DSI SYSTEM OPTIMISATION

Dr. Ian Saratovsky, Martin Dillon and Gerald Hunt, Lhoist, examine dry sorbent injections (DSI) as a cost-effective solution for complying with acid gas emission control requirements.
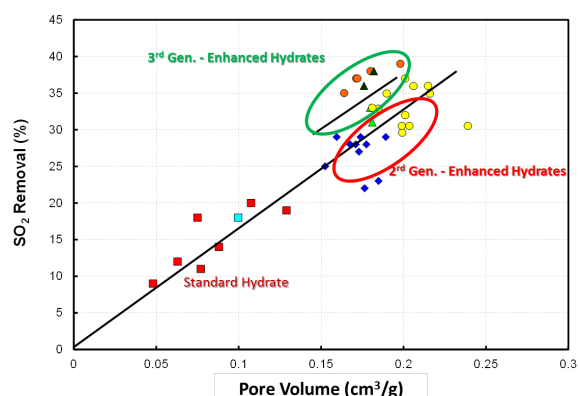
The Portland cement (PC) production process often results in emissions of gaseous pollutants, including SO_2, HCl, and mercury (Hg) released from the heating of raw materials as well as the firing of solid fuels inside the kiln. Throughout the US and the world, PC production facilities are required to control their acid gas and mercury emissions as a result of limits dictated in their operating permits, consent decrees and/or other regulatory mandates. In the US, the Clean Air Act previously drove acid gas emission control requirements, however, other regulations and limits have recently been passed, such as National Ambient Air Quality Standards (NAAQS) which drives increasingly more stringent limits on SO_2 emissions. Specific to PC manufacture in the US, the National Emission Standards for Hazardous Air Pollutants (NESHAP) provides numerical limits for the emissions of particulate matter (PM), hydrocarbons, dioxins/furans, mercury, and HCl. Dry sorbent injection (DSI) offers a cost-effective solution to comply with these regulatory requirements.
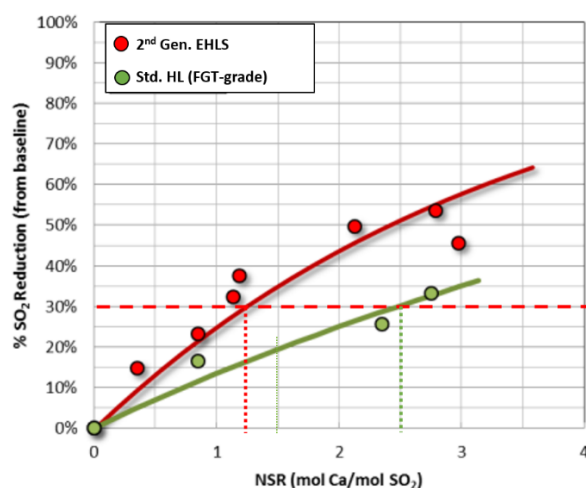
During the DSI system design phase, careful attention must be paid to sorbent selection, sorbent application location, and sorbent distribution into the gas stream to maximise the DSI system performance. In this article, various critical aspects of system optimisation are discussed in order to achieve the lowest overall cost of compliance.
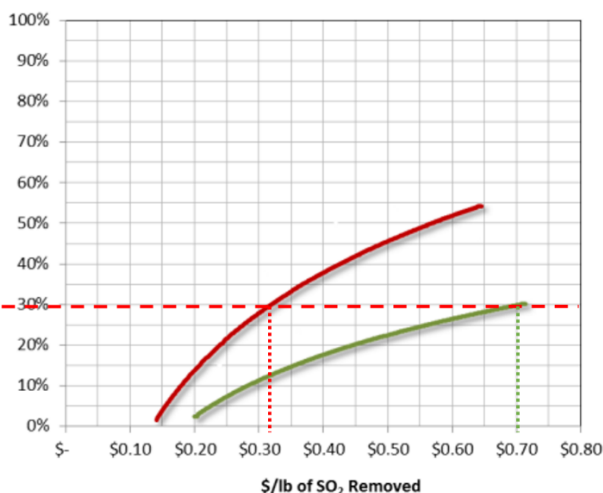
Background

