How dry bulk sorbent injection effectively removes stack gas pollutants

Jerry VanDerWerff   Nol-Tec Systems

Several technologies are used to reduce pollutant emissions of SO_2, SO_3, Hg, HCl, and HF, common in flue gas streams from coal and other fossil fuel–fired boiler plants. But when it comes to dry bulk sorbent injection, the reagent best suited for mitigating one pollutant may or may not be the one best suited for a different pollutant.

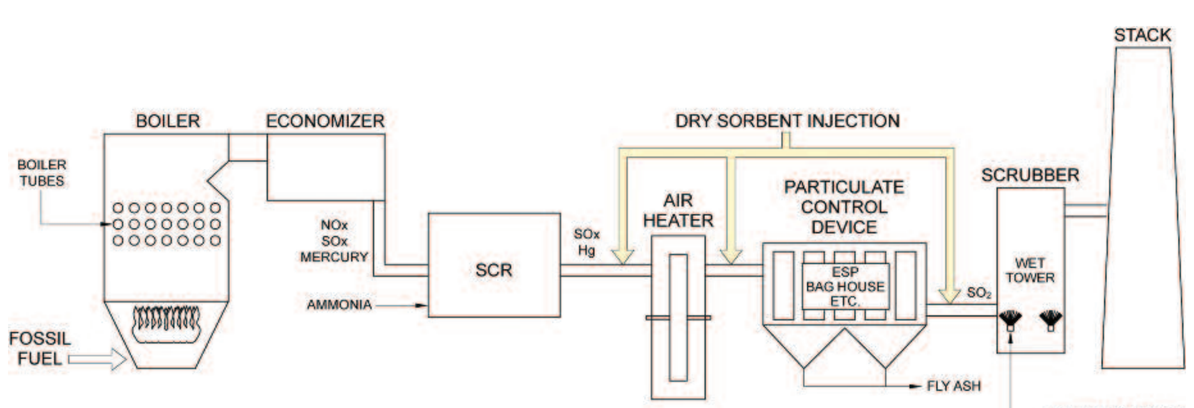
For the better part of the last two decades, increased legislation and mounting regulations have driven research and design efforts in the industrial boiler market to improve their emission mitigation technologies and to reduce stack gas pollutants to ever-decreasing levels of concentration. The early target for this increase of mitigation efficacy has been the coal-fired power generating facility.

Coal–From one fuel, many problems

When coal is oxidized (burned) as fuel, the elemental sulfur it contains is converted to sodium dioxide (SO_2). Some of the SO_2 is converted to sodium trioxide (SO_3) when oxygen left over from the combustion process causes further oxidization in the boiler. These SO_3 concentrations increase when a selective catalytic reducer (SCR) system is used to reduce nitric oxide (NO_x) emissions. The SCR converts additional SO_2 to SO_3. When sulfur oxide (SO_x) combines with flue gas moisture, vapor-phase sulfuric acid is formed.

The presence of sulfuric acid in flue gas escaping into the atmosphere causes a visible plume to form and also increases particulate emissions from the stack. Sulfuric acid also corrodes ducts and damages equipment downstream. In addition, SO_x emissions are known for their detrimental effects on human health and the environment, such as causing smog, acid rain, and ozone depletion. The use of high-sulfur coal, while more economical, exacerbates these issues, driving more legislation with increasingly tighter standards for more stringent emissions controls.

What follows is a description of mitigating SO_2 and SO_3 emissions by injecting powdered sorbent materials directly into a utility's ductwork. The injection point for the reagent is typically located between the air heater and the particulate control device. However, with mitigating efficiencies often affected by the temperatures of the stack gas flow itself, the injection point of the sorbent may differ. There is also detail on the typical design criteria for this technology and an itemization of the major components for the mitigation system.



Standard schematic showing possible sorbent injection points

Types of sorbent

The method of dry sorbent injection described in this article would use a fairly well defined list of typical sorbent materials: hydrated lime, Trona (sodium sesquicarbonate), and sodium bicarbonate. The various sorbents are compared in this article.

