Utilizing Dry Sorbent Injection Technology to Improve Acid Gas Control

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ABSTRACT

Today there are a number of existing industrial facilities that have already installed air pollution control technologies for acid gas control to comply with previously mandated emission regulatory requirements. However, new and existing facilities are forced to comply with even tighter emission requirements as new regulations are implemented and/or as their fleet of air pollution control technologies begin to age and performance may degrade. Typically these industrial facilities have utilized wet or dry scrubbing technologies for compliance. However, dry sorbent injection (DSI) technology has proven to be a low capital cost investment option to enhance a facility's acid gas scrubbing efficiency, which can be easily retrofitted to most existing plant configurations. As DSI technology has matured, the systems have become more reliable and advancements in calcium based sorbents have provided new compliance solutions that weren't available in years past. The enhanced physical properties of Lhoist's Sorbacal® SP and SPS enhanced hydrated lime products have demonstrated at least 90% SO_2 reduction with DSI technology over a range of applications where DSI was an "add-on" air pollution control technology to an existing Flue Gas Desulfurization (FGD) system. Additionally, as high as 99% HCl removal has also been achieved in high HCl applications, such as a waste incinerator when using DSI technology coupled with Lhoist's Sorbacal® products. This paper will present data from full scale DSI demonstration testing for SO_2 and HCl control at a variety of applications using Lhoist's Sorbacal® products, which may be beneficial to waste burning and incinerator facilities.

INTRODUCTION

The landscape of environmental regulations in the United States is complex and continues to develop. It includes compliance deadlines for various hazardous air pollutants via the Mercury Air Toxics Standards, SO_2 and NO_X via the Cross State Air Pollution Rule or Regional Haze as well as consent decree agreements made by plants with state and local environmental agencies. These regulations and agreements will require an increased emission reduction for a number of acid gas species (i.e. SO_2, HCl, HF, SO_3), Mercury (Hg) and particulate matter. As a result of the need to comply with these stringent emission limits there is a growing desire for DSI and activated carbon injection (ACI) technologies, which offer a low capital cost solution with a relatively small equipment footprint, low power consumption and the ability to easily retrofit a majority of existing facilities compared to alternative technologies such as wet and dry FGD.

Over time the plants that installed FGD systems may have a need to achieve incremental increases in SO_2 removal efficiencies due to changing regulations and/or changing fuels or due to degradation in performance from an aging FGD system. Using DSI as an "add-on" technology to plants with existing Flue Gas Treatment (FGT) systems offers the following advantages;

- Increase overall SO_2 removal efficiency beyond current "ceiling" of existing FGD system performance
- Ability to provide fuel flexibility to utilize higher sulfur fuel while maintaining current SO_2 removal efficiency and/or SO_2 emissions without substantial retrofit to existing FGD system
- Improve system reliability and flexibility by utilizing DSI to alleviate operating pressure of FGT system by reducing slurry feed in these systems, which may aid in reducing build up and erosion potential of spray nozzles
- Utilize DSI as a complete replacement of existing FGT systems, which are proving to be costly and troublesome from an operations and maintenance perspective
- Enable a plant to minimize or avoid handling a slurry product within existing FGT system and instead utilize a dry product as is the case with utilizing DSI

DSI is a mature technology that has been widely applied since the early 2000's by utilities in the USA requiring SO_3/H_2SO_4 emissions reduction for mitigation of a visible blue plume. DSI offers the following benefits over other acid gas control technologies;

- Low installed capital cost
- Relatively easy to retrofit to a majority of facilities (only injection lances are in contact with exhaust gas)
- System has good process flexibility for various sorbents and ability to easily modulate based on unit load and/or different fuels
- Small equipment footprint (typically footprint of one or two silos and blower building)
- Relatively short schedule as there is approximately one year schedule from contract award to commercial operation
- Low consumable requirements (i.e., air and water) as well as low parasitic power requirements

Over the past few years there have been significant design improvements to DSI systems based on operating experiences from past installations, which have increased current DSI system design reliability and availability. Concurrently, there have also been developments to improve the performance of some DSI sorbents (i.e., enhanced hydrated lime sorbents) such that a given level of acid gas removal can be achieved at lower sorbent injection rates or alternatively an improved performance previously unattainable can now be obtained. This paper discusses the development and application of Sorbacal® SP and SPS, which are enhanced hydrated lime products that have been developed and engineered by Lhoist specifically for acid gas emission control applications. This paper will also address how the performance of Lhoist's enhanced hydrated lime sorbents has created an additional compliance solution for acid gas (HCl, SO_2, SO_3/H_2SO_4 and HF) control.

There is an abundance of past DSI data and experience from the utility industry in the USA which has helped establish DSI as a viable acid gas control technology. However, the past few years have illustrated that the industry is quickly evolving as new applications are appearing and new industries are evaluating and applying DSI technology for acid gas control as the overall constraints have changed in recent years (i.e., control efficiencies required, desire for dry technologies to avoid needing to treat an effluent stream, concerns over fly ash / residue leaching due to use of sodium sorbents[1], etc.). Recent full-scale trials utilizing enhanced hydrated lime sorbents such as Sorbacal® SP and SPS are surpassing previously perceived performance limitations of DSI technology and opening up the potential for more applications and opportunities that were not previously considered viable. Utilities, which have been using DSI systems for acid gas control are "pushing the envelope" by additional optimization efforts through the use of improved mixing technologies as well as further improvements to equipment design to further improve DSI system reliability in addition to the discovery of operational co-benefits to improve plant operation and reliability[2].

