ambient atmospheric air conditions. The following graph shows the relationship between the dew point of the process air and the amount of sulfuric acid generated:

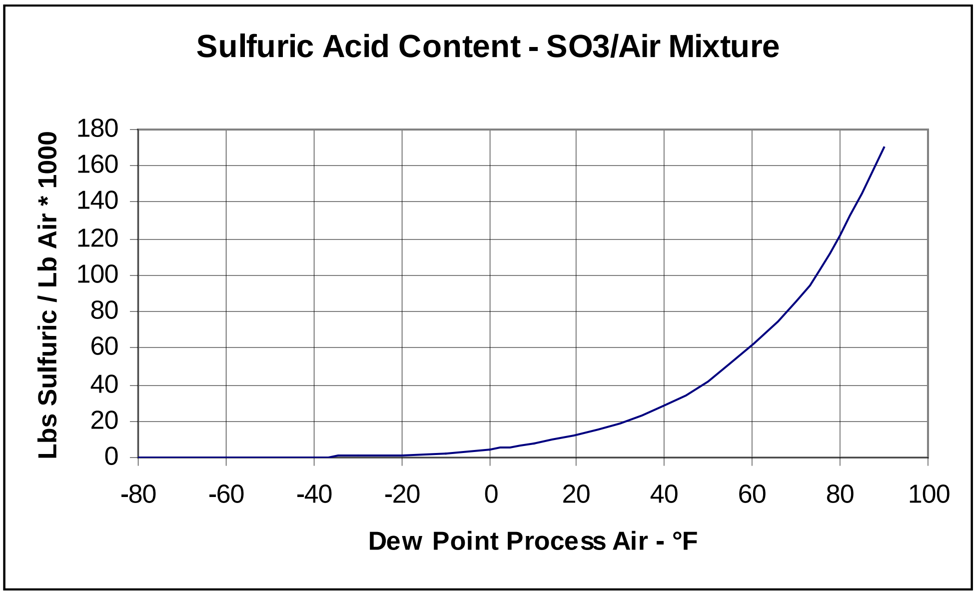

Figure 2: Sulfuric Acid Content vs. Air Dew Point

During SO_3 flue gas conditioning, the formation of sulfuric acid occurs in the hot SO_3 gas piping and continues to form with the moisture in the flue gas. SO_3 flue gas conditioning systems are designed to maintain the SO_3 gas temperature above the sulfuric acid dew point in order to minimize problems associated with the condensation of sulfuric acid in the hot gas piping systems. The formation of sulfuric acid is not a problem in terms of flue gas conditioning and fly ash resistivity. However, sulfuric acid formation should be confined to the flue gas ducting and not in the SO_3 gas piping and injection probes.

In a warm and humid climate, a 165 lb/hr (76 kg/hr) sulfur burning SO_3 FGC system has the capability of forming over 350 lb/hr (159 kg/hr) of sulfuric acid. The unique relationship between sulfuric acid and SO_3 further complicates the issue. The SO_3 and sulfuric acid combine to form a mixture known as oleum. Oleum is often referred to as “fuming acid” due to the fact that oleum will release fumes of SO_3.

Another important aspect of the air dew point is the way it relates to the sulfuric acid dew point of the hot SO_3 gas. Figure 3 shows why it is desirable to maintain the minimum SO_3 injector probe temperatures above 450°F (232°C).

