OPERATIONAL CONSIDERATIONS AND LESSONS LEARNED FOR DRY SORBENT INJECTION SYSTEMS

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ABSTRACT

Dry sorbent injection (DSI) has become a widely accepted acid gas (SO_2, HCl, HF, SO_3) emission control solution for a multitude of industries, including the glass industry. While the technology offers a relatively simple and low capital cost solution it also has operational and design components which should be properly considered to minimize future headaches for the end user. Lhoist North America will describe a range of issues that have been experienced over the past decade of operating experience and provide some considerations and lessons learned that may be valuable for the glass industry. These topics aim to provide value to end users, as it may provide insight into current DSI operational users in the glass industry or alert new/future DSI end users in the glass industry of issues to look out for to ensure their DSI system has maximum reliability and optimized system performance. Such issues may include DSI design considerations, addressing conveying line design as well as scaling/plugging, sorbent dispersion, as well as operating cost optimization potential with enhanced hydrated lime products. This paper will include photos and case studies from actual DSI installations which address the problems, lessons learned and solutions. The objective of this paper is to provide a guide explaining common DSI issues, based on a decade of actual operating experience, in order to reduce the learning curve for DSI system users in the glass industry and to ensure the DSI technology remains a cost effective and trusted technical solution for acid gas control.

INTRODUCTION

Driver for Installation of DSI Systems

The glass production process can lead to the generation of acid gas emissions, in particular SO_2, HCl and HF, as a result of fuel combustion and/or from the raw materials. While many glass production facilities utilize natural gas or fuel oil, the raw materials as well as additives used in the manufacturing process typically dictate the acid gas emissions profile. Subsequently, glass producing facilities are required to control their acid gas emissions as a result of emission limits dictated in their operating permit, consent decrees and/or other regulatory mandates.

The Clean Air Act has previously driven the acid gas emission control requirements; however, other regulations and limits have also come into play such as (National Ambient Air Quality Standards) (NAAQS) which drives increasingly more stringent SO_2 emissions. The Resource Conservation and Recovery Act (RCRA) presents some additional regulatory hurdles on heavy metals that the glass industry must comply with. These regulations set forth the need for economical and innovative solutions to tackle emissions of acid gases (HCl, SO_2, and HF) as well as stabilize heavy metals in residues (arsenic, vanadium, lead, and selenium). DSI is a multi-purpose, low capital cost solution to comply with these regulatory needs; functioning as both a means of mitigating acid gases as well as improving the stability of heavy metals in waste residues.

DSI also provides operational benefits beyond acid gas emissions controls, such as corrosion protection, minimized air heater/heat exchanger "fouling," and reduced heavy metal leachability in residues just to name a few[1]. The electric generating utility (EGU) industry has done significant work with DSI in the past two decades having installed hundreds of DSI systems for acid gas emission control. Additionally, the EGU industry is currently exploring utilization of DSI to take advantage of these co-benefits in order to reduce operating costs to compete against other forms of power generation such as natural gas, wind and solar power.

DSI System Background

DSI systems are an attractive Air Pollution Control (APC) technology for controlling acid gas emissions due to relatively low capital cost and high flexibility[2]. Hundreds of DSI systems have been installed on both EGU and industrial facilities in the past two decades due to regulatory drivers put in place over that time period[3]. While each end user may have a customized DSI design, each DSI system generally consists of a motive air system, storage silo, dosing system, piping / portioning device as well as injection lance system (refer to Figure 1)[2].

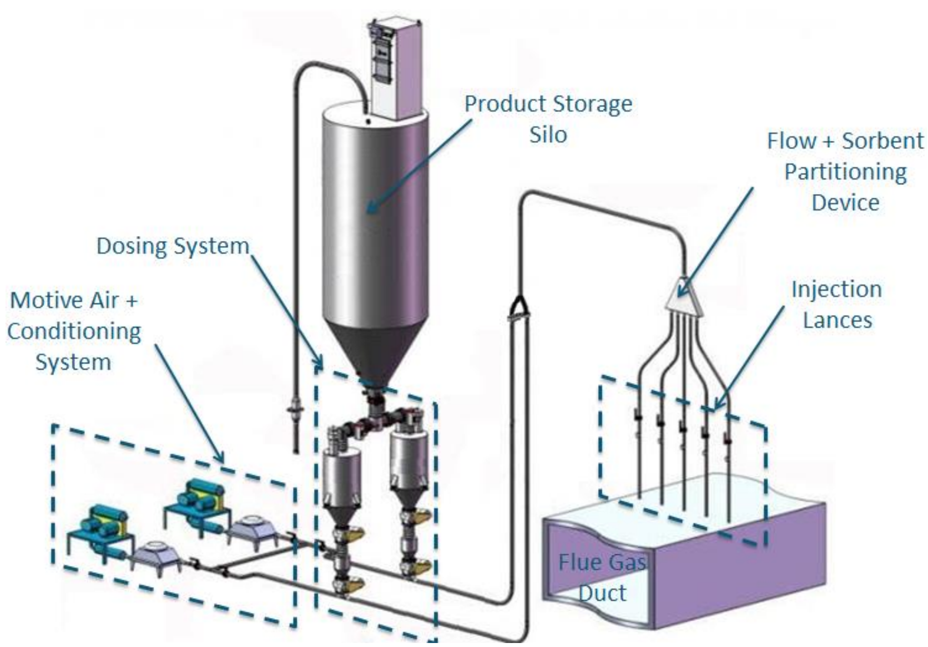


Figure 1 – Generic Schematic of Typical DSI System

Some important fundamental questions around the DSI system process should be answered that can dictate system reliability and flexibility as well as capital cost expense:

1) Motive air – How many blowers are needed? Is the motive air conditioned? What equipment is necessary to condition motive air?
2) Sorbent unloading – Should a conditioned air unloading system be used or only the truck unloading blowers?
3) Sorbent storage – Is a silo or super-sack system required? How much storage capacity is necessary? Should the silo be designed for hydrated lime or sodium sorbents or both?
4) Silo fluidization – Should vibrating bin bottom or fluidizing air be installed or install both?
5) Dosing System – Screw feeders or rotary valves? Volumetric or gravimetric feed design? How can motive air blow back be minimized? What dosage rate to design for? How much turn-down capacity is necessary?
6) Sorbent Milling – Is on-site sorbent milling necessary to reduce particle size?
7) Piping – What line size should be used? What types of elbows are recommended? What is the proper piping design?
8) Partitioning – How can sorbent flow be evenly to each injection lance?
9) Injection Grid – How many lances should be used? Where should injection lances be installed? How long should the injection lances be? How can injection lances plugging be minimized?

Photo 1 below illustrates how answering these fundamental questions based on each site's specific needs and constraints can lead to very different DSI system designs, showing a shop fabricated DSI silo system in contrast to a super-sack system.

