

Advances in Semi-dry Absorption for Multi-Pollutant Control

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Abstract

Semi-dry absorption has evolved from rotary atomizer-based vessels at 10-14 second gas residence time and limited gas-solids mixing to flash-dry absorbers with appreciable gas-solids mixing and 1-2 seconds gas residence times. Recent applications of a third-generation flash-dry absorber in a multi-pollutant emission control system are described. Performance and cost comparisons are made to conventional SCR/ ESP/wet FGD technology combinations. Future applications and enhancements are discussed including dealing with the uncertain impact of future fine PM and mercury regulations.

Introduction

This paper traces the development of semi-dry scrubbing in the United States. It is written from the viewpoint of the author, covering experiences from the first USA installation through current available technology.

The technology has evolved from use of a conventional spray dryer linked to a utility type shaker type collector, to a nozzle type vessel, to a fluid bed/reactor type and finally to a flash drying reactor utilizing a pulse collector fabric filter.

This paper does not trace variants on each of these types but deals with the generic design that is the basis of the majority of the units employed in the utility and waste burning industries. In the same manner no patent search was performed or reported.

The author was directly involved in the first installation of a semi-dry scrubber. The author has also been involved in the development, pilot, demonstration, and commercialization of the different technologies. Each type is discussed along with its advantages and shortcomings.

The operating concept and cost of the flash-drying unit is discussed as applied to utility coal fired boiler plants.

A short discussion about the use of lime based semi-dry scrubbing is presented as a reason for further investigation into this technology.

In the beginning

The early installations (during the 80's and 90's) for the removal of SO₂ and HCl in the United States employed wet scrubbing systems. The most popular technique was limestone scrubbing, in an absorber, utilizing multiple stages of sprays or trays. These systems have been demonstrated to operate at very high removal efficiencies (above 95%).

The second most popular wet system was thiosorbic lime technology developed and patented by Dravo Lime Inc. This technology has recently added a process to produce gypsum in lieu of calcium sulfates and sulfites. The byproduct was stabilized, dried and recovered for use as pozzolanic cement.

The use of limestone versus lime is normally based on availability, cost, and disposal considerations. Limestone is widely viewed as a lower cost sorbent when compared to lime. However, limestone requires greater quantities, fine grinding, process additives and increased material handling at the site. When these factors are considered, the cost per ton of SO₂ removed is much closer for both systems.

Semi-Dry scrubbing was developing during this period, but was in limited use due to the large unit size that was being selected for scrubbing.

The New World

New regulations for mercury control, as well as other air toxics, have introduced a concern for wet systems following electrostatic precipitators. This configuration has become the standard for large utility boilers that are scrubbed. Now, with the addition of SCR systems (for control of NO_x) upstream of the electrostatic precipitator, the problem gets more confusing. Ammonia slip, SO₃, Mercury, and fine particulate will not be controlled.

BOILER → SCR → ESP → Scrubber

A final filter will probably need to be added following the scrubber to improve mist elimination and fine particle removal. The ESP may need to be upgraded using fabric filter slipstreaming to increase the overall removal efficiency. In addition, the introduction of ammonia into the collected flyash could result in decreased fly ash sales and the market for the gypsum byproduct is decreasing.

A better solution may be the use of a semidry scrubber followed by a fabric filter; where Ammonia slip, SO₃, Mercury and fine particulate are controlled.

BOILER → SCR → Semi-Dry → Fabric Filter

For either a new unit or a retrofit, the capital cost as well as the operating cost should be lower for this arrangement than following the ESP/Scrubber route. In fact, a semi-dry scrubber and fabric filter will be lower in capital cost than a wet scrubbing system.

In the case of an existing ESP, it may be retained for flyash sales or removed if there is no flyash market after the SCR is installed.

Having made a case for consideration of semi-dry scrubbing we will move on to describing the technology and looking at costs.

Rotary Atomized Spray Dryer

Spray dryer absorption was first used commercially on utility boilers in the late 1970's. The process consists of a large chamber in which an absorbent liquid is sprayed and mixed with incoming flue gas. The water in the spray is evaporated, while the reagent, calcium hydroxide or sodium carbonate, reacts with acid gases to form dry particulate products that are collected in a downstream filter or precipitator. The drying vessel consists of a large cylindrical chamber, conical hopper, gas distribution device, and gas outlet duct. The atomization device is installed in the center of the gas distribution section and sprays horizontally into the gas flowing into the top of the chamber.