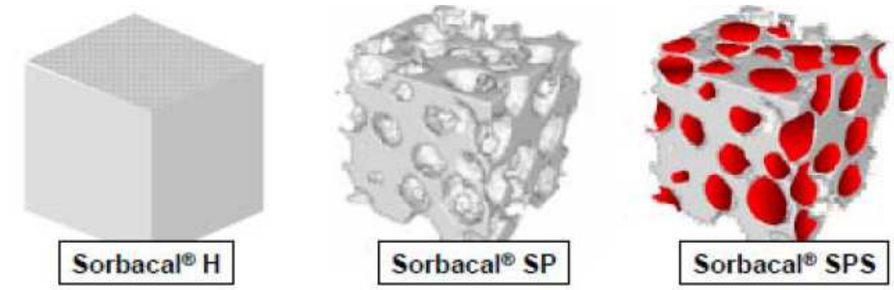
Sorbacal® Development

The first generation of enhanced hydrated lime sorbents (designated by Lhoist as Sorbacal® A) was developed in the 1980's by increasing the surface area of hydrated lime from around 20 m^2/g seen in standard hydrated limes to about 38 m^2/g. The high surface area combined with a small particle size, gave Sorbacal® A a significant performance enhancement compared to standard hydrated lime. During the acid removal reaction, the rate is slowed down because the reaction products, such as $CaSO_4$, form a diffusion layer on the fresh unreacted $Ca(OH)_2$ material. More important, the reaction product $CaSO_4$ has a higher molar volume and thus gradually fills up the porosity of the sorbent.

Extensive research by the Lhoist group in the 1990's showed that indeed both the capture capacity and the reactivity of the sorbent are directly proportional to the pore volume. In contrast, the surface area was found to be contributing to a lesser extent to the acid gas removal efficiency. This research led to the development of a second generation of sorbents with both a higher pore volume (> 0.2 cm^3/g), which is twice that of standard hydrated lime) and a higher surface area (> 40 m^2/g), which Lhoist designated as Sorbacal® SP. Laboratory scale, pilot scale and commercial scale tests have demonstrated that the reactivity of Sorbacal® SP can be up to twice that of high quality hydrated lime.

The third generation of sorbents is designated as Sorbacal® SPS and combines the enhanced pore structure properties of Sorbacal® SP with a chemical reaction enhancement, which provides an additional reaction rate enhancement over that of Sorbacal® SP. Today, Lhoist operates six Sorbacal® SP/SPS manufacturing locations in Europe, has licensed the technology to five Japanese plants and has a manufacturing location in the USA with two additional Sorbacal® SP/SPS hydrators becoming operational during the 1st quarter of 2016. Figure 1 shows the characteristics of the different sorbents in graphical form.

Figure 1. Illustration of Various Hydrated Lime Particles



This paper presents two case studies for SO_2 abatement using DSI technology at Industrial and Utility applications with existing FGD systems and one case study where DSI was applied to a medical waste incinerator, which required additional HCl capture utilizing DSI technology as primary means for acid gas control technology. These cases represent a wide range of applications (Utility and Industrial) and operating conditions. Table 1 provides a brief summary of each case to highlight their differences.

Table 1. Summary of DSI Case Studies Presented

Unit Size	Sorbent(s)	Fuel(s)	Particulate Control Device	Baseline Acid Gas
500 MW	Sorbacal® SPS	Low Sulfur Coal	Pulse Jet FF	225-250 ppmv SO_2
55,000 ACFM	Sorbacal® SPS	Industrial	Pulse Jet FF	300 ppmv SO_2
55,000 ACFM	Sorbacal® SP	Medical Waste	Pulse Jet FF	575-1,250 ppmv HCl