System capital expenditure

DSI and activated carbon injection (ACI) are two mature and low capital technologies for acid gas control and vapour-phase mercury reduction, respectively. Both Hg and acid gas control sorbents have proven effective in a variety of industrial plants (i.e. utility, biomass, cement, waste incinerators, etc.) and have been used commercially in Europe and the US for over 20 years. Trial results from the previous HCl test campaign with CEMEX and Lhoist North America were detailed in a previous World Cement article.[1] DSI and ACI injection systems usually consist of storage (either silo storage or bulk bag, i.e. 'super sack') after which product is metered into an air stream and conveyed via dilute-phase into the process gas stream, upstream of a particulate collection device. However, while often considered a low capital solution relative to other acid gas scrubbing technologies, the greatest capital associated with DSI and ACI is the initial equipment procurement and installation. For applications where mercury control is either intermittent or low injection rates are needed, a blended hydrated lime (HL) and powdered activated carbon (PAC) sorbent allow for a single feed system to be used. For example, Lhoist North America's blended HL-PAC product enables concurrent acid gas and Hg control using a single sorbent injection system (versus installing and maintaining two nearly identical systems) and the injection of the sorbents simultaneously as a pre-blended, homogeneous product. The company produces customised enhanced hydrated lime (branded Sorbacal® SP and SPS) blends with brominated PAC in either

Sorbent	Standard Hydrated Limes	FGT Grade Sorbacal® H	Sorbacal® SP	Sorbacal® SPS
Figure	Standard Hydrate	Sorbacal® H	Sorbacal® SP	Sorbacal® SPS
Typical Available $Ca(OH)_2$ - [%]	92 – 95	93	93	93
Typical Surface Area - [m^2/g]	14 – 18	20	40	40
Typical Pore Volume - [cm^3/g]	~0.07	0.08	0.20	0.20
Typical D_{50} - [microns]	5 – 7	5 – 7	8 – 12	8 – 12

Figure 1. Physical and chemical properties of various hydrated lime sorbents.

Figure 2. Impact of sorbent physical properties on SO_2 capture. Pore volume and surface are the two key performance indicators for hydrated lime products.

Figure 3. SO_2 Reduction : Sorbacal SP (2nd generation EHLS) vs. standard hydrate. Sorbacal SP (2nd Generation EHLS) resulted in a 54% reduction in sorbent usage over a standard hydrated lime.

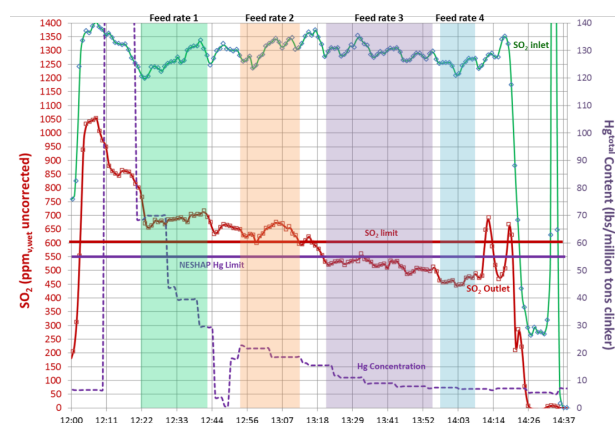bag or bulk, in 5% PAC (w/w) blend increments up to 30%.