Typical system concept for coal-fired plants

Dry bulk sorbent injection systems continuously transfer reagent from storage silos to injection ports on boiler flue gas ducts. Although system configurations vary with each application, a typical process includes multiple storage silos designed to hold 5 to 10 days' worth of sorbent material.

Imperials Industries Inc, Wausau, WI

A three-silo configuration for a flue gas desulfurization sorbent injection system

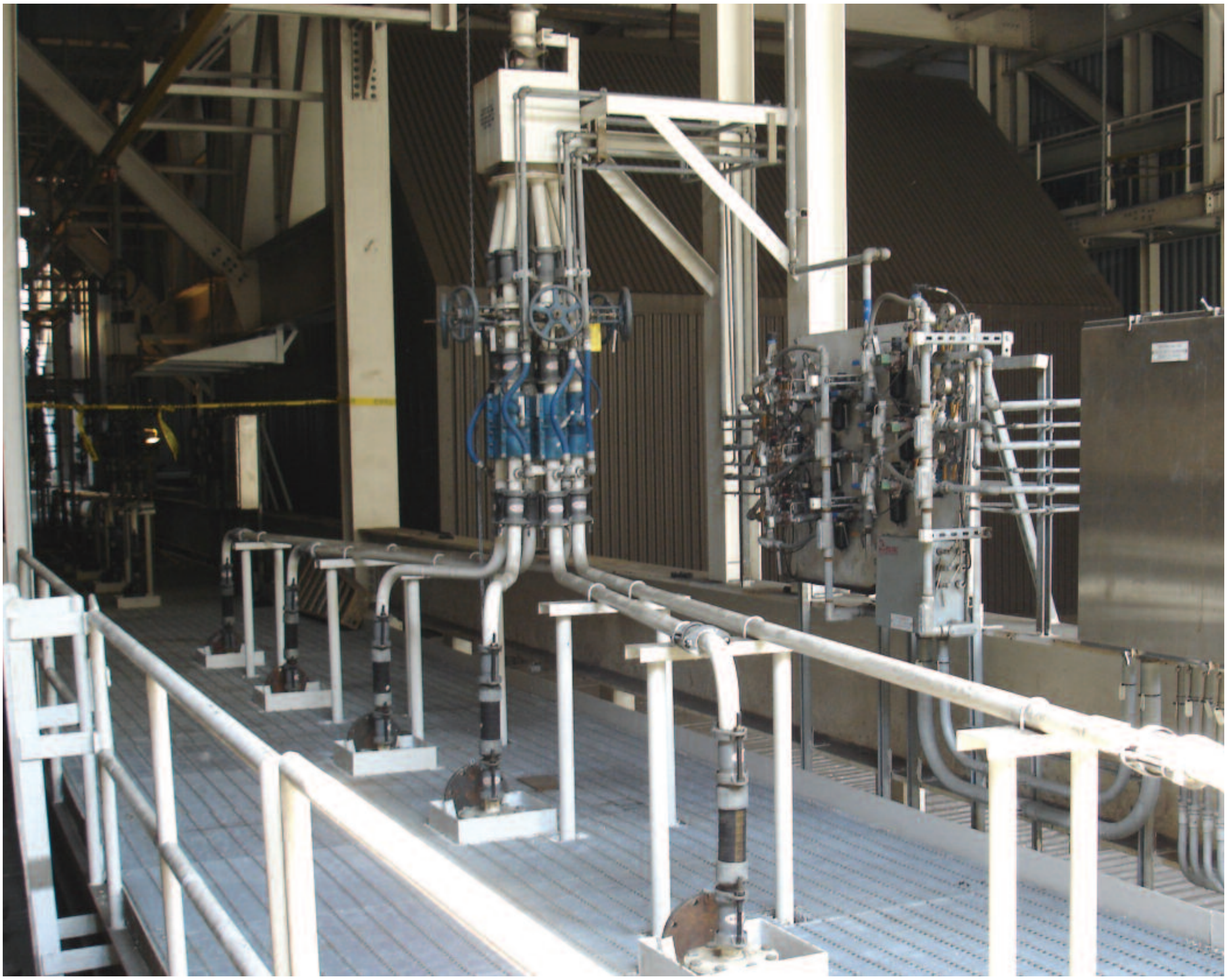
A fluidizing bin bottom is installed on each silo to ensure reliable material flow out of the silo. An automatic butterfly valve is mounted below each fluidizing silo cone bottom, with an air-activated silo discharge system located below to serve as the refill device for the continuous loss-in-weight (LIW) feeder situated under each silo. Except for the butterfly valves used in refilling the LIW feeders, the sorbent is not exposed to any moving parts throughout the entire silo and its discharge system.