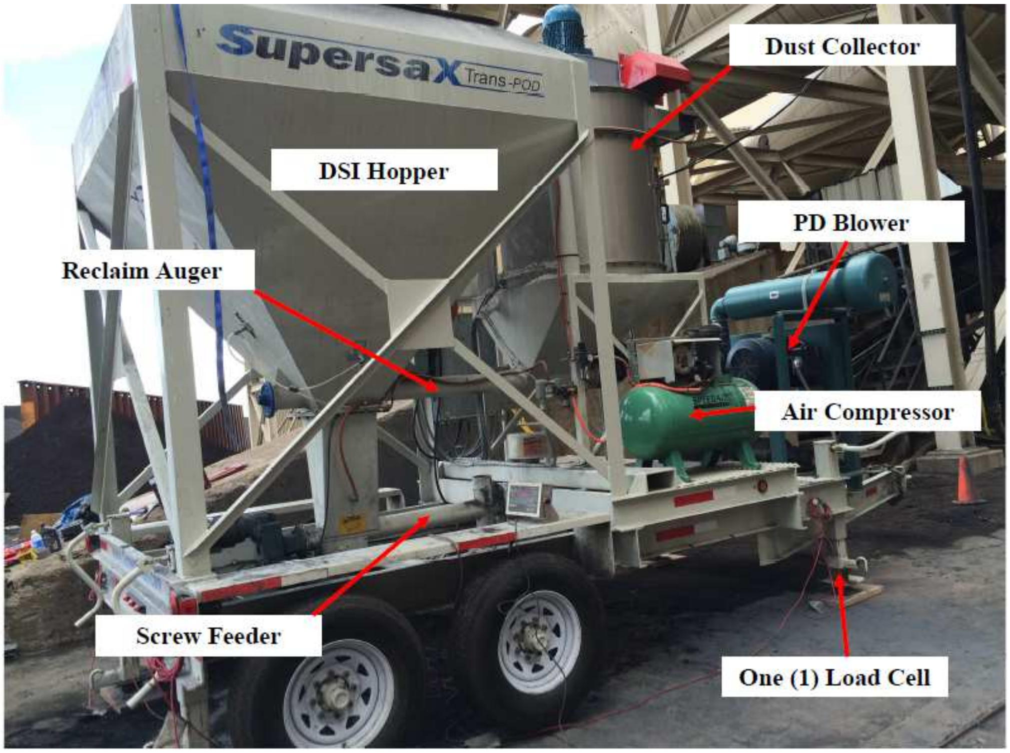
PROJECT APPROACH

The project approach for each case study described in this paper varied based on the needs and constraints at each respective facility. The data presented in this paper is based on short term parametric tests, which represent "proof of concept" evaluation of DSI technology with Lhoist's enhanced hydrated lime sorbents. While the results presented in this paper represent an accurate representation of DSI technology's ability to mitigate HCl and SO_2, a long term evaluation may be desirable to fully understand how fluctuations and variations in process conditions at each application will impact performance. Longer term testing will allow a facility to develop a larger data pool to make correlations to acid gas emission control and to evaluate the impact on the balance of plant processes.

Case Study #1 was a 500 MW EGU evaluating DSI technology with various alkaline sorbents in order to meet a future SO_2 emission reduction requirement. The plant uses a coal with sulfur content comparable to Powder River Basin (PRB) coal as the fuel. The system configuration includes a regenerative air heater for boiler heat recovery, FGD for SO_2 control and a pulse jet fabric filter for filterable PM control. The plant was evaluating DSI technology with Lhoist's Sorbacal® SPS as well as a standard FGT grade hydrated lime and a pre-milled sodium bicarbonate to determine if DSI was a viable solution to retrofitting the existing FGD in order to further reduce SO_2 emissions.. The existing FGD was not able to achieve the necessary SO_2 removal to meet compliance with the future regulations due to inadequate system design. The plant performed a short term parametric DSI trial conducted over five days as a "proof of concept" test of the DSI technology and various alkaline sorbents. Lhoist's Sorbacal® SPS was tested during two 12 hour test days and a temporary DSI test skid system mounted on load cells for gravimetric operation was used to inject the alkaline sorbents. DSI storage silo weights were logged manually every 10 minutes, which were used to calculate the sorbent injection rates. The plant had an existing SO_2 CEM located at the stack and upstream of the DSI location, which provided one minute average SO_2 emission data. Baseline SO_2 removal efficiencies prior to the start of DSI testing determined the average SO_2 removal efficiency and this existing FGD's average SO_2 removal efficiency was then applied during the DSI testing in order to calculate the incremental SO_2 removal provided by each respective sorbent.

Case Study #2 was an industrial plant requiring treatment of SO_2 in the exhaust gas, which was generated as a byproduct of the industrial manufacturing process. The plant was evaluating DSI technology with Lhoist's Sorbacal® SPS to determine if DSI was a viable solution to retrofitting the existing FGD system in order to reduce SO_2 emissions. The existing FGD was not able to provide consistent and reliable SO_2 compliance due to the system design and could not achieve the 95% SO_2 removal efficiency that was required. However, during DSI testing, the existing FGD vessel was used to reduce exhaust gas temperature upstream of the pulse jet fabric filter by spraying water into the exhaust gas (no slurry) to protect the filter bags. The plant performed a short-term parametric DSI trial conducted over three days using Lhoist's Sorbacal® SPS. Lhoist supplied and operated a temporary DSI test skid system, which was mounted on load cells for gravimetric operation and DSI hopper weights were logged manually every 10 minutes to calculate the sorbent injection rates. The plant rented a temporary SO_2 CEMS, which was placed at the stack and also used a handheld SO_2 monitor to do spot checks at the stack and upstream of the DSI location. The temporary SO_2 CEMS provided one minute average data, which was stored on a laptop. Since SO_2 emissions were not monitored upstream of the DSI location the baseline SO_2 conditions were determined by measuring the SO_2 emissions prior to the start of DSI testing in order to calculate the SO_2 removal efficiency. Figure 2 is a photograph of Lhoist's DSI super-sack test skid system, which was used for testing at Case Study #2 facility.