Photo 1 – View of DSI Silo System vs. Super-Sack System[4]

HYDRATED LIME SORBENTS REVISITED

A previous Lhoist presentation described the development of enhanced hydrated lime sorbents (EHLS), in particular the development of the 2nd and 3rd generation EHLS which are now commercially available around the globe[2]. Realization of the importance and effects of physical properties such as particle size distribution (PSD), pore volume, and surface area led to the development of EHLS by engineering these properties to create more reactive hydrated lime sorbents. Each hydrated lime's specific physical properties have a direct impact on acid gas removal performance; learnings obtained during EHLS development continue to promote the evolution of EHLS. Physical properties and resultant effectiveness of sorbents in DSI systems can have balance of plant implications which will be discussed in more detail. Figure 2 compares various commercially available hydrated lime sorbents and their typical properties.

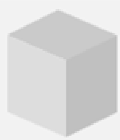
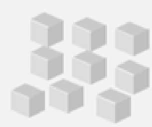
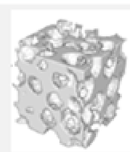
Sorbent	Standard Hydrated Limes	High Quality Standard Hydrated Lime	2nd Generation EHLS	3rd Generation EHLS
Figure				ACTIVATION 
Typical Available $Ca(OH)_2$ - [%]	92 – 95	93	93	93
Typical Surface Area - [m^2/g]	14 – 18	20	40	40
			High Pore Volume & Surface Area	
Typical Pore Volume - [cm^3/g]	~0.07	0.08	0.20	0.20
			Larger particles → Better handling properties	
Typical D_{50} - [microns]	5 – 7	5 – 7	8 – 12	8 – 12

Figure 2 – Summary of Physical and Chemical Properties of Various Hydrated Lime Sorbents

EHLS can provide the following benefits due to their engineered and improved physical properties designed to enhance acid gas reactivity[2];

1) *Operating cost savings* – EHLS typically reduces sorbent usage by 30-50% over standard hydrated lime sorbents which could translate to a lower annual spend on sorbent. This also results in residue disposal savings since less sorbent injected generates less residue for disposal.

2) *Lesser impact on ESP/BH filter* – Lower sorbent dosage rates will result in less dust loading to back end equipment. Less dust to an ESP may directly impact particulate collection efficiency and for a BH filter this could impact bag cleaning cycle frequency.

3) *Fuel and raw material flexibility* – If a lower cost fuel or raw material becomes available but results in an increased acid gas emission profile then an EHLS can provide additional flexibility since it has the ability to achieve higher acid gas removal efficiencies than standard hydrated limes.
4) *Increased storage silo capacity* – Lower sorbent consumption using EHLS results in more days of available storage in a fixed silo volume. Hence, reducing sorbent consumption by 50% equates to doubling the silo storage capacity.
5) *Fewer deliveries* – Lower sorbent consumption also means fewer sorbent deliveries required and decreased opportunity for delivery issues.

DSI SYSTEM DESIGN CONSIDERATIONS

The purpose of this section of the paper is to elaborate on important DSI system design considerations based on observations in the field that could help reduce future operating issues for end users.

Silo Storage Capacity

The DSI silo design is important because silo size dictates how frequently end users will require sorbent deliveries, but the DSI silo size also has a significant impact on the DSI system capital expense. Fundamental decisions must be made regarding the sorbent(s) to be used as well as the desired silo usable storage capacity since this will drive the DSI silo design, size and cost.

One of the first considerations for the DSI system will be whether it is designed for hydrated lime or sodium sorbents or if the flexibility to use either sorbent is desired. Hydrated lime and sodium sorbents each have different densities so even if the same dosage rate is required they will require different cubic foot of storage[3]. Once the sorbent(s) has been selected the end user must estimate the typical and maximum sorbent dosage rates to consider in the usable cubic foot of storage capacity calculation using test data and/or extrapolation of similar performance data.

One critical design parameter that is simply based on the end user’s preference will be the required days of DSI silo usable storage capacity. While having several days of storage may be desired, it may not always be practical depending on the sorbent consumption basis as it may lead to extensive cost impacts if it requires multiple silos. It may be typical that an end user aims to have at least 7 days of usable storage at the “normal” dosage rate; however, some end users may only get 3 days or less with a single shop fabricated silo depending on the dosage rates. The end user’s proximity to the sorbent manufacturing facility as well as the delivery lead time should also be taken into consideration. Once the desired number of days of storage is determined then the silo storage capacity can be calculated with the following equation:

$$\text{Dosage Rate (lb/hr)} \times \text{Storage (hrs)} / \text{Density (lb/ft}^3\text{)} = \text{Silo Storage Capacity (ft}^3\text{)}$$

Since the current industry standard is to utilize DSI storage silos that are shop fabricated to the maximum extent possible (as opposed to field constructed silos) there may be limitations on how much storage can be achieved without having to install additional DSI storage silos. The largest shop fabricated silo is approximately 100-110 feet tall from grade to top of the silo; therefore, if the storage capacity provided by a single shop fabricated silo is not sufficient, additional capital expense is required for another silo system.

Photo 2 – View of Two (2) 100+ Foot Tall Shop Fabricated DSI Silos

Metering System Design

One of the most challenging aspects of DSI is determining the correct sorbent dosage rate to achieve the target acid gas emission control. Understanding the appropriate dosage rate is not only essential for determining the silo storage capacity but for the metering equipment design as well. One industry presentation illustrated how challenging this can be without field data specific to each site through the bid process on an industrial HCl control application. In Figure 3, eight different vendors estimated the hydrated lime dosage rate for this application, with estimates of required dosage rates ranging from 30 to 1,410 lb/hr. Subsequent field testing determined that 125 lb/hr was required[5].

HCl Removal	Vendor Estimated Dosage Rates (lb/hr)								Actual Dosage (lb/hr)
	A	B	C	D	E	F	G	H	
80%	256	800	1,410	150	625	1,000	60	30	125

Figure 3 – Table of Estimated Injection Rates at Low End of Vendor Ranges[5]

System Turndown

DSI system turndown is the ability to change the sorbent metering system dosage rates between the minimum and maximum rates and can be controlled by a Variable Frequency Drive (VFD) on the metering device. A common turndown ratio is 10-to-1; meaning the maximum feeder speed is 10 times greater than the minimum feeder speed. DSI system turndown is controlled by the metering system design and this can be very important if the end user wants to design a system for a multitude of sorbents, have a highly variable acid gas emission profile and/or simply have unique operating constraints (i.e. "must run" condition)[6]. Figure 4 plots the DSI dosage rates over a 3 month period from an EGU facility to illustrate how sorbent consumption can be highly variable due to changes in the coal sulfur and how an appropriate metering system design with the appropriate turndown is necessary.