The LIW feeders are designed to discharge a continuous flow of sorbent. This example uses a nominal material feed rate of 4,000 lb/hr per duct. Each feeder is capable of holding a minimum of 45 ft^3 of material, which minimizes the number of refills per hour. Minimizing the number of refills in turn maximizes the amount of time the feeders spend in gravimetric (LIW control) mode.

Each feeder hopper is mounted on three load cells linked to the control system. A rotary valve operated by a variable-frequency drive linked to the control system is mounted at the hopper discharge and serves as the material metering device. This valve discharges material through a small, vented chute directly into a blow-through rotary airlock running at a constant speed. The blow-through rotary airlock is the primary seal between the metering systems and the pneumatic conveying line; the metering rotary valve is the secondary seal. Each feeder hopper is equipped with its own reverse-jet pulse filter system that traps nuisance dust generated during feeder refill and returns it to the process. The dust filter also facilitates air displacement in the hopper as material is metered out, as well as air leakage from the blow-through rotary airlock.

Dilute-phase, positive-pressure pneumatic conveying technology is used to transfer and inject metered sorbent into the flue gas duct, and every precaution is taken to ensure that the conveying lines do not become plugged. Each line is equipped with a dedicated positive-displacement blower. These blower packages are coupled with air-to-air heat exchangers to ensure that the conveying air remains cool. As any variation in a blower's steady-state operation could signal the need for conveying line maintenance, flowmeters, pressure transducers, temperature transmitters and variable-frequency drive controls are usually included with the blower packages. The conveying lines may be supplied with blowout ports used to help locate and manage any issue that may arise.

The conveying lines lead to convey line splitters that distribute sorbent to the duct injection lances. The line splitters are vertically oriented to achieve the best distribution possible. Special design considerations ensure an equal distribution of sorbent through each outlet of the splitter. An industrial automation and bulk material handling company has developed a method to analyze the status of each injection lance. Should a blockage occur, the injection lance is automatically purged.



An injection lance array shown supplied by a splitter assembly injects silos

Typical design criteria

The following criteria apply to an effective dry sorbent injection system:

Sorbent:	Hydrated lime, Trona, sodium bicarbonate, or any dry bulk sorbent material
Bulk Density:	25–50 lb / ft^3
Particle Size:	325 mesh
Moisture:	<1%
Temperature:	Ambient
Abrasiveness :	Mild
System Capacity:	Based on plant's flue gas flow rate and chemical composition
Convey Lines:	As required based on number of flue gas ducts

Sorbent considerations

Pros and cons of hydrated lime

Hydrated lime is plentiful and relatively inexpensive. For the money, hydrated lime is effective in mitigating SO_3 to the 5 ppm level. It is "ash-friendly" (that is, environmentally safe). Pilot scale testing has shown that when hydrated lime reacts with SO_x in flue gas, synthetic gypsum is formed. If collected separately from the fly ash, the recovered by-product may be sold to gypsum wallboard plants worldwide.

Although hydrated lime effectively mitigates SO_3, it is less effective in mitigating other acid gases. For example, to mitigate SO_2 with hydrated lime, water must be added to the process to reach acceptable performance levels. The water is needed to facilitate the reaction of hydrated lime and SO_2. This presents an added level of difficulty in designing a cost-effective solution. Last, under certain operating conditions, hydrated lime has a tendency to develop conveying line plugs as compared to sodium-based sorbents.