Typical spray drying systems for SO₂ absorption operate within the following performance envelope:

Table 1. Rotary Spray Dryer.

Gas inlet temperature, °F	275 – 500 (special applications up to 1800)
Approach to saturation, °F	15 - 35
Product Moisture, %	5 - 15
SO ₂ Removal, %	70 - 90
Lime Stoichiometry	1.0 – 2.0
Feed solids, %	5 (single pass) – 35 (recycle)
Collector inlet loading, gr/acf	2- 10
Gas residence time, sec	10 - 15
Atomizer feed pressure, PSIG	10 - 25
Chamber H/D Ratio	.75 – 1.0

The first semi-dry systems utilized rotary atomizers to spray absorbent liquid into the flue gas. The atomizer consists of a wheel lined with abrasion-resistant ceramic inserts, driven by an electric motor through a speed increaser at speeds up to 16000 RPM. The speed increasers used in this application were epicyclic or parallel-shaft designs with integral or external lubrication systems, special feed piping and liquid distributors, and cooling and sealing systems adapted for the service. The typical mean droplet size produced by rotary atomizers is approximately 30 microns.

Lime preparation systems consist of ball-mill slakers, screens, tanks, agitators and pumps in a field-erected arrangement that includes an extensive enclosure and lime storage silos. Although the technology was utilized increasingly in industrial boiler and process applications, packaged shop-assembled systems using detention or paste slakers began to predominate. In these systems, the lime processing equipment is contained within a cylindrical or rectangular enclosure that also supports the lime storage silo(s).

In early utility applications of spray drying, recycling of the product was used to increase utilization of lime and to improve drying performance at close approach to saturation. Recycle systems typically consist of storage bins, feeders, mixing tanks and pumps; these are field-erected and often require extensive enclosure and support structures.

After commercial acceptance of this technology on coal-fired boilers, spray drying in single-pass mode was used increasingly on solid waste incineration systems to collect SO_2 , HF, and HCl. In this application, the approach was increased to 150 °F due to the hygroscopic nature of CaCl_2 . Typical removals are 90 % SO_2 , 95% HF, and 95 % HCl. The use of activated carbon was initiated in these applications for control of mercury and polycyclic aromatic hydrocarbons (dioxins and furans).

Problems encountered and addressed, in varying degrees, for this wheel type design include: undersized drying chambers (build-up), wheel abrasion, wheel failure, and efficiency.

Nozzle Atomized Spray Dryer

Dual-fluid nozzle atomizers were tested in the early 1980's as a cost-saving alternative to rotary atomizers. In lieu of the motor and speed-increasing gearbox of the rotary atomizer, the nozzle requires a high-pressure feed pump and a compressor for the atomizing fluid.

The process consists of a large chamber in which an absorbent liquid is sprayed and mixed with incoming flue gas. The water in the spray is evaporated, while the calcium hydroxide reacts with acid gases to form dry particulate products that are collected in a downstream filter or precipitator. The drying vessel consists of a large cylindrical chamber, conical hopper, gas distribution device, and gas outlet duct. In all but the smallest systems, multiple atomizers are installed in the roof of the vessel and spray vertically downward into the vessel.

Typical nozzle spray drying systems for SO₂ absorption operate within the following performance envelope:

Table 2. Nozzle Spray Dryer.

Gas inlet temperature, °F	275 – 500
Approach to saturation, °F	25 - 50
Product Moisture, %	10 - 15
SO ₂ Removal, %	90
Lime Stoichiometry	1.0 – 2.0
Feed solids, %	5 (single pass only)
Collector inlet loading, gr/acf	2- 5
Gas residence time, sec	15 - 20
Atomizer feed pressure, PSIG	100 - 125
Chamber H/D Ratio	1.5 – 2.5

The dual-fluid atomizer consists of a lance assembly with feed and compressed air pipes. They include machined tips, mixing sections, and impact devices in some of the designs. Some designs include ceramic internals for abrasion resistance. Due to the high pressures involved, the absorbent liquid leaves the nozzle at a high velocity, and therefore causes accelerated abrasion of the internals.