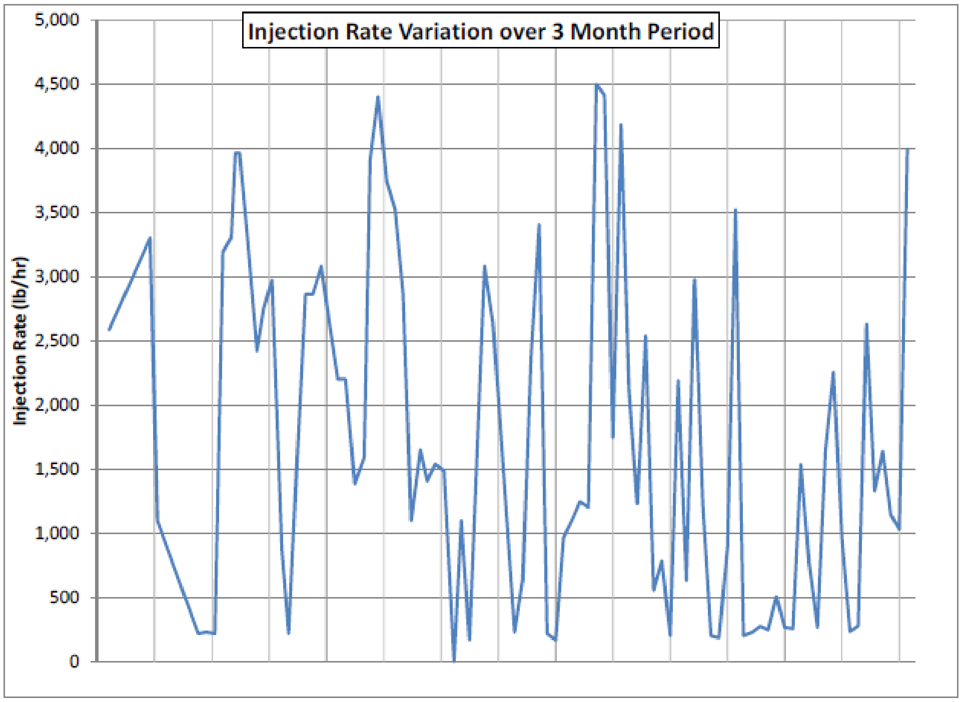


Figure 4 – Real-Time Plot of Sorbent Dosage Rate from an EGU Facility[6]

Another important consideration of appropriately designing the sorbent metering system and DSI system turndown is process flexibility. Not only does the proper metering system design provide the ability to easily modulate dosage rates to accommodate changes in acid gas emissions associated with changing fuels or plant operation, but it also enables the end user the flexibility for using other sorbents. For example, EHLS could be used in lieu of standard hydrated lime sorbents which typically reduces the dosage rate by 30-50% (refer to Figure 5

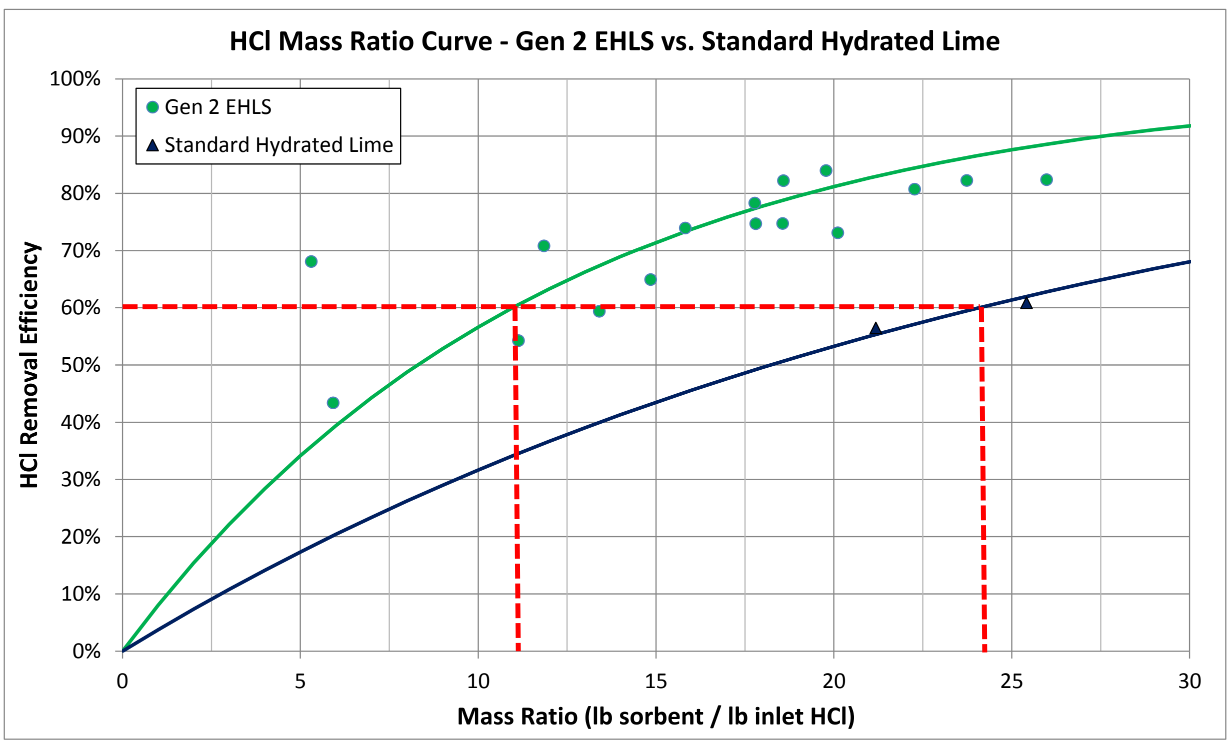


Figure 5 – Full Scale DSI Data Comparing 2nd Generation EHLS vs. Standard Hydrate

Gravimetric vs. Volumetric Feed

The dosage rate from a DSI system is measured using either volumetric or gravimetric operation. In volumetric operation, a calibration curve is used to determine the sorbent dosage rate from the metering device speed. Gravimetric operation uses a load cell system to continuously measure a hopper weight for loss-in-weight measurements to determine the sorbent dosage rates.