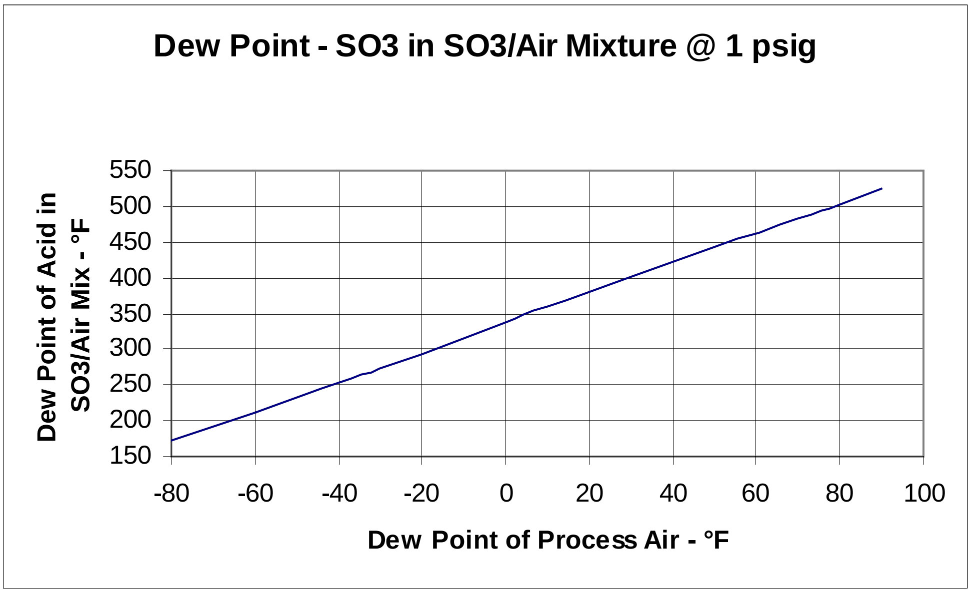

Figure 3: Sulfuric Acid Dew Point vs. Air Dew Point

SO_3 Injector Fouling

SO_3 injection probe fouling is a major concern in the operation and maintenance of an SO_3 Flue Gas Conditioning system. The source of the problem is moisture in the process air used in the sulfur burning flue gas conditioning unit. The moisture in the process air reacts with the SO_3 and creates sulfuric acid (H_2SO_4) and oleum (SO_3 + H_2SO_4). Attempting to keep SO_3 gas temperatures well above the sulfuric acid dew point minimizes injector fouling.

Operating with fouled injectors results in reduced performance. In order to achieve the full benefit of SO_3 conditioning, the SO_3 must be properly distributed throughout the ESP inlet duct. Fouled injectors prevent this from happening.

Minimizing SO_3 Injector Fouling in Conventional SO_3 Systems

The local climate, system design/configuration, installation, maintenance, startup and operating procedures all have an influence in the amount and frequency of SO_3 injector fouling. For existing systems it is important to focus on proper maintenance and startup/operating procedures in order to avoid problems and costly SO_3 injector replacements. For new systems it is equally important to design, configure and install them in such as way as to avoid injector-fouling problems.

The method by which the injector is installed into the ductwork is a very important factor in injector fouling. The most desirable installation is for the injector to be in a vertical position with the SO_3 gas inlet at the top of the injector. The injection of SO_3 gas should always be at right angles to the flow of flue gas. The injector should be equipped with a nozzle located at the bottom of the injector to facilitate the draining of any sulfuric acid that should form. Although horizontal installations have been attempted, the incidence of fouling is much greater. The reason for this appears to be a lack of drainage of sulfuric acid from the injector. The build up of sulfuric acid fills the lower half of the injector pipe until it reaches a level that allows it to flow from the injector nozzles. The build up of sulfuric acid in the injector pipe leads to both a reduction in flow, by removing half the available flow area in the injector, and excessive cooling on the lower half of the injector pipe. The most undesirable method for installation of injectors is from the bottom of the ductwork, with the injector in a vertical position, with the SO_3 gas entering from the bottom of the injector. This type of installation is subject to the greatest incidence of injector plugging. The reason is very similar to the horizontal installation in that all sulfuric acid that is formed flows back down to the inlet, eventually cutting off all gas flow to the injector. It is important when selecting a location for injectors that the length of the SO_3 piping is considered carefully and heat loss is accurately assessed. The shortest possible route to the injection site is advised to cut down on heat loss.