Optimising operating expenditure

While a blended sorbent for Hg and acid gas can decrease overall system capital expenditure by only using a single system, careful attention should be paid to optimising the quantity of sorbent required to achieve compliance. DSI system design guidelines are discussed in detail elsewhere.[2,3] The focus of this article is to

Figure 4. Simultaneous SO$_2$ and Hg abatement with Sorbacal SP-PAC blended product. Acid gas emission measurements by FTIR were simultaneously conducted upstream of the injection lances (i.e. 'SO$_2$ inlet' – green trace) and at the inlet to the baghouse filter (i.e. 'SO$_2$ outlet' – red trace) to provide instantaneous performance even with variable process conditions. Hg was measured by CEMs at the stack (dashed purple trace). The relative quantity of PAC blended with Sorbacal can be custom-tailored (between 5% and 30%) to meet specific needs.
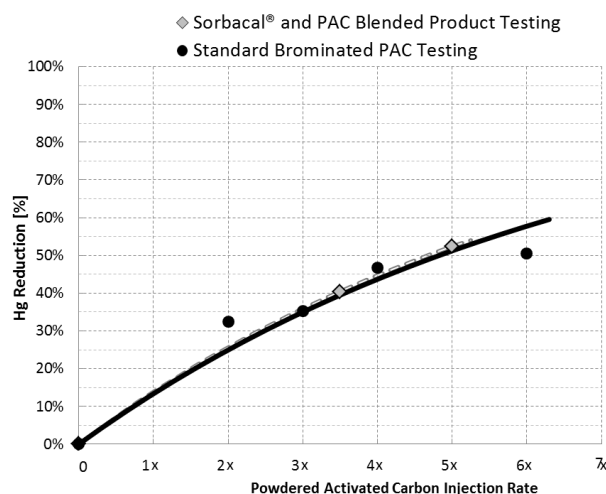
Figure 5. Hg reduction with Sorbacal - PAC blended product compared with a standard brominated PAC. Blending PAC with Sorbacal hydrated lime products does not alter PAC performance.

provide sorbent selection and sorbent application guidelines to achieve the most operationally cost-effective DSI programme. To this end, prior to equipment design and selection phases (or after system commissioning, if this was overlooked during design), plants should consider:

▸ Optimal injection location (depends on target pollutants).
▸ Sorbent type.
▸ Sorbent application/distribution within the gas stream.

Sorbent trials with temporary DSI systems are highly recommended before system design and selection phases, or to evaluate alternative injection locations after a DSI system is installed. Sorbent trials should include measurement of dose-response (i.e. parametric) curves at several different locations within the plant to identify the most efficient injection strategy.

DSI programme design considerations to minimise operating costs

▸ Sorbent type – Standard hydrated lime? Enhanced hydrated lime? Hydrated lime blended with powdered activated carbon (PAC) for simultaneous acid gas and Hg abatement?
▸ Injection location – Sorbent injection at kiln inlet? Gas conditioning tower (GCT) inlet? GCT outlet? Baghouse inlet? ID fan inlet? Abatement of HCl and SO$_2$ often require different injection locations.
▸ Injection lance type and configuration – Standard pipe lances? Advanced sorbent distribution technologies? Static mixing lance designs? Dynamic mixing lance designs?

Differences in hydrated lime sorbents

Over the past 20 years, calcium-based sorbents have evolved, driven by the need to improve acid gas capture efficiencies. Realisation of the importance of physical properties, such as particle size distribution (PSD), pore volume, and surface area led to the development of enhanced hydrated lime sorbents (EHLS) by engineering these properties to create more reactive hydrated lime sorbents. Sorbent physical properties directly impact material handling properties and acid gas removal performance, ultimately dictating annual operating expenditures. Figure 1 compares Lhoist's hydrated lime sorbents and their typical properties. Lhoist's EHLS products are branded Sorbacal, the 2nd generation product is Sorbacal SP, and 3rd generation is Sorbacal SPS. Sorbacal SPS is a chemically-activated formulation of Sorbacal SP, designed to provide the best possible acid gas capture performance. Figure 2 demonstrates the evolution of EHLS product physical properties and the resultant impact on