Pros and cons of sodium-based sorbents

The two most popular sodium-based sorbents are Trona (sodium sequicarbonate) and sodium bicarbonate. Trona is a mined product from Green River, WY. It is abrasive because of its silica content, a factor that must be considered during the design process of the pneumatic injection system. To reduce wear on direction-change elbows, for example, T-bends can be used.

Sodium bicarbonate (SBC) is a nonabrasive, processed chemical typically manufactured to a 400-micron particle size. In most cases, SBC is milled to increase its effectiveness. As a processed chemical, SBC carries a higher purchase cost than Trona, a factor often alleviated by SBC's superior reactive characteristics.

An upside of both Trona and sodium bicarbonate is the improved emissions reduction efficiencies through the "popcorn" effect. For both materials, at temperatures of 300ºF–700ºF, moisture calcines from the particle and creates more surface area to react with acid gases in the stack gas flow.

This means it is very advantageous to inject sodium at the higher temperature of the gas flow (closer to the boiler) to trigger the popcorn effect. This increases the particle's surface area and also the residence time the particle is in the gas flow, improving the reduction of SO_2, HCl, and other pollutants.

Negatives of sodium in ash

Because removing SO_2 requires so much sodium sorbent to be used (10:1 compared to SO_3 mitigation), the recovered ash may contain too much sodium to be acceptable as a resellable by-product.

Sodium-based sorbent efficacy in SO_2 mitigation

Flue gases carry a much higher concentration of SO_2 than SO_3. As a result, higher volumes of sorbent (often 10 times higher) are necessary to satisfactorily remove SO_2 from the flue gas stream.

In dry sorbent injection, Trona and sodium bicarbonate offer higher SO_2 removal efficiencies than does hydrated lime. This is because of the chemical reaction of sodium and SO_2. Milling the sodium increases the efficiency of the removal. Sodium's ability to be milled allows for particle size reduction to increase the effective SO_2-grabbing surface.

Milling to optimize particle size

Milling sodium sorbents offers substantial benefits. A smaller particle size greatly increases the removal efficiency of pollutants. It would be reasonable to expect a reduction of the sorbent injection rate by 15% to 30% when a coarser product is milled to a finer particle size. The molecular structure of sodium lends itself well to the milling process.

This would mean that if 10,000 lb/hr of a coarse sorbent is normally injected, only 7,000 lb/hr of a milled sorbent might be necessary. Over time, this reduced sorbent quantity requirement would add up to a lot of money in a big hurry.