Understanding the correct time to bring the SO_3 system into service in order to minimize both the accumulation of sulfuric acid and ash on the SO_3 injectors, is the key to successful plant operations. It is in the initial start up stages, when a boiler is coming off of an outage, that consideration must be given as to when to start the SO_3 equipment. It has been demonstrated that as soon as there is the potential for ash to be entrained within the flue gas stream, such as when the ID or FD fans are started, that the SO_3 system should be put into a hold or preheat mode.

There is a dual purpose in starting the SO_3 system prior to the FD or ID fans. The first is to provide a sufficient flow of air through the injector nozzles, preventing the introduction of residual ash left in the ductwork from being deposited into the injector lance through the nozzle opening. The second purpose for starting the SO_3 system early in the boiler start-up process is that during start up of the boiler, the SO_3 system is typically not needed until boiler loads increase to a level where opacity issues arise. It is at this time that most operators turn to the SO_3 system to help bring opacity under control as boiler output continues to rise. In the quest to continue to increase boiler output in a timely fashion, the SO_3 system will be put into a run mode as soon as possible to begin to inject SO_3, increasing precipitator performance. If the SO_3 equipment was not started far enough in advance to allow for complete heating of the entire SO_3 above the sulfuric acid dew point, the production of sulfuric acid in SO_3 piping and in the injectors will be significant once production of SO_3 begins in the system. It is this production of sulfuric acid, together with fly ash, that leads to injector plugging during boiler start-up. Figure 4 displays sulfuric acid on a cold injector. Figure 5 shows the resulting nozzle blockage when acid and fly ash mix together.

Figure 4: Sulfuric Acid Deposits on Injector nozzle due to cold operation less than 232 °C

Figure 5: Sulfuric Acid Deposits together with ash have completely blocked SO_3 flow from injector nozzle

Operations must also examine the way in which the SO_3 system is taken off line just prior to an expected outage and during forced outages as well.

Most modern SO_3 systems on the market today have a control philosophy that stops the injection of SO_3 below a certain boiler load and places the unit into a hold or stand-by mode, keeping it ready to inject SO_3 at anytime. At low loads the requirement for SO_3 is removed because the precipitator can handle low ash loading with little or no problem. Therefore, as boiler load is gradually decreased, at some point the injection of SO_3 stops and the system enters a purge mode. During this purge mode, the unit is kept hot to finish burning any residual sulfur and convert any residual SO_2 to SO_3, and to prevent the accumulation of sulfuric acid throughout the system due to cooling of residual gases. This process should not be circumvented by completely turning the unit off prior to complete purging of the system as recommended by the manufacturer. The residual SO_3 gases in the piping and injectors will cool to dew point and form sulfuric acid. It is impossible to re-vaporize this sulfuric acid once it has formed in the pipe work and injectors. In addition, the SO_3 unit should be allowed to remain in the hold mode to provide hot air to the injector nozzles, preventing ash accumulation as mentioned above, as long as the ID or FD fans are in operation. As with starting up the SO_3 unit, the airflow through out the SO_3 unit should be maintained anytime there is the possibility that ash is moving through the ductwork.

Tuning and maintenance of the SO_3 equipment, in order to achieve maximum SO_3 gas temperature in the piping and at the injectors, while still remaining within those operating temperatures that allow for maximum SO_2 conversion to SO_3, should also be considered as a means of preventing injector fouling.

The longer the SO_3 hot gas piping lines are to the injectors, the larger the heat loss along this route. In order to compensate for this heat loss, the outlet temperatures, as well as the airflow of the SO_3 system, should be reviewed and adjusted to maximize both while assuring proper operation of the SO_3 plant.

Figure 6 shows the decrease in efficiency of most converters as gas temperatures begin to rise. It reveals that good conversion can still be achieved in the 450 to 510 °C range. High converter outlet temperatures assure good heat input to the hot gas piping. High gas temperatures prevent injector fouling but must be balanced against conversion efficiency.