Figure 2. Lhoist DSI Super-Sack Test Skid System



Lhoist's DSI super-sack test skid system in Figure 2 consists of the following components:

- DSI hopper, which holds approximately 3,300 lbs of hydrated lime
- A screw feeder with variable frequency drive (VFD) to meter sorbent into the eductor and control the sorbent injection rate with a range of approximately 30-1,000 lb/hr
- An eductor used to meter sorbent into the conveying line and mitigate conveying line blowback
- A positive displacement blower, which pressurizes ambient air for use as the motive air to convey sorbent from the pick-up point into the exhaust gas
- An air compressor with desiccant to provide dry air to fluidize the bottom of the hopper and clean the dust collector filter bags
- A dust collector and vent fan used to reduce fugitive dust emissions
- A reclaim auger to recycle fugitive dust captured by the dust collector back to the hopper
- Four load cells (one per trailer leg) including a summation box and scale read-out to monitor trailer weight
- Air pads and a mechanical vibrator to aide sorbent fluidization and minimize rat-holing and bridging
- Conveying hose, splitters and injection lances to convey sorbent from the DSI test skid and disperse sorbent within the exhaust gas stream

Case Study #3 was a medical waste incinerator that had previously performed parametric testing of DSI technology with various alkaline sorbents and moved forward with installation of a permanent DSI system in order to comply with tighter HCl emission regulatory requirements. The plant has two multi-chamber incinerators in which medical waste is fed in order to destroy pathogens and remove bottom ash that falls out during incineration. Upon exiting the incinerator chambers, the exhaust gas enters a heat recovery boiler and then enters a pulse jet fabric filter. The plant injects Powdered Activated Carbon (PAC) and hydrated lime at the fabric filter inlet via a multi-lance injection grid. Once the permanent DSI system was installed, the plant performed long-term testing to evaluate various sorbents including Lhoist's Sorbacal® SP to determine the most economical solution for long term operation. Lhoist's Sorbacal® SP was tested over a nine day period with injection occurring 24 hours per day using the permanent DSI system, which operated gravimetrically via load cells mounted under the DSI weigh hoppers. The plant had existing HCl monitors at the stack and upstream of the DSI location which provided one minute average HCl emission data points.

RESULTS AND DISCUSSION

Case Study #1 – SO_2 Control for 500 MW Electric Generating Utility Application

The plant's objective was to increase the overall SO_2 removal efficiency from approximately 45-50% to at least 70% while injecting Lhoist's Sorbacal® SPS upstream of the existing FGD. Sorbacal® SPS was injected downstream of the air heater and upstream of the existing FGD inlet using five injection lances where the exhaust gas temperature was approximately 275-300°F. While the flue gas moisture from the existing FGD was not provided, the stack relative humidity was measured to be in the 18-21% range throughout DSI testing. During DSI testing the baseline SO_2 emissions were approximately 225-250 ppmv (wet). Figure 3 is a summary of the results from the Sorbacal® SPS DSI testing.

Figure 3. Sorbacal® SPS Performance for SO_2 Abatement on 500 MW EGU with FGD / PJFF