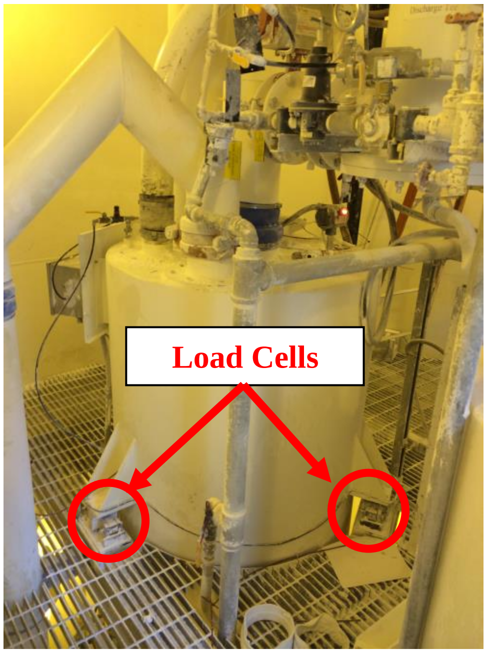


Photo 3 – Photo of DSI Weigh Hopper Designed with Load Cells

While designing a DSI system for volumetric operation offers a minor capital cost savings, it also eliminates an important diagnostic tool. Gravimetric operation can allow identification of sorbent flowability issues, such as sorbent "arching" over the discharge opening ("bridging") or channeling of sorbent flowing over stationary sorbent at the discharge ("rat-holing"). The flowability of a sorbent is fluid and can be impacted by several factors such as ambient conditions, sorbent quality, silo design, silo level and/or fluidization air moisture content. Having the ability to perform loss-in-weight readings enables the end user to recognize when a flowability issue occurs. Figure 6 shows a series of calibration curves generated from loss-in-weight readings during a full scale DSI trial to illustrate how even a properly operating DSI system will experience variability in sorbent flowability.

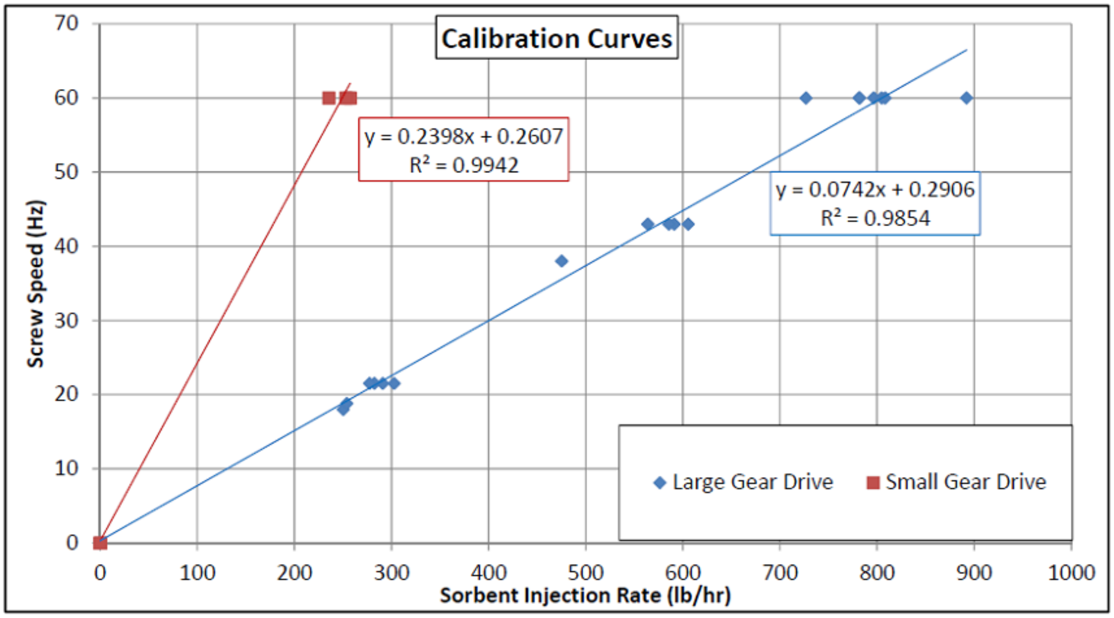


Figure 6 – DSI Calibration Curves from a Full Scale Trial

In one particular industrial application, the end user had a super-sack based DSI system with volumetric operation and recirculated the residue back into the process. With this type of system the end user had no indication or alarm to identify when a flow issue was occurring. The end user experienced changes in the residue chemistry due to high variations in the sorbent dosage rate associated with unplanned and unidentified sorbent flow issues. The high variability of the residue chemistry would also directly impact the plant's finished product so the DSI system's volumetric operation was particularly troublesome. This facility has since retrofitted their DSI system with load cells to operate gravimetrically to alleviate this issue.

Volumetric operation can be inaccurate when changes in sorbent type are made because different sorbents can have different flowability properties. Switching between hydrated lime and sodium sorbents will also impact sorbent dosage rates solely due to their different densities. Even different hydrated lime products that have similar densities may have different handling properties due to differences in PSD, which will be explained in further detail later in this paper.

Conveying Air Design

One important consideration that has been studied over the years is how conveying air properties (i.e. moisture, temperature, velocity) impact the frequency at which calcium carbonate scale formation occurs within conveying piping[7]. As a minimum, a DSI system consists of a motive air source to generate the transport air. Conveying air systems may also utilize one or more of the following components:

1) Chiller – initially cool ambient air used for transport
2) Dehumidifier – removes moisture from the air
3) Heat exchanger – cools conveying air after it is discharged from the blower/compressor
4) Dew point monitor – measures conveying air dew point prior to the introduction of the sorbent into the conveying air stream

Figure 7 is from a DSI system end user who collected data to show how a chiller as well as desiccant wheel dehumidifer impacted the conveying air properties[8]. Each of the conveying air components has pros and cons associated with them. Ambient conditions play an important role on scale formation including end user location. Ambient conditions may also drive a customized conveying air system design.

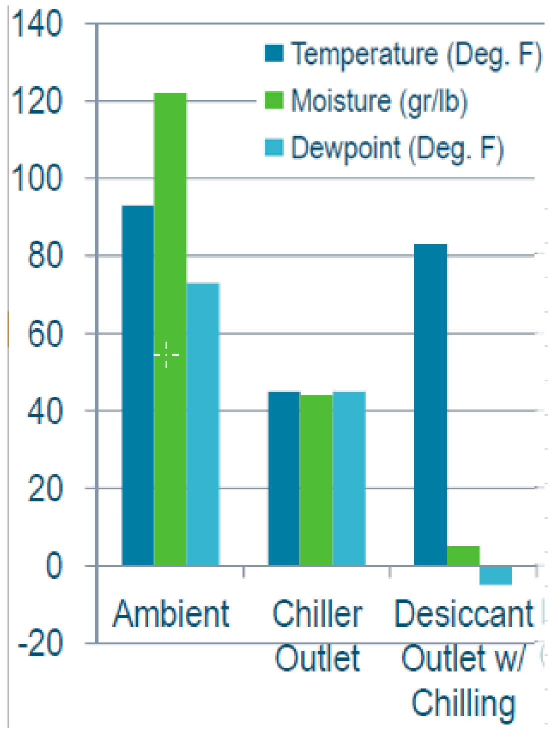


Figure 7 – Conveying Air Conditioning Equipment Impacts on Conveying Air Properties[8]

Injection Grid

Am important aspect of the DSI process is the specific design of the injection grid. The injection grid design directly impacts how the sorbent is introduced into the exhaust gas stream which will affect acid gas removal efficieny and drive the operating costs associated with sorbent consumption. Injection grid designs have been as simple as a single injection lance or as complicated as a multi-lance design consisting of various penetration depths. The injection grid is the interface between the DSI mechanical system performance and the sorbent performance as it relates to the acid gas removal efficacy.