SO$_2$ capture efficiencies. Surface area and pore volume are the key performance drivers for acid gas capture. Sorbent particle size dictates material handling properties and removal efficiencies in electrostatic precipitators and baghouse filters. Empirical data from the field as well as laboratory flow testing have demonstrated that larger median particle diameters (i.e. D$_{50}$) are recommended for optimum handling.[2,6] Specifically, a 32% improvement in flow properties was demonstrated between particles with D$_{50}$ = 2 µm and particles D$_{50}$ = 11 µm.[7,8] This is likely due to small particle sized hydrated lime sorbents being more cohesive than larger particles, and that small particles can facilitate pluggage in the conveying system.[7] Additionally, fine particle sized hydrated lime can become irreversibly lodged in baghouse filter bags and bin vents (i.e. 'blinding'), and can result in premature wear and poor bag cleaning efficiencies. Users should refer to their manufacturers' design information regarding particle size and carefully weigh the impacts of introducing particles outside of the design range. Likewise, electrostatic precipitator (ESP) particulate capture efficiencies decrease below approximately 6 µm and can result in increased particulate emissions.[7,8]

The key parameters to consider when choosing sorbents are surface area, pore volume, and median particle size (D$_{50}$). Surface area and pore volume are the most critical performance drivers for acid gas capture. Particle size dictates material handling properties and removal efficiencies in electrostatic precipitators and baghouse filters. Larger median particle sizes (≥ 6 µm) have been found to offer the best handling[7] and particle capture results[7,8.] It is noteworthy that 'available Ca(OH)$_2$' impacts acid gas removal performance to a much lesser extent than surface area and pore volume, since sorbent utilisation rates (i.e. fraction of calcium ions consumed in the reaction) are seldom in excess of 30%.

Enhanced hydrated lime sorbents provide the following benefits versus standard hydrated lime due to their engineered and improved physical properties designed to enhance acid gas reactivity:

▶ Operating cost savings – EHLS typically reduce sorbent usage by ≥ 30% over standard hydrated lime sorbents, which results in a lower annual spend on sorbent.
▶ Less impact on ESP/BH filter – Lower sorbent dosage rates will result in less dust loading to particulate capture equipment. Less dust to an ESP may directly impact particulate collection efficiency and for a BH filter, this could impact bag cleaning cycle frequency. Particle sizes play a critical role in ESP/BH operational efficiencies.

Respective equipment manufacturers should be consulted on particle size guidelines.
▶ Fuel and raw material flexibility – If a lower cost fuel or raw material becomes available but results in increased acid gas emissions, then an EHLS can provide additional flexibility since it has the ability to achieve higher acid gas removal efficiencies than standard hydrated limes, without having to modify the existing DSI system.
▶ 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.
▶ One DSI system for acid gas and Hg control – EHLS blended with PAC are available and preclude the need for two separate systems.
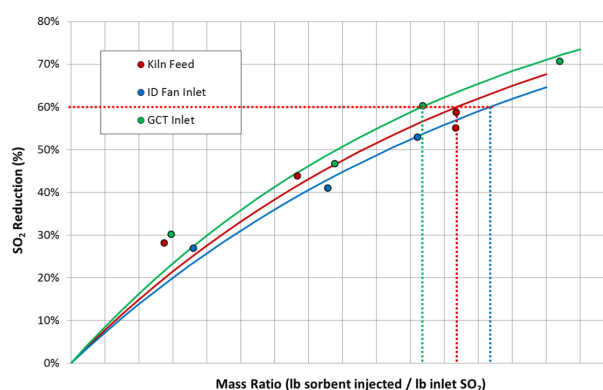
Figure 6. Comparison of DSI performance as a function of injection location. Sorbacal was injected at three locations: (1) with kiln feed, (2) at the gas cooling tower inlet, and (3) at the ID fan inlet. Note: these results do not always translate from plant to plant. It is critical to evaluate different injection locations at each plant to find the optimal injection location.
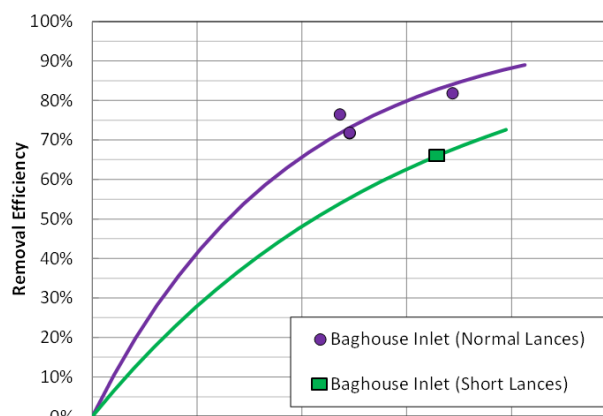
Figure 7. DSI performance with different injection lance configurations. CFD modelling is a useful tool to guide lance configuration and design to maximise efficiency and cost-effectiveness.