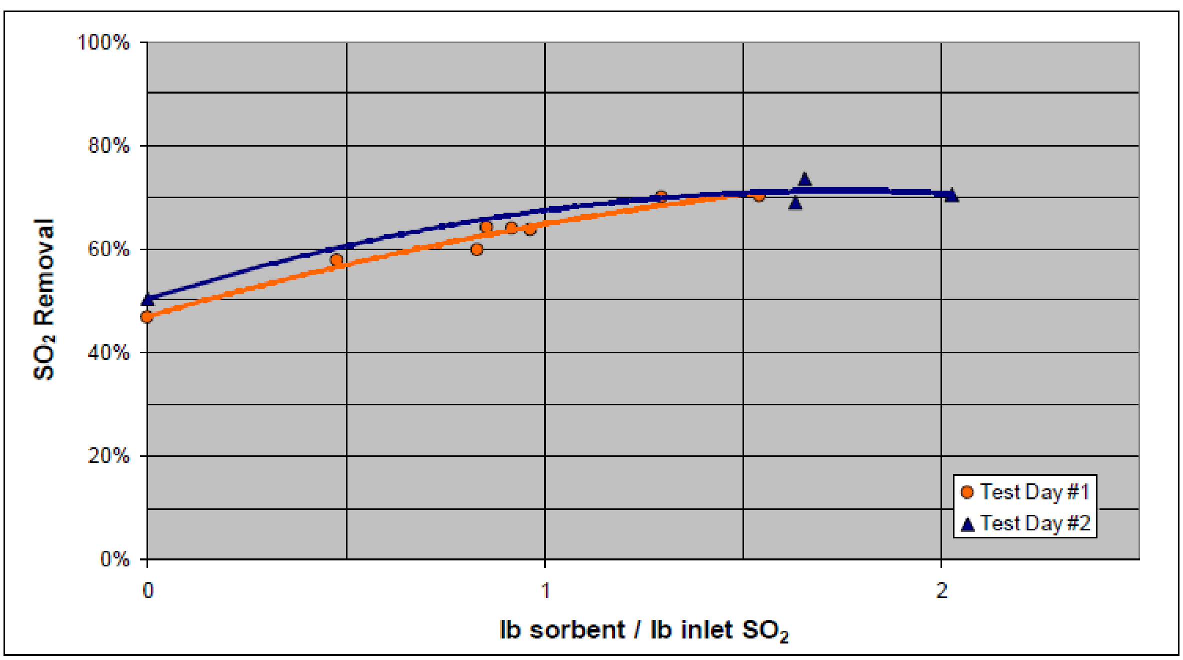


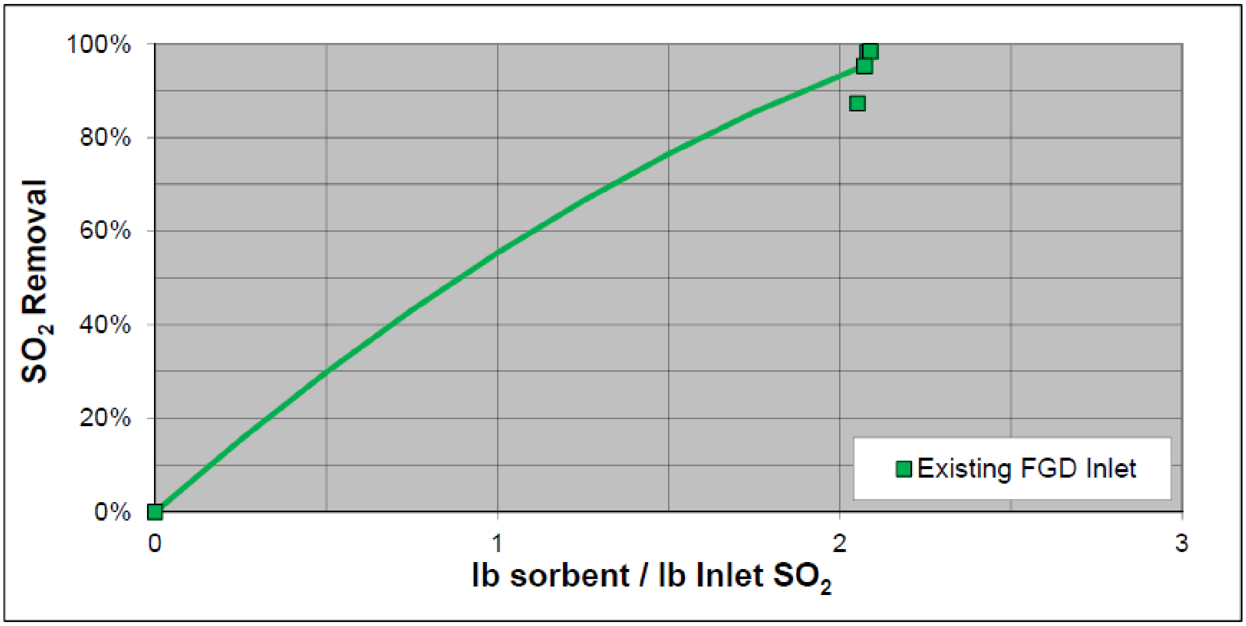
Figure 3 shows that prior to Sorbacal® SPS injection the existing FGD was achieving 45-50% SO_2 removal. Injection of Sorbacal® SPS was successful in increasing the plant's overall SO_2 removal to approximately 70% using DSI technology with a mass ratio of 1.25 – 1.50 lb sorbent / lb inlet SO_2. Since the plant achieved their targeted SO_2 removal efficiency higher injection rates were not evaluated to determine the maximum amount of SO_2 removal possible. Figure 3 shows that the DSI test results with Sorbacal® SPS was consistent and reproducible by comparing the test results from Test Day #1 to Test Day #2. Overall, the DSI trial with Sorbacal® SPS was successful in achieving the desired SO_2 removal efficiency and additional optimizations could further improve the SO_2 removal efficiency and/or improve sorbent utilization (i.e., shift Figure 3 mass ratio curve to the left). Potential optimizations in performance could be:

- Injection upstream of the air heater to increase sorbent residence time, provide better sorbent-to-gas mixing as well as provide improved kinetics at the hotter flue gas temperature.
- An engineered injection grid designed to provide appropriate injection lance quantity, spacing and lengths to optimize sorbent coverage across ductwork cross-sectional area.
- Process optimizations involving operation of existing FGD and/or fabric filter operation (i.e. optimize fabric filter cleaning cycles).
- Optimization could be realized by more long-term operation and conditioning of the system not observed from short-term parametric testing.

Case Study #2 – SO_2 Control for 55,000 ACFM Industrial Application

The plant's objective was to achieve at least 95% SO_2 removal efficiency while only using the existing FGD as a quench tower (no slurry) and Lhoist's Sorbacal® SPS. Sorbacal® SPS was injected into a 5 foot diameter round duct using a single injection lance where the exhaust gas moisture was approximately 36% by volume while SO_2 emissions were continuously measured by stack SO_2 analyzer. Prior to the start of DSI testing the baseline SO_2 emissions were approximately 300 ppmv (wet). Figure 4 is a summary of the Sorbacal® SPS test results.

Figure 4. Sorbacal® SPS Performance for SO_2 Abatement on Industrial Plant with PJFF



Sorbacal® SPS was successful in achieving 95% SO_2 removal (as noted by green squares in Figure 4) while injecting at the existing FGD inlet. Continued testing was successful in reproducing the performance as evident by Figure 4. The test results showed that at least 95% SO_2 removal efficiency was achievable with Sorbacal® SPS at a mass ratio of approximately 2 lb sorbent / lb inlet SO_2 while injecting at the existing FGD inlet.

As the existing FGD inlet testing progressed the fabric filter differential pressure began to increase as the filter cake appeared to become more difficult to clean from the filter bags, which required additional manual compressed air cleaning to return back to the typical fabric filter differential pressure range. It is believed this impact on the fabric filter operation was due to the poor design of the existing FGD. If additional residence time were provided to ensure evaporation of the water droplets and/or a finer water droplet particle were obtained then sufficient drying of the dust loading to the fabric filter would be expected, which would prevent reoccurrence of this observed balance of plant effect.