Over the past few years new injection technologies have emerged, allowing reduced sorbent consumption. These ssystems can result in operating costs savings with a relatively quick return on investment[8, 9, 10]. Additionally, in-duct cameras have been utilized to visually inspect sorbent distribution. Photo 4 is a screen shot from an in-duct camera inserted into the exhaust gas stream to evaluate sorbent dispersion during a full scale DSI field trial.

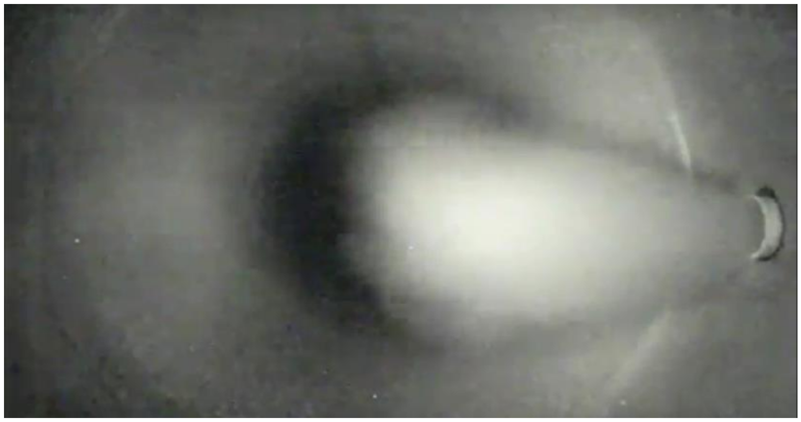


Photo 4 – View of Sorbent Dispersion in Exhaust Gas Stream

Sorbent Considerations

Care should be taken when preparing sorbent requests for proposals (RFPs), since the quality specification outlined in the the RFP could inadvertantly drive an end user to select a unsuitable supplier. Since limestone that is used to make hydrated lime is mined from various locations globally, hydrated lime quality may vary based on geography. Determining the logical potential sorbent suppliers and communicating with them to understand their sorbent(s) quality is important for the end user in order to prepare an acceptable sorbent specification that is suitable for all the potential sorbent suppliers. Without such considerations, an end user may unknowingly assemble an RFP that essentially specifies a single sorbent supplier.

It is not uncommon for RFPs to specify chemical composition as well as PSD; however, they typically do not have minimum requirements for surface area and pore volume. Better understanding of how pore volume and surface area impact acid gas removal eficacy came through the EHLS development activities. Figure 8 is from pilot scale testing on multiple EHLSs showing how increased pore volume for 2nd generation EHLS increased SO_2 removal over standard hydrate. Then the chemical enhancements in 3rd generation EHLS further improved performance over 2nd generation EHLS.

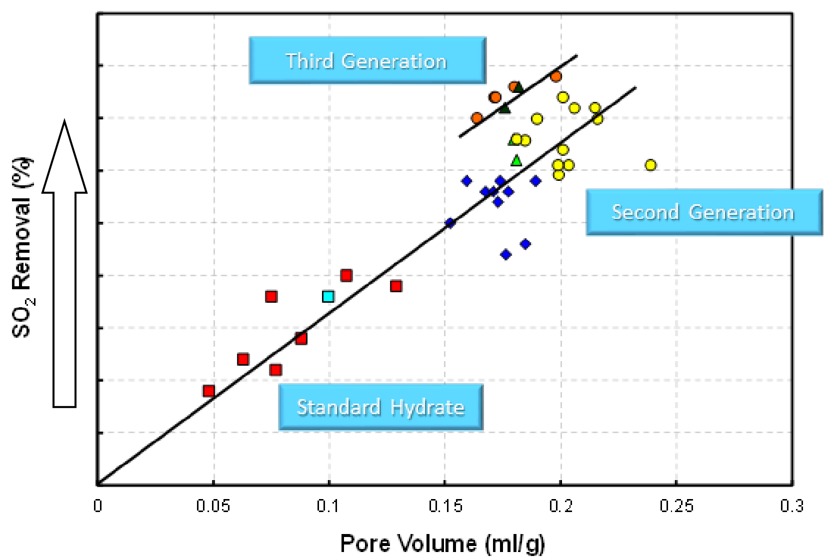


Figure 8 – Data Illustrating Hydrated Lime Pore Volume Impacts on SO_2 Removal

COMMON DSI SYSTEM OPERATIONAL ISSUES AND LESSONS LEARNED

No mechanical system is without operational issues and DSI processes are no exception. If details such as the DSI process design, poor or improper equipment installation, or sorbent quality issues are not properly considered and anticipated, they can result in operational issues that could impact DSI system reliability. In an extreme case this could force a plant shutdown due to non-compliance for acid gas emission regulatory requirements. This section of the paper will touch upon some common themes encountered in the field in regards to DSI operational issues.

DSI Process Design

Some DSI systems contain design features that are thought to provide capital cost saving, but which actually may end up causing more issues and costs than the up-front savings. For example, DSI systems that lack a VFD and can only operate at a single blower speed. In many processes there is some degree of conservatism and/or margin incorporated in the design. Over-designed conveying blowers may end up leading to excessively high conveying line velocities which can exacerbate conveying line scale formation[7]. With a VFD installed, the conveying blower speed can be easily modified to optimize line velocity without causing sorbent drop out in the conveying piping. Inability to control conveying air line velocity can ultimately lead to additional maintenance costs associated with cleaning conveying piping that has calcium carbonate scale formation.

The design of the injection grid is another key DSI system consideration. One end user had an injection grid designed with multiple injection lances of various penetration depths into the exhaust gas stream. While exploring a performance issue the injection lance configuration was manipulated in an attempt optimize operation and remedy the issue. The injection lance penetration depths were shortened by a few feet and the performance was evaluated with this new configuration. Figure 9 shows how the original injection lance design (noted as "normal" lances) provided a better performance than the modified injection lance design (noted as "short" lances)[4]. The results in Figure 9 demonstrates how that the injection grid design plays a critical role in the acid gas removal efficiency and that optimizing the injection lance design is critical to the DSI system performance[4].