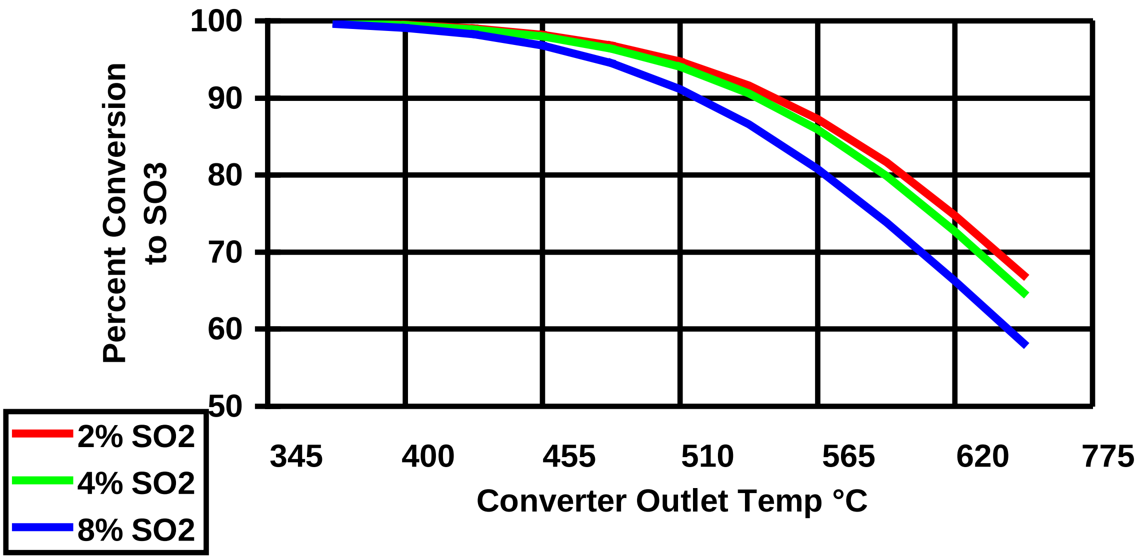

Figure 6: Converter Efficiency Graph at Varying Gas Strengths

One of the most common problems encountered in the field is the lack of maintenance or a break down in the insulation on SO_3 lines. It should be stressed that the conservation of every degree of heat along the SO_3 line is an effective way of preventing injector fouling. The following figures show problems associated with poor maintenance of SO_3 insulation.

Figure 7: Damaged insulation on SO_3 piping leading to injectors

Figure 8: This shows insulation being completely removed from SO_3 piping leading to the injector. The sulfuric green acid on the exterior indicates failure of the SO_3 piping due to acid attack. This unit also shows a bottom of the duct installation. Further complicating matters.

Figure 9: Injector inside of duct with insulation problems on the SO_3 line leading to injector

Based on observation in the field, the minimum inlet temperature to the injectors that seems to prevent most injector fouling is one that is greater than 320 °C. In most cases this will allow the injector temperature profile to remain above 230 °C. Although some manufactures may feel that lower temperatures are sufficient, this does not seem to be supported by evidence in the field. The reason for the high inlet temperature at the injector is that as the SO_3 gas flows down the injector, the volume of flow is gradually reduced as SO_3 is injected at each nozzle location. The reduced flow does not have not sufficient BTU's, when injected at lower inlet temperatures, to compensate for the heat lost through the injector insulation and the gas cools dramatically near the end of the injector. Most instances of injector fouling first occur at the bottom or last nozzle of the injector, fouling then progresses up toward the top or inlet of the injector. This gradual blockage further decreases flow, allowing for greater cooling of the SO_3 gas, which eventually leads to complete blockage of the injector.