Sorbacal® SPS was successful in achieving the desired SO_2 abatement while using the existing FGD vessel as only a quench tower (no slurry). While the existing FGD inlet injection location achieved the desired performance as indicated by Figure 4 additional optimizations at this location could include:

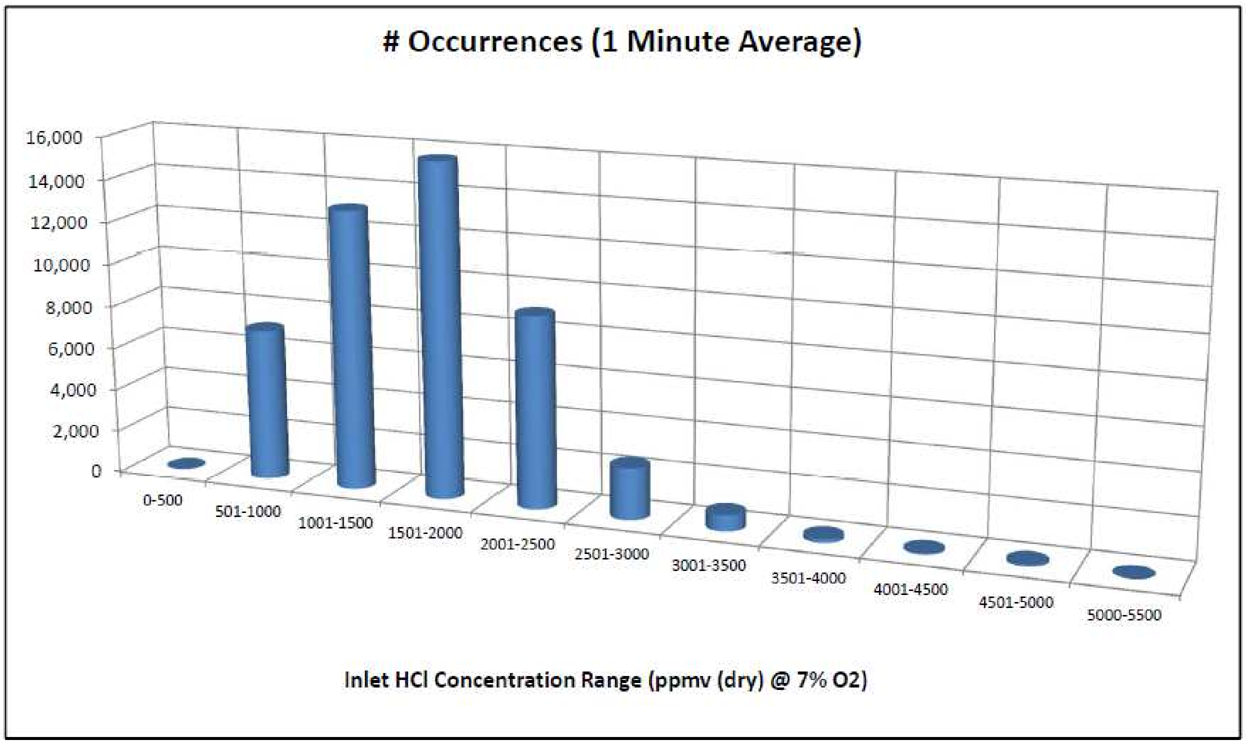
- Injection further upstream to the existing FGD inlet to increase sorbent residence time, provide better sorbent-to-gas mixing as well as provide improved kinetics at the hotter flue gas temperature.
- A properly engineered injection grid designed to provide appropriate injection lance quantity, spacing and lengths to optimize sorbent coverage across ductwork cross sectional area.

- Process optimizations involving operation of existing FGD (i.e., quench spray quantity and design) and/or fabric filter operation (i.e., optimize fabric filter cleaning cycles).
- Optimization could be realized by more long-term operation and conditioning of the system not observed from short-term parametric testing.

Case Study #3 – HCl Control for Medical Waste Incinerator

The plant's objective was to install a modern permanent DSI system to increase the overall HCl removal efficiency to achieve a more stringent regulatory limit on a 24-hour rolling average. Given the high variability of the chloride concentration in the waste incinerated a reliable DSI system was necessarily to ensure compliance. Figure 5 illustrates the variability in HCl emissions as measured by the HCl monitor upstream of the DSI injection location. In order to comply with the plant's regulatory HCl limit essentially all inlet HCl emissions were in excess of 500 ppmv (dry) @ 7% O_2, which requires at least 98.7% HCl removal efficiency.

Figure 5. Baseline HCl Concentration Distribution from Medical Waste Incinerator



Lhoist's Sorbacal® SP was one of the alkaline sorbents evaluated at this facility in order to demonstrate the viability of this sorbent to achieve this high degree of HCl removal efficiency. Sorbacal® SP was injected downstream of the heat recovery boiler and upstream of the fabric filter using eight injection lances per duct (two ducts total) where the exhaust gas temperature was approximately 500-600 °F.