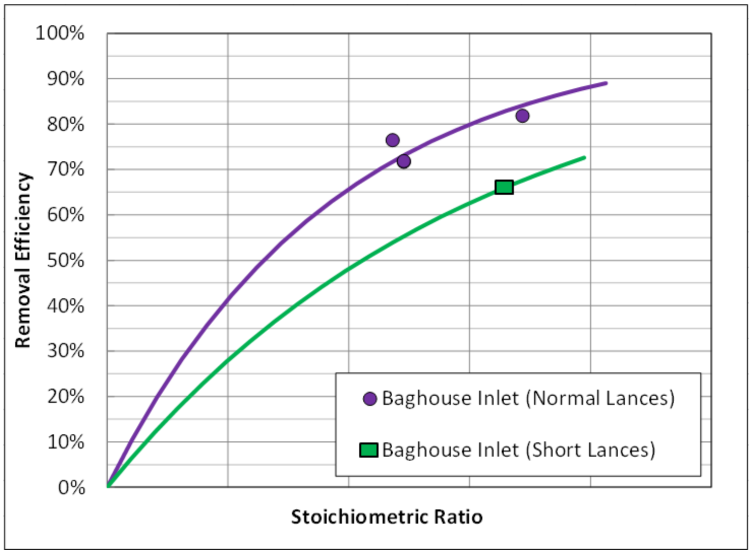


Figure 9 – Comparison of DSI Performance with Varying Injection Grid Design[4]

Balance of Plant Impacts

Several important lessons have been learned over the past two decades of DSI operation associated with various balance of plant impacts. To determine the best holistic solutions and process design, it is important to determine how DSI will impact a plant's operation, fly ash quality, or interact with other APC systems.

The DSI impact on particulate emissions is an important consideration especially when end users have electrostatic precipitators (ESPs), since sorbents may modify the bulk resistivity of the dust entering the ESP and also increase the mass loading. The hydrated lime product's PSD is important on ESP applications since some hydrated lime products have more fine particles than others. Second and third generation EHLS have more coarse particles than standard hydrated lime products and generally are collected more easily in both ESP and bag house (BH) applications. Figure 10 shows the effect of particle size on ESP particulate collection efficiency[11]. The trends in Figure 10 are important because even a few micron delta in a hydrated lime PSD could have an impact on the ESP performance[11]. The 3rd generation EHLS product not only has a more coarse PSD than standard hydrate but it is also chemically modified such that it reduces the bulk fly ash resistivity by approximately an order of magnitude compared to other hydrated lime sorbents[11].

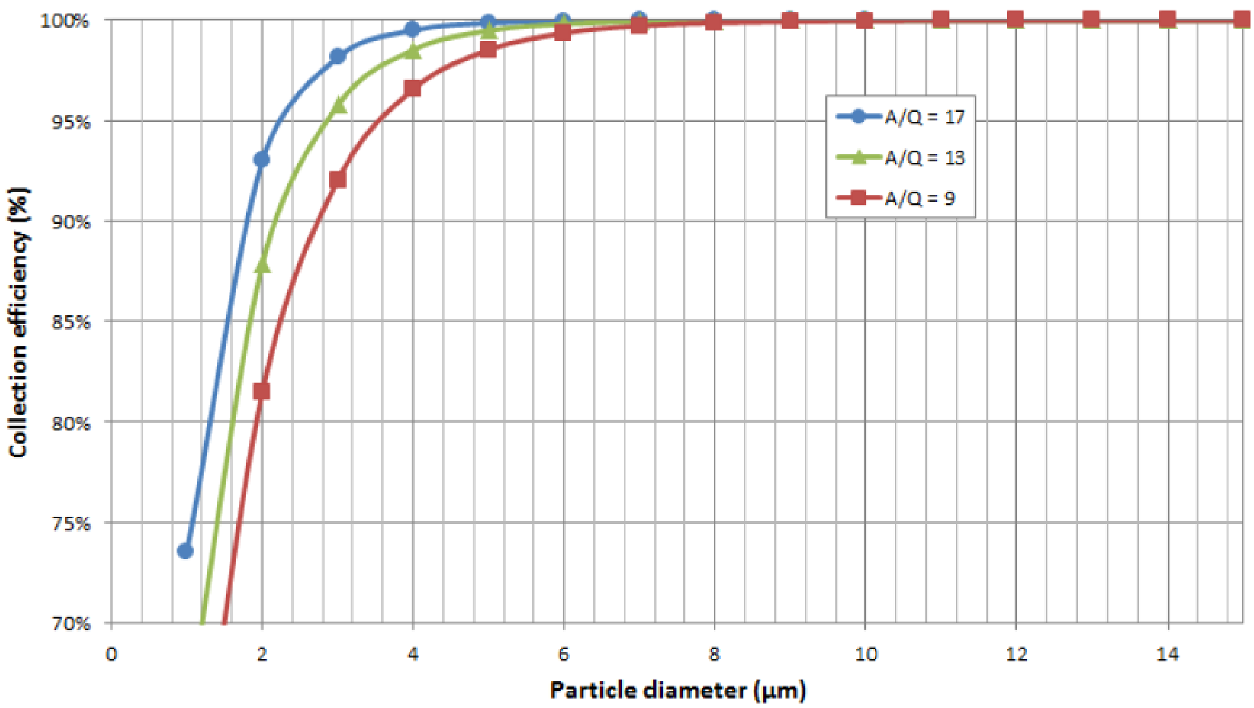


Figure 10 – Effect of Particle Size on ESP Particulate Collection Efficiency[11]

Another balance of plant consideration with respect to hydrated lime is how particle size impacts flowability in a DSI system. Measurements during trials and operations at end user facilities showed that different hydrated lime sorbents flowed differently even in the same DSI sysetms. The differences in hydrated lime flowability were attributed to the different particle sizes: hydrated lime sorbents with a larger PSD flowed better than hydrated lime sorbents with a smaller PSD. Subsequently, this was studied in a pilot scale hopper system with different hydrated lime products and the data showed that the flowability, represented by the flow factor, was directly correlated to the hydrated lime particle size, represented by D_{50}. Figure 11 shows the results of this study and illustrates that as the particle size increased hydrated lime sorbents became less cohesive[6].

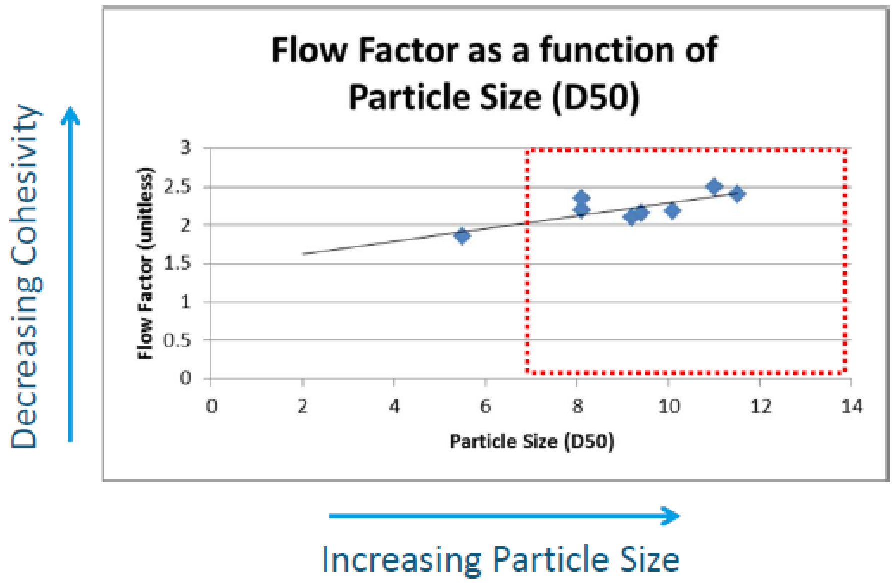


Figure 11 – Effect of Particle Size on Handling Properties[6]