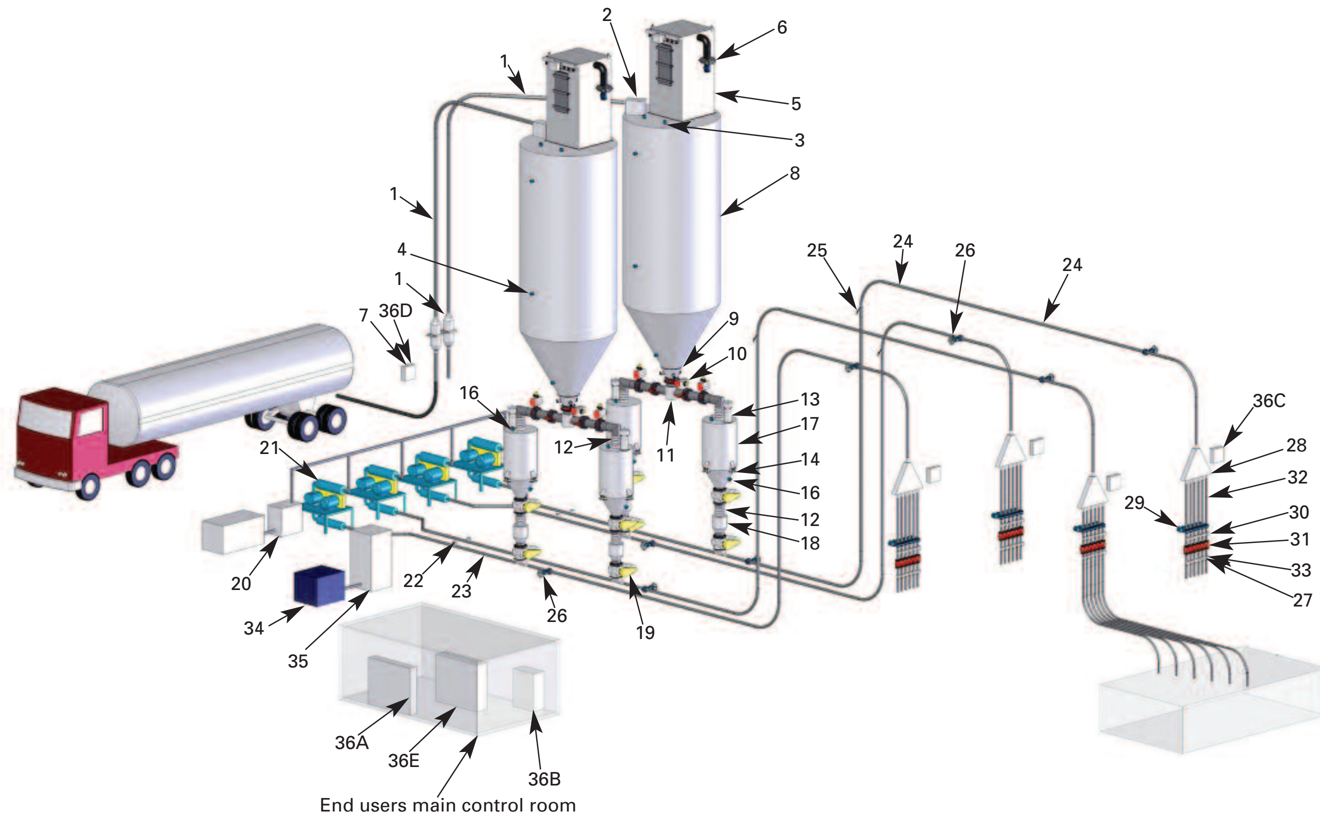
Types of mills

One company in St. Paul, MN, has been successfully using a "blow-through" vertical shaft pin mill through which sorbent is pneumatically conveyed from the silo into the injection lances. The sorbent goes through the mill, is reduced in particle size, and is carried along in the conveyor system airstream to the ductwork. The advantage of this approach is in keeping the product suspended in the airstream to avoid reagglomeration. The blow-through approach is clean, simple, and cost effective.

The only negative to the in-line, blow-through mill is the achievable milled particle size. This design has a practical size reduction limitation compared to other, more complicated mill designs.

There is another type of particle size-reduction mill called an air classifier mill (ACM). ACMs generate a much finer particle size than that of the pin mill—a definite advantage. The design of the ACM is such that material cannot be directly conveyed through it to the injection lances, as is the case with the blow-through pin mill.

Typically, the ACM is used for sodium bicarbonate. Sodium bicarbonate is nonabrasive and more expen-



Dry bulk sorbent injection system diagram

Typical system components

1. Bulk truck unload line components
2. Silo end receivers
3. Guided radar continuous-level indicators
4. Point-level indicators
5. Dust collectors
6. Exhausters
7. Sign for delivery instructions
8. Storage silos
9. Fluidizing bin bottoms
10. Maintenance gates
11. Air-activated silo discharge systems
12. Gravity flexible connectors
13. Single-cartridge dust filters
14. Load cell systems
15. Emergency high-level indicators
16. Emergency low-level indicators
17. Loss-in-weight feeders
18. Vent adapters
19. Air lock packages
20. Air-drying systems
21. Blower packages
22. In-line thermal mass flow meters
23. Air line components from dryers and blowers to rotary airlocks
24. Conveying line components
25. Blow-out ports
26. Knife gates with hand wheel
27. Ball valves
28. Convey line distribution splitter assemblies
29. Pressure transducers
30. Air-operated pinch valves
31. Conveying line components from distribution splitters to injection lances
32. Solenoid valves for injection lance cleaning
33. Injection lances
34. Rotary screw compressors
35. Compressed air dryer packages
36. Electrical controls:
    - a. Main PLC control panel
    - b. HMI workstation for system control room
    - c. Remote I/O panels for injection area
    - d. Truck unloading operator panel
    - e. Motor control center