Figure 6 shows a real-time 24-hour snapshot of the DSI performance using the permanent DSI system while injecting Sorbacal® SP. The blue and orange lines represent the stack and inlet

HCl emissions, respectively, as measured by the plant's installed HCl monitors. The maroon line represents the real-time sorbent injection rate measured gravimetrically by the permanent DSI system, which was measured by load cells installed on the weigh hoppers. Figure 6 illustrates how utilizing DSI with Sorbacal® SP was successful in reducing average daily HCl emission below the target of 6.6 ppmv (dry) @ 7% O_2; however, there were a few HCl excursions observed, which briefly exceeded the target HCl emissions. The first HCl excursion observed in Figure 7 illustrates the response of the DSI system while injecting Sorbacal® SP when inlet HCl excursions occurred due to a high chlorine waste product being incinerated. When the inlet HCl concentration spiked above the typical inlet concentration (> approximately 2,500 ppmv (dry) @ 7% O_2) while the sorbent injection rate set point was held constant the stack HCl concentration would increase. Figure 6 shows this effect and the plant's response to increase the sorbent injection rate in order to reduce stack HCl emissions below the 6.6 ppmv (dry) @ 7% O_2 target. The second HCl excursion observed in Figure 6 represents the HCl recovery from the daily HCl monitor calibration once the HCl monitor's operating status was changed from "calibrating" to "operating" in which the HCl emissions were then to be counted towards the plant's rolling HCl average. From Figure 6 it can be observed that once the HCl monitor was back online following calibration an additional 60-90 minutes were required after the HCl monitor calibration completion for 100% recovery of pre-calibration HCl emissions. This occurrence was non-trivial due to the high degree of HCl removal efficiency required by this plant in order to demonstrate HCl compliance.

Figure 6. Daily Plot of Real-Time HCl Performance Using Sorbacal® SP

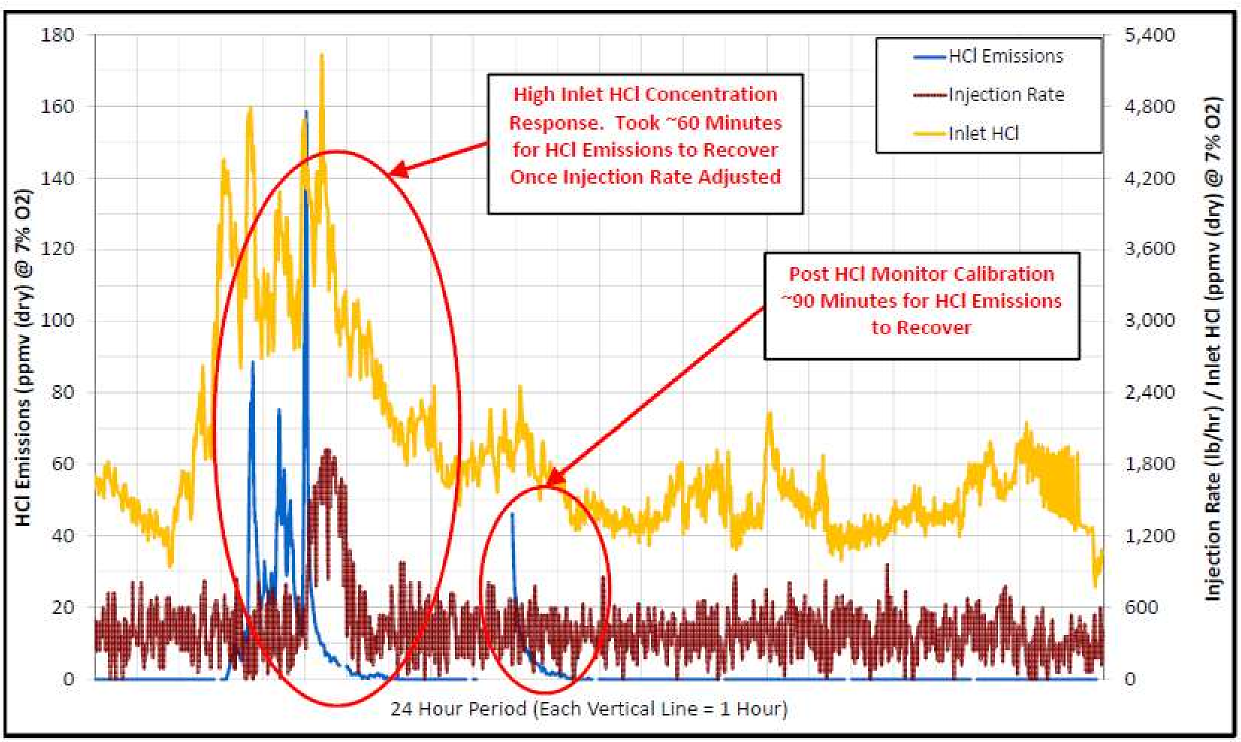
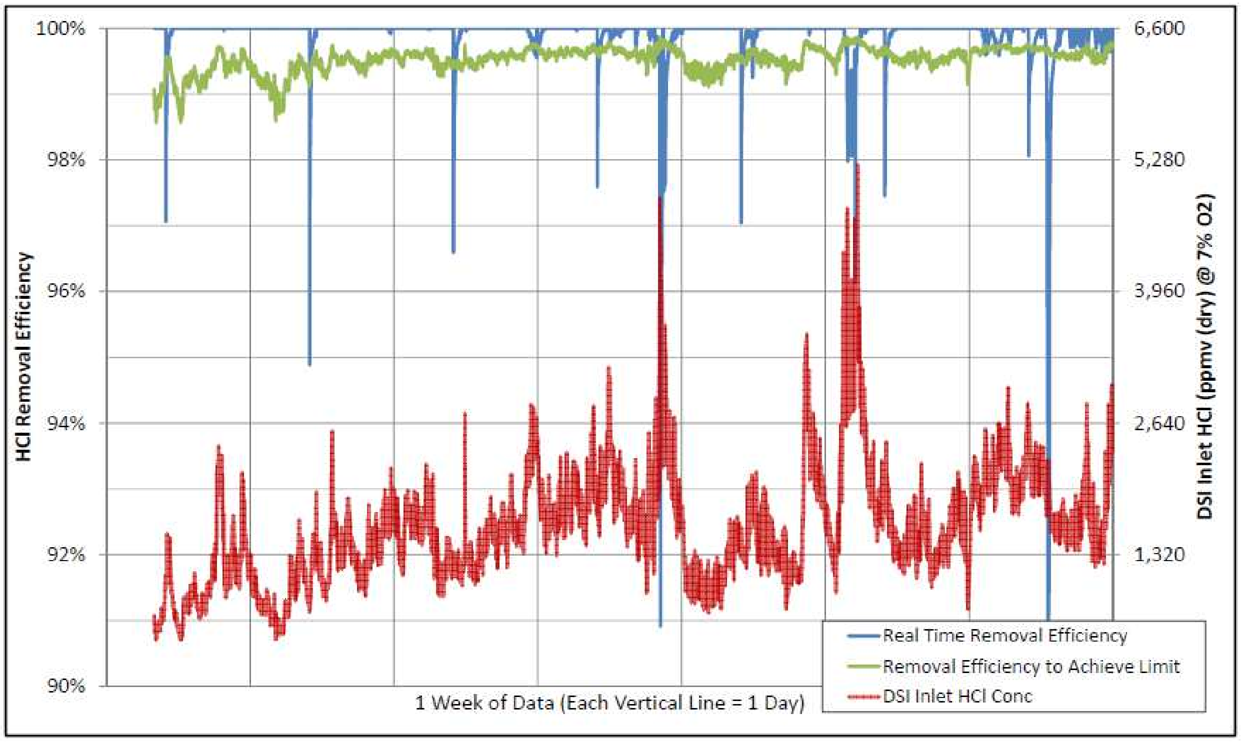