Impacts on the residue should be evaluated with DSI since each sorbent can impact the residue chemistry differently. The DSI sorbent chosen can impact the residue chemistry and how it affects the leachability of heavy metals, such as selenium. Heavy metal leaching can have a significant impact on the residue disposal costs. If a residue becomes classified as a hazardous waste due to high metals leaching, disposal costs would be greater than a non-hazardous waste and the DSI sorbent used could directly impact the residue classification. Figure 12 shows the TCLP results from an industrial application that was using sodium bicarbonate and later converted to the 3rd generation EHLS[12]. Hydrated lime and sodium sorbents have different impacts on the residue chemistry as illustrated in Figure 12 which could result in significant differences in the disposal costs, depending on whether residue is classified as hazardous or non-hazardous.

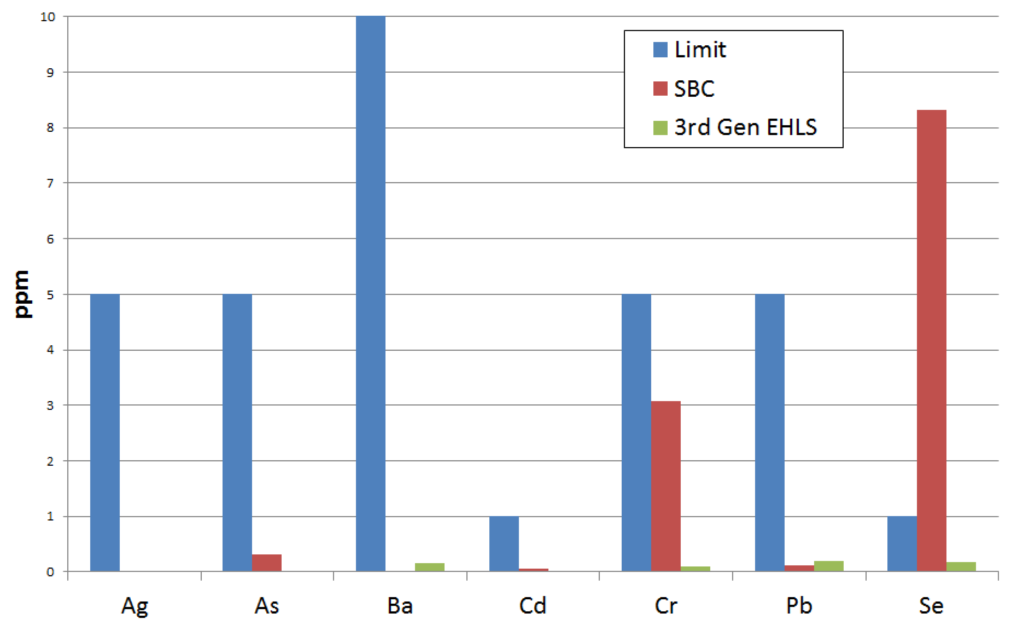


Figure 12 – TCLP Results from an Industrial DSI Application[12]

How DSI interacts with powdered activated carbon (PAC) products and how this impacts Hg emissions has been observed and studied for the past few years. For example, several years ago it was determined that SO_3 has a negative impact on Hg emissions. Removing SO_3 from the process helps reduce even native Hg emissions and/or improve PAC Hg removal efficacy[3]. It was also observed that sodium sorbents generate an undesirable byproduct, NO_2, which also has a negative impact on PAC performance and Hg removal[3]. Figure 13 shows the DSI and activated carbon injection (ACI) interaction from an EGU in which the quantity of PAC increased when a sodium based sorbent was used with DSI compared to when DSI was not in operation[3]. This interaction is important to recognize and understand in order to determine the appropriate sorbent(s) selection as well as injection locations to provide the best hollistic solution.

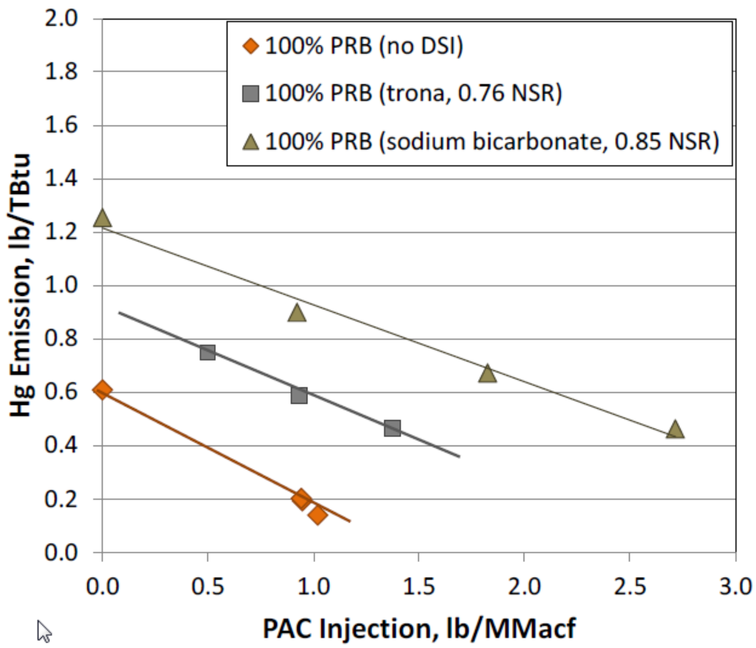


Figure 13 – Hg Emissions as a Function of Non-Brominated PAC Injection Rate with and without Sodium DSI Sorbents[3]

Sorbent Quality and Sampling

Poor sorbent quality can lead to DSI operational issues. While sorbents may leave the manufacturing facility within typical quality specifications, sorbent contamination may occur during transit. Moisture could be present in the pneumatic truck hoppers and/or piping but end users may not realize this issue until the sorbent is fully unloaded and the carrier is off-site. Photo 5 was taken when a sodium sorbent was being unloaded at an end user's facility. It was theorized that exposure to water remaining in the pneumatic truck led to several large, hard "chunks" being formed within the pneumatic truck[6].