Packaged shop-assembled lime slaker systems are used almost exclusively in nozzle systems. Since recycle operation increases abrasiveness of the feed, recycling is not generally used with nozzles.

Problems encountered and addressed, in varying degrees, for this nozzle type design include undersized drying chambers (build-up), nozzle abrasion, nozzle plugging, and efficiency.

Fluid Bed Reactors

Fluid bed reactors were first used commercially for SO₂ removal in the late 1980's - early 1990's. These systems consist of a vertical reactor vessel in which a moving or stationary bed of recycle material is contained. Gas flows upward through the bed where SO₂ reacts with lime to form the solid product. Lime slurry is sprayed into the gas upstream of the bed. In some cases, dry hydrated lime is mixed with the recycle stream external to the reactor. The gas flows from the reactor to a cyclone collector in which the particulate is removed for recycle. Upon leaving the cyclone, gas flows to the final filter. The absorbent feed system consists of single or multiple nozzles installed at the bottom of the reactor, which spray upward into the gas stream. Multiple reactors are used in most systems.

Typical fluid bed systems for SO₂ absorption operate within the following performance envelope:

Table 3. Fluid Bed & Reactors.

Gas inlet temperature, °F	275 – 500 (special applications up to 1800)
Approach to saturation, °F	15 - 35
Product Moisture, %	1 - 5
SO ₂ Removal, %	90- 95
Lime Stoichiometry	1.0 – 2.0
Feed solids, %	20
Collector inlet loading, gr/acf	10 - 50
Gas residence time, sec	1 - 2
Atomizer feed pressure, PSIG	100 - 125

As in industrial spray drying applications, the lime preparation system is packaged and shop-assembled to reduce cost.

The Case for Recycle

It was recognized early in their development that wheel type units required recycling of the collected lime and reaction products to improve SO₂ removal efficiencies, improve utilization and allow closer approaches to saturation. This was not easily added to either the wheel or nozzle type spray dryers.

A secondary requirement is the need for chlorides in the system, which reduces the vapor pressure and improves removal efficiencies.

The requirement to recycle led to the use of fixed bed and rotating bed reactors, where recycle is inherent in their design.

Gas Entrainment Reactors

Gas entrainment reactors use vertical vessels to mix a gas stream with recycled particulate, which is entrained in the gas and flows to a down-stream filter or ESP. The reactor consists of a horizontal gas inlet section, optional isolation valve, and a vertical chamber. A venturi section is used in some designs to provide uniform distribution of the gas into the reaction chamber. A feed chute is provided at the bottom of the reaction chamber. Recycled particulate mixed with lime slurry and water in an external mixing device flows through the chute, and mixes with flue gas at the entrance to the reaction chamber. The water absorbed on the recycle mixture flashes in the reaction chamber, while the acid gases present in the flue gas react with the lime slurry to form solid particulate. The gas with its entrained particulate flows to the final filter, is separated and recycled or discharged to disposal.

Typical gas entrainment reaction systems for SO₂ absorption operate within the following performance envelope:

Gas inlet temperature, °F	275 – 500 (special applications up to 1800)
Approach to saturation, °F	15 - 35
Product Moisture, %	1 - 5
SO ₂ Removal, %	90- 95
Lime Stoichiometry	1.0 – 2.0
Feed solids, %	80 - 98
Collector inlet loading, gr/acf	50 - 200
Gas residence time, sec	1 - 2
Atomizer feed pressure, PSIG	100 - 125

As in industrial spray drying applications, the lime preparation system is packaged and shop-assembled to reduce cost.

The recycle system consists of a silo, feeder(s), twin-shaft paddle mixer(s), a conveying system from the collector, and an overflow conveyor from the recycle silo to the disposal silo. The mixer consists of twin, counter-rotating paddle shafts contained within a rectangular housing, driven by electric motor and reduction gears. Lime slurry and water are sprayed onto the recycle material as it flows through the mixer. The mixer product is a free-flowing material consisting of 80 – 98 % solids and water.