sive than Trona, thus making this an attractive milling option. As noted previously, making sodium bicarbonate particles finer improves reaction with pollutants in the gas stream. This, in turn, helps make the expense of this sorbent more acceptable. It is generally recognized that SBC must be milled to make a financially feasible installation.

In a typical ACM design, the sorbent is metered into the inlet of the unit, along with a large quantity of air. The negative airflow is created by a material-handling fan placed after the mill outlet. The milled product and air are drawn into the fan's inlet and then pressure-conveyed out of the fan to the duct.

The problem with this approach is that the material-handling fan has a limited capacity for vacuum and pressure. The fan moves a lot of air, but with very limited pressure and vacuum differential. The mill must be placed very close to the duct injection location. In most power plant applications, the flue gas ducts are quite large. To get sufficient dispersion of sorbent, multiple injection lances are required. The limited pressure capability of the ACM material-handling fan precludes the use of multiple injection lances. ACMs are best suited for use in the relatively small ducts of industrial boilers.

Another option is to take an ACM and put a vacuum (negative pressure) dilute-phase system to vacuum the material from the mill and send it up and into a filter receiver. From that filter receiver, a rotary valve feeds the material into a dilute-phase positive-pressure system to convey it to the injection points. This option is viable, but it significantly increases total system cost.

Emissions mitigation with improved cost efficiencies

Traditionally, wet scrubbers have been used at fossil fuel–fired electrical generating plants to effectively remove SO_2 from stack gas flows. Unfortunately, with a typical price tag of 400 to 600 million dollars, wet scrubbers can be costly.

Sodium-based dry sorbent injection systems are available at a significantly lower capital cost. At 1.5 to 10 million dollars, sodium injection systems provide acceptable levels of emission control. Mitigation levels with Trona approach 70% to 80% SO_2 removal. With its smaller particle size, sodium bicarbonate achieves up to 80% to 90% SO_2 removal. This compares to EPA and state requirements for SO_2 commonly in the 70% to 80% removal range, although this rate may differ by state.

Another option for SO_2 mitigation is the gas suspension absorber (GSA) offered by another large company specializing in air pollution control. This technology utilizes a reactor vessel that recirculates a bed of reagent, promoting contact between the lime and the SO_2 and increasing removal efficiency up to 98%. This proprietary technology is reagent-flexible and can be used with dry lime injection, with lime plus a separate water injection loop for humidification and temperature control, or with lime slurry. While there is a higher capital cost for the GSA (compared to dry sorbent injection alone), it is considerably lower in cost than wet scrubbers.

Environmental considerations

From an environmental perspective, hydrated lime is a more attractive sorbent material than either Trona or sodium bicarbonate. Lime is not considered a problem for landfills and water supplies.

Sodium is water-soluble, so it can leach into soil and water tables. A greater risk of contamination by sodium products requires careful consideration for ash disposal.

Nevertheless, because of sodium's superior mitigating effectiveness for SO_2 and HCl emissions, the extra considerations to protect soil and water resources may prove to be worth the investment.

Jerry VanDerWerff *is the national sales manager for Sorb-N-Ject™ Technology provided by Nol-Tec Systems, Inc. of Lino Lakes, MN. He has been with Nol-Tec Systems for 22 years and holds a degree in design technology from St. Paul Technical College. Jerry can be reached at 651-780-8600 x206; fax 651-780-4400; email JerryVanDerWerff@nol-tec.com.*