Photo 5 – Moisture Contaminated Sodium Sorbent Samples Collected during Unloading[6]

Typically DSI systems are not equipped with convenient sorbent sampling capabilities. However, in the event of DSI operational issues periodic samples could provide insight into the root cause of the operational issue. For example, sorbent samples could be taken from the following locations:

1) *Sorbent manufacturing facility* – Having a sorbent sample taken transport will provide a basis for the "as produced" sorbent quality.
2) *During unloading* – Collecting a sorbent sample during the unloading process will help identify if a sample was exposed to moisture during transport and/or unloading.
3) *Silo discharge* – Collecting a sorbent sample as it discharges from the silo prior to the metering system will determine if contamination occurred within the silo due to a leak or "wet" fluidization air.
4) *Metering discharge* – A sorbent sample collected from the metering system just prior to being introduced into conveying air stream will help determine if any contamination occurred at all in the weigh hoppers and/or feeders.
5) *Injection lances* – Collecting a sorbent sample just prior to injection into the gas stream is important as it will be most representative of the sorbent quality just prior to being introduced into the exhaust gas stream. Also, this will help determine the impacts the conveying air has on sorbent quality.

While collecting sorbent samples from these locations may seem cumbersome, a routine sorbent sampling plan can be beneficial for root cause analysis when operational issues occur. Sorbent samples, if sampled and sealed properly, can be stored and archived until an issue occurs and the appropriate samples can then be analyzed to look at relative change in the sorbent quality. Typically, DSI system designs do not have accommodations to allow for convenient and safe sorbent sample collection at any of these locations.

Improper Equipment Installation

Any lack of attention to detail during DSI equipment installation can result in operational issues. Photo 6 was taken from a DSI end user's site when they removed the 1st elbow after the sorbent was introduced into the conveying air stream. This plant had been experiencing issues with conveying line scaling and plugging which was being attributed to the hydrated lime. However, upon inspection it was found that the inlet to the pipe elbow was clean but the elbow discharge had significant calcium carbonate scale build up. It was also observed that the elbow discharge went to a vertical pipe that appeared to have a frozen puddle below it which was an indication that water would run down the vertical pipe run. These observations suggested that this elbow may not have properly installed, allowing for the conveying air and hydrated lime to be exposed to water. This photo just illustrates one example where a minor detail was over-looked during installation and it had a direct impact on the DSI system reliability.

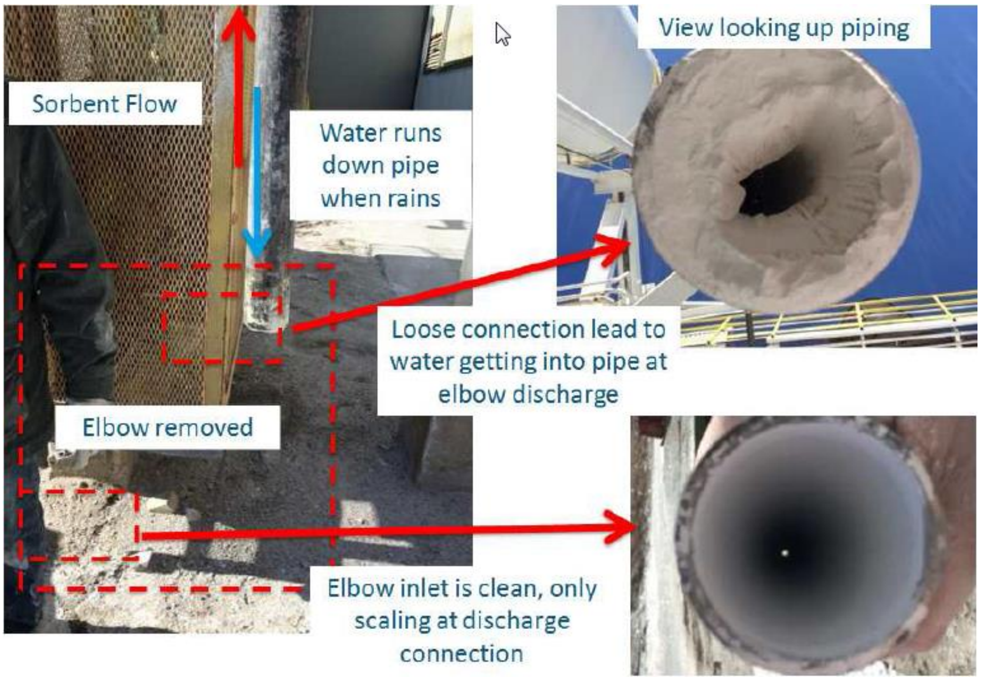


Photo 6 – View of Conveying Piping Elbow Exhibiting Scaling at Discharge

Photo 7 shows another example where the missing a detail during the DSI installation phase may have resulted in higher operating costs. Photo 7 shows the discharge hoses from the partitioning device to the injection lances in an industrial application. In Photo 7, it can be observed that the hoses are all of different lengths and as sorbent tends to the follow the path of least resistance, sorbent flow may be biased to the shorter hoses. Sorbent dispersion may be biased to the right side of the duct due to the hose configuration which could have a negative impact on the DSI performance.

Photo 7 – View Partitioning Device Hose Run to Injection Lances

CONCLUSIONS

The purpose of this paper is to present common DSI design and operational considerations, mistakes and lessons learned to benefit current and future end users looking to install a DSI system as told from the sorbent supplier's perspective. DSI has been a growing technology due to the many regulatory drivers in place across a multitude of industries, and due to the relatively low capital cost expense and its attractive features.

In addition to the evolution of the DSI system design, hydrated lime sorbents have also evolved as 2nd and 3rd generation EHLS have engineered physical and chemical properties to reduce sorbent consumption for acid gas removal by 30-50% over standard hydrated lime. Due to the improved performance with EHLS there are potential benefits using EHLS over standard hydrated limes such as operating cost savings (associated with annual spend in sorbent and residue disposal), lessened balance of plant impacts, increased silo storage capacity as well as fewer deliveries.

Given that each DSI system is essentially customized for each end user to some degree there's a multitude of DSI design considerations that deserve proper attention. Silo capacity, conveying air design, as well as injection grid design are all important design considerations. Each of these DSI design features should be evaluated on an "as needed" basis for each DSI system, as part of the customized design each end user may have specific drivers and constraints. When these design features are not properly considered, operational issues could arise that may have been avoided. The intent of this paper is to identify some common operational issues past end users have experience in hope that future DSI system users can avoid a similar fate.

ABBREVIATIONS

ACI	Activated carbon injection
APC	Air pollution control
BH	Baghouse filter
$Ca(OH)_2$	Calcium hydroxide
DSI	Dry sorbent injection
EGU	Electric generating utility
EHLS	Enhanced hydrated lime sorbent
ESP	Electrostatic precipitator
HCl	Hydrogen chloride
HF	Hydrogen fluoride
Hg	Mercury
NAAQS	National Ambient Air Quality Standards
NO_2	Nitrogen dioxide
PAC	Powder activated carbon
PSD	Particle size distribution
RCRA	Resource Conservation and Recovery Act
RFP	Request for proposal
SO_2	Sulfur dioxide
SO_3	Sulfur trioxide
TCLP	Toxicity characteristic leaching procedure
VFD	Variable frequency drive

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