Choosing the most cost-effective sorbent

The two most critical components to implementing a successful compliance strategy are: (1) proper sorbent selection and (2) sorbent distribution in the gas stream. Assuming that the DSI system is properly designed, installed, and operated,[2,6] choosing the most effective sorbent, injection location, and injection grid design are the next critical steps to optimising system cost-effectiveness. Although ELHS are typically more costly than standard sorbents on a delivered basis (i.e. $/t), higher sorbent efficiencies often result in overall lower total cost of ownership. For example, an EHLS may cost 30% more than a standard hydrated lime; however, EHLS usage rates are often 30 – 50% lower than the standard hydrated lime, resulting in net cost savings. Figure 3 illustrates relative SO_2 capture performance of a standard hydrated lime sorbent and an EHLS at an industrial facility.

Requesting proposals from sorbent suppliers

Care should be taken when preparing sorbent requests for proposals (RFPs), since the quality specification outlined in the RFP could inadvertently result in selection of an unsuitable or single source supplier. Identify potential sorbent suppliers and communicate with them to better understand the most critical sorbent attributes as well as the chemical and physical properties of the sorbents they offer. For example, not understanding that sorbent purity (i.e. 'available $Ca(OH)_2$') is less critical than surface area, pore volume, and that large particles are superior to smaller particles may result in choosing a single supplier, which may not be the most cost-effective choice.

Sorbents blended with PAC

For simultaneous Hg and acid gas abatement, Lhoist's Sorbacal acid gas sorbents can be blended with powdered activated carbon (PAC). Simulateneous capture of mercury and acid gases offers the advantage of requiring only one feed system to install and operate. For applications in which mercury control is either intermittent (i.e. when using certain raw materials) or only needed for low injection rates, a blended product can be advantageous.

Injection location and lance configuration

Another critical aspect of the DSI process is choosing the best injection location and specific design of the injection grid. The injection location and grid design directly impact how the sorbent is introduced into the gas stream. Sorbent distribution and coverage in the gas stream dictate pollutant removal efficiencies and resultant operating costs. A key question is where to locate the injector(s). The target pollutant(s) typically guide where to locate injection lances; however, it is recommended that each facility performs site-specific testing, especially for cement applications. It is recommended that several injection locations are evaluated during a trial, with a temporary DSI system. For example, SO_2 capture by hydrated lime is typically favoured with injection at higher temperature,