The local climate has a big impact on the amount of sulfuric acid formed in the hot gas piping and SO_3 injector probes. One approach to both existing and new installations is to dry the combustion air used by the sulfur burning SO_3 gas generator systems. In existing systems, those installations that, due to cost or other factors, are unable to modify their injector installations or SO_3 piping system, may benefit from a dry air installation. This benefit would come in the form of reduced operational cost of injector maintenance, replacement and greater reliability of the SO_3 system in general. Greater reliability of the SO_3 system would reduce de-rates due to opacity problems associated with SO_3 equipment problems.

The next section explores a few of the different methods that could be used for drying air and presents the operating impacts of each. Dry air has the potential to remove the primary cause of injector fouling, sulfuric acid, which accumulates in both the SO_3 piping and injectors. When water is removed from the combustion air, the ability to form sulfuric acid in the piping and injectors is greatly reduced. The SO_3 gas still performs its desired function when released into the ductwork were ample moisture is available to form sulfuric acid and thus condition the ash prior to it entering the precipitator.

Dry Air SO_3 Flue Gas Conditioning

There are a number of practical methods for reducing the dew point of the combustion air. Compression of the air can reduce its moisture content. This is often seen at the combustion air blower discharge on units located in the Southeast United States. Cooling or chilling the air prior to entry into the SO_3 system can also reduce the dew point of the combustion air.

In a humid environment, approximately half the moisture in the air can be removed by chilling it to 60°F (16°C). Further reductions require the use of a desiccant type air dryer system. Simply getting to a 20°F (-7°C) dew point can result in a 90% reduction in the amount of sulfuric acid produced and reduce the sulfuric acid dew point by 120°F (67°C) as shown in fig 3.

The type of air drying system used will depend on the specific installation. For small SO_3 FGC systems that only require 200 SCFM of combustion air, it may be feasible to use equipment similar to that used in instrument air systems, which typically achieve dew points below -40°F (-40°C). For very large SO_3 FGC systems (>1,000 SCFM), air chillers and regenerative type air dryers can be used.

The use of dry air for SO_3 flue gas conditioning can also reduce the capital costs for new installations when combined with SO_3 gas flow splitting and biasing technology by eliminating the need for multiple sulfur burning FGC systems. A single larger sulfur-burning unit could provide the SO_3 gas necessary for two or more electrostatic precipitators. The cost of installation is also reduced in high-pressure systems (2 bar) due to smaller piping sizes and reduced insulation thickness.

Modifications to existing systems require the installation of one of the drying methods described above and some piping modifications to allow for the introduction of dry air at the existing SO_3 generation skid. As mentioned above, a single drying system may be able to provide sufficient air for several SO_3 generation skids. When weighed against continued replacement of injector lances and the increases in opacity associated with the failure of SO_3 conditioning due to injector fouling, the long term cost benefit becomes apparent.

Conclusion

Proper startup and operating procedures are critical in minimizing SO_3 injector fouling in sulfur burning SO_3 flue gas conditioning systems. The use of dry air for SO_3 flue gas conditioning can offer significant benefits over conventional wet air processes and can be especially beneficial where injector fouling is a recurring problem. SO_3 injection probes are expensive and a shutdown or “outage” is usually required to maintain them. Retrofitting existing system can be a cost effective means of reducing injector plugging and failure.

The overall effect is that the higher this process air dew point, the higher the sulfuric acid dew point and the greater the potential to generate sulfuric acid in the hot SO_3 gas piping. The advantages of using dry air for SO_3 flue gas conditioning can be summarized in this way:

- Reduces the quantity of sulfuric acid generated in hot gas piping, resulting in an exponential decrease in the quantity of sulfuric acid per degree of improvement in dew point of process air.

- Reduces the dew point of SO_3 process gas at a rate of approximately a degree for degree decrease in dew point of sulfuric acid with improvement in dew point of process gas.

References

1. William Hankins, Ray George. Cost Efficient Flue Gas Conditioning System. Presented at American Power Chicago April 1993.