Flash Drying Reactor

The flash drying reactor arose out of work to improve the vertical spray type reactor. The following changes (improvements) were made to the Beaumont Environmental Systems unit identified as the RAP (Rapid Absorption Process).

- The cyclone between the reactor and the final filter was removed. This reduced the pressure drop of the system.
- Recycle from the final filter was incorporated. Designs using the cyclone required recycle from both the cyclone and the final filter. This change now utilizes the fines collected in the final filter and improves the surface area available for flash drying. The grain loading introduced to the reactor can be much higher than that from a cyclone only reactor design. You do not run out of recycle which allows a simple overflow from the recycle transfer bin to be transferred to final disposal.
- All the lime slurry is introduced outside the reactor, mixed with recycle (to a specific solids concentration), and then introduced into the reactor. This reduces potential buildup, eliminates slurry spray nozzles, and reduces the capital cost.
- Rapid drying (flash drying) occurs as the material is introduced into the reactor. Velocities can be increased and residence reduced to 1 to 2 seconds. The unit can be operated much closer to saturation, which improves utilization and removal efficiency.

- A pulse filter is utilized as the final filter. The design includes improved hopper dropout and allows for the high grain loading from the reactor.

This concept utilizes established reactor equipment designs while lowering the cost and improving the overall operation.

The design is currently in demonstration at a facility in Ohio along with a low temperature NOx removal system.

Some Economics

A number of coal-fired units have been priced for utility plants considering the addition of SO₂ removal systems. It has the advantage of providing removal of ammonia slip, SO₃, Mercury, and fine particulates. The disposal material is dry and easily handled.

The EPRI study dating from 1992 established cost per KW for most of the available SO₂ recovery systems. These costs covered site, engineering, risk, etc. and were representative of today's costs. Commonly available vendors and erected equipment costs are utilized to compare the technologies. One of the difficulties is that the older wet scrubbing technologies reduce in cost as the plant size increases. The cost of a flash drying system, which is normally furnished in modules, will remain quite constant. The exception is for the sizes less than 30 MWe where higher costs are expected.

Typical Limestone forced oxidation scrubber - \$125 per KW
 Typical Thiosorbic Lime forced oxidation system - \$110 per KW
 RAP Flash Drying (Semi-Dry) - \$34 per KW
 RAP Flash Drying (Semi-Dry) with fan and Pulse filter - \$74 per KW

The cost per ton of SO₂ removed will vary according to the sulfur content of the coal and the removal efficiency desired. The 80 MWe system for which the above capital costs were established used a low sulfur coal and 90% removal. The cost per ton of SO₂ removed was \$451 based on the plant specific utility and service costs.

Future Work

There are several new concepts that work is progressing on which will be incorporated in this and future designs that are worth discussing.

- Enhanced particulate filtration is in the demonstration phase. The pulse collector has charging electrodes installed between bags. This changes the character of the cake deposited on the bags. It reduces fine particulate emissions by up to 10 times. It also reduces the pressure drop. Better SO₂ removal from the bags is also expected due to the larger surface area exposed to the gas flow. This is now commercially available.
- Enhanced sorbents are available that allow for mercury removal without the use of carbon. These are lime based slaked with other oxidants to produce a more

active sorbent. Sorbents to reduce NO_x emissions are being evaluated, and may be incorporated into the semi-dry reactor.

- A secondary additive port in the reactor allows for staged reactions and/or removal of additional pollutants following the SO₂ stage.
- The reactor will be used as an evaporative cooler, to protect the baghouse, during start-up and shutdown.
- The reactor will be designed for dry scrubbing for a single pollutant such as mercury, but will be upgradeable to a full semi-dry scrubbing system.

These improvements to the system represent the on-going nature of semidry scrubbing technology.

Conclusions

Current technology for NO_x control using an SCR, followed by an Electrostatic Precipitator and a Wet limestone Scrubber, has both cost disadvantages and performance shortcomings that will require new approaches to utility power plant pollution control.

Semi-dry scrubbing has evolved and several designs are available to address the current and anticipated future requirements. Combined with a Pulse Baghouse we have a true multi-pollutant control system that can work well with several types of NO_x control systems.

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References

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