Figure 7 shows a real-time plot of HCl removal efficiency achieved with the permanent DSI system while injecting Sorbacal® SP as well as the real-time HCl removal efficiency required to meet the 6.6 ppmv (dry) @ 7% O_2 HCl emission target as well as the DSI inlet HCl concentration as this over the course of the week long DSI trial with Sorbacal® SP. The HCl excursions discussed in Figure 6 are observed throughout Figure 7 as the daily spikes downward in HCl removal efficiency are the HCl monitor calibration issue previously described or DSI inlet HCl concentration excursions. Figure 7 shows that despite the high degree of variability in the DSI inlet HCl concentration and high HCl removal efficiency required utilizing DSI technology and injecting Sorbacal® SP was successful in maintaining HCl emission compliance.

Figure 7. DSI Testing Snapshot of Real-Time HCl Performance Using Sorbacal® SP



SUMMARY

Lhoist conducted multiple full-scale trials using DSI technology as an “add-on” system to plants with existing FGT systems to enhance the overall SO_2 emission control solution. Additionally, Lhoist performed a successful full-scale DSI trial at a medical waste incinerator, which required high HCl removal efficiency from exhaust gas where baseline HCl emissions typically exceeded 500 ppmv (dry) @ 7% O_2. In these full-scale DSI trials Lhoist’s Sorbacal® SP or SPS was the sorbent tested at each facility to demonstrate the viability of the proposed solution using Lhoist’s enhanced hydrated lime products. Based on the full-scale DSI trials described in this paper Lhoist concludes the following:

- Case Study #1 demonstrated that utilizing DSI using Sorbacal® SPS as “add-on” controls to existing FGD was a viable solution to enhance the overall SO_2 removal efficiency even on a large facility such as a 500 MW Electric Generating Utility.
- Case Study #2 demonstrated that DSI using Sorbacal® SPS could potentially be a viable retrofit solution on facilities with under-performing existing FGD systems by fully

eliminating the slurry spray in the existing FGD and relying strictly on DSI to achieve the required SO_2 removal efficiency.

- Case Study #2 also illustrated that DSI technology has the ability to achieve high SO_2 removal efficiencies (> 95% SO_2 removal efficiency) using Sorbacal® SPS. Comparing the results from this case study with past DSI trial data indicate that sorbent utilization and the relative DSI performance is also dependent on the exhaust gas properties such as acid gas concentration, flue gas moisture content, etc.
- Case Study #3 demonstrated that using DSI with Sorbacal® SP was successful in consistently providing a high HCl removal efficiency (> 98% HCl removal efficiency) over a week-long trial at a medical waste incinerator where the inlet HCl concentration was highly variable due to the variability of the waste incinerated.

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KEYWORDS

Dry sorbent injection, Sorbacal® SPS, Sorbacal® SP, sulfur dioxide, SO_2, hydrogen chloride, HCl, electrostatic precipitator, fabric filter, spray dryer absorber, enhanced hydrated lime, flue gas desulfurization, calcium hydroxide, waste incinerator.