Before Optimization   **After Optimization**
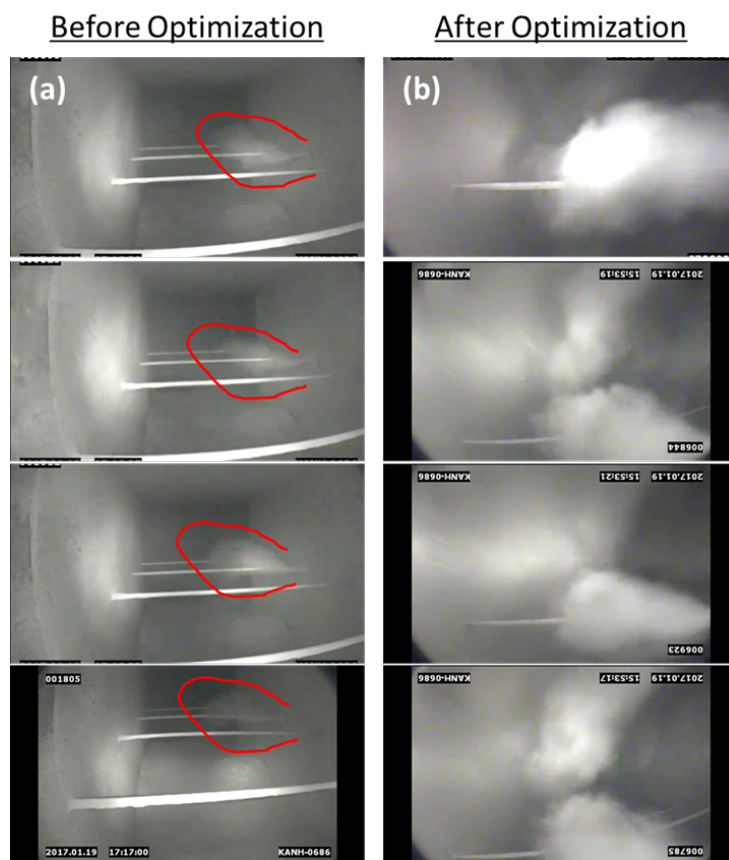
Figure 8. View of sorbent dispersion in process gas stream. In-duct camera images of sorbent distribution at a cement plant. Images were recorded upstream of the injection lance(s), which were located between an electrostatic precipitator and baghouse. (a) Illustrates the poor-sorbent distribution with the original single-lance configuration. The area in red highlights the white sorbent plume. (b) Illustrates the improved sorbent distribution with the addition of lance (for a total of six). Additionally, flow was balanced by modulating dampers at the baghouse clean air plenum. Originally, flow in this duct was highly stratified (as verified with Pitot tube measurements), and flow balancing and addition of lances resulted in a cloud of sorbent distributed across the duct.

whereas, HCl capture tends to be favoured at cooler temperatures. Figure 6 illustrates relative SO_2 abatement performance in a cement plant, with injection at kiln feed, gas cooling tower inlet, and ID fan inlet. Figure 7 illustrates the impact of lance design on sorbent performance. Without a trial to determine the best injection location, incorrect injector location selection can result in higher usage rates and annual costs.

Once injection location is determined, injection grid design is the next key performance driver. Injection grid designs can be as simple as a single injection lance or as complicated as a multi-lance design with various penetration depths. Over the past few years, new injection technologies have emerged, significantly improving sorbent distribution within the gas stream, and reducing sorbent consumption. These systems can result in operating cost savings with a relatively quick return on investment. CFD modelling is a beneficial tool to be used to guide injection grid design in order to optimise sorbent distribution. In-duct cameras can also be employed to visually inspect sorbent distribution following system installation to corroborate good distribution, and identify distribution inefficiencies. Figure 8 is a photograph taken with an in-duct camera inserted into the gas stream to evaluate sorbent dispersion during a full scale DSI field trial.

Conclusions

Sorbent selection, proper location of injectors, and injector grid/lance design are the most critical parameters that determine overall DSI system efficiency. Over the past two decades, enhanced hydrated lime sorbents (EHLS) have been specifically optimised for acid gas abatement applications. In the past, sorbent selection was driven by geologically-dictated hydrated lime purity (i.e. available $Ca(OH)_2$). Today, sorbent purity has little impact on performance and sorbent performance is primarily driven by porosity (i.e. surface area and pore volume). Additionally, blended sorbents (PAC and EHLS in one sorbent) can reduce the system cost (i.e. only one injection system is needed). EHLS particle sizes have been optimised for superior material handling and particulate capture by baghouse filters and/or precipitators (i.e. larger particles are better). Locating injectors in a cement plant should be driven by data from trials with temporary DSI systems. Once injectors are located to maximise sorbent efficiency, injection grid design should be guided by CFD modelling. Following system installation, in-duct cameras can be used to evaluate and tune sorbent injection grids to ensure excellent distribution and coverage. Many of these critical parameters are easily evaluated during a short product trial and can result in significant operating cost savings in the long run. ∎

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