Circulating Fluid Bed Scrubbing Technology: Low-Cost SO_2 Control for PF Units for the Indian Power Market

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Tighter control of Sulfur Oxides (SOx), Nitrogen Oxides (NOx) and particular matter (PM) has become a priority for many countries around the world. As an example, India's Ministry of Environment & Forest (MOEF) has issued stringent regulations that affect an estimated 140 GW of operating coal-fired power plants and all new plants built in the future. By 2022, SO_2 emissions for all operating plants in India that are 500 MWe or larger must not exceed 200 mg/Nm3 and all new coal plants regardless of rating and other special category plants must meet even tighter SO_2 limits of 100 mg/ Nm3 (Table 1). In other words, for an existing coal plant with baseline SO_2 emissions ranging from 1200 – 1400 mg/ Nm3 this amounts to an 80-90% SO_2 emissions reduction from uncontrolled levels.

Pollutant	Units installed before Dec. 31, 2003	Units installed after Jan. 1, 2004 through Dec. 31, 2016	Units installed after Jan. 1, 2017[2]
PM	100 mg/Nm^3	50 mg/Nm^3	30 mg/Nm^3
SO_2	600 mg/Nm^3 for units < 500MW[1] 200 mg/Nm^3 for units ≥ 500MW	600 mg/Nm^3 for units < 500MW[1] 200 mg/Nm^3 for units ≥ 500MW	100 mg/Nm^3
NOx	600 mg/Nm^3	300 mg/Nm^3	100 mg/Nm^3
Mercury	0.03 mg/Nm^3 for units ≥ 500MW	0.03 mg/Nm^3	0.03 mg/Nm^3

Table.1: New Indian coal-fired power plant air emission standards ***Source****: MOEF*

Notes:
1. Units < 500MW located in or within a 300km radius of non-attainment areas (densely populated areas in excess of 400 people/km2) must meet ≥ 500MW SO_2 standard.
2. Includes units under construction as of December 2015.

Competing FGD Technologies

The choice of a flue gas desulfurization (FGD) system for an Indian power plant, can either be a wet, dry or semi-dry system depending on the level of SOx removal needed and the plant specifics. The conventional approach to remove SO_2 from coal-fired power plant flue gases has been wet flue gas desulfurization (wFGD) technology, or, to a lesser extent, spray dryer absorber (SDA) technology. Another technology that may be better suited especially for Indian power plants is the circulating fluidized bed (CFB) technology, a dry FGD process that achieves increased SO_2 removal with a much more fuel flexible treatment process that is not dependent on wet chemistry.

Each of these alternatives are discussed in the following sections and prospective owners must evaluate them with respect to their current site conditions, initial & lifecycle costs, and possible future regulation of additional pollutants.

Wet flue gas desulfurization– Until now, wFGD technology has been the incumbent FGD option selected by Indian power plants largely due to its track record on large scale units, limestone cost, and its ability to produce gypsum as a by-product for possible sale. The wFGD process uses a wet slurry produced from milled limestone mixed with water that is pumped through banks of spray headers in the absorber vessel. Flue gas enters the bottom of the absorber vessel, below the spray nozzles. The slurry droplets created by the sprays flow countercurrent to the incoming flue gas in order to mix the SO_2 with the calcium-rich reagent. The resulting wet chemical reaction produces a mixture of calcium sulfite and calcium sulfate ($CaSO_4$), also known as gypsum. A portion of the slurry is continuously removed from the absorber, collected by a separate recovery process, and then dewatered with drum or belt filters. The gypsum recovered, if not commercially recycled, must be properly and permanently stored either on-site in containment facilities or transported to an offsite location.

There are several expensive drawbacks of wFGD technology, such as process equipment that requires a large footprint near the boiler island, very high water usage to make the slurry used for sulfur removal, and significantly increased auxiliary power consumption necessary to run the wFGD. Some Indian plants that selected wFGD expecting to offset increased O&M expenses with gypsum sales have been disappointed. The quality of gypsum produced in the Indian power plant has been poor due to the low purity (<80%) of local limestone. Additionally, the Indian market for gypsum is also saturated so the expected income stream from the sale of gypsum has been replaced with a recurring expense of large-scale gypsum disposal.

The wFGD plant also requires a long-term, reliable source of high quality limestone as large quantities of limestone must be regularly delivered to the plant. Also, water usage by wFGD is 30% to 40% higher than either the SDA or dry CFB scrubber options, which poses a challenge for plants built in drier parts of India such as Rajasthan, Gujarat, Tamil Nadu where water supplies for power generation are limited. Finally, a plant with a wFGD must significantly increase operating, maintenance, and laboratory testing staff because the wFGD option is much more manpower intensive, particularly with respect to routine maintenance. For a country like India that has little to no experience with the installation, maintenance, or operation of modern air quality control systems, particularly FGD, this can be a challenge.

The wet desulfurization process also requires expensive glass or plastic liners or stainless steel for the absorber vessel, not required by the other two SO_2 removal processes, which increases the capital cost, particularly for a single vessel system. The Indian power market is very price sensitive so the much higher capital cost of a wFGD compared to other technology options, remains an important evaluation factor.

Spray drier absorber. Spray drier absorber (SDA) sulfur removal systems are typically employed on plants that burn low-to medium-sulfur (<2%) coal. SDA systems generally achieve sulfur removal efficiencies in the range of 90% to 95%, depending on inlet conditions. Higher sulfur removal rates will require the addition of a fabric filter that provides for the needed reaction and mass transfer time for the sorbent and SO_2 to react in a surface filter cake.

The SDA process begins with a lime sorbent, usually quicklime (CaO), that is slaked with water to form a slurry reagent. Lime is typically stored in silos much like the wFGD process. Slurry preparation can also use recycled dust from the plant's particulate collection system to increase the solid content of the slurry to improve SO_2 removal efficiency. The reagent slurry is pumped to the top of the SDA absorber vessel and is led through one or more high-speed spinning wheels within rotary atomizers located at the top of the absorber vessel to produce a spray cloud of reagent. The flue gas mixes with the spray cloud and the sorbent reacts with SO_2 and SO_3 to form calcium sulfite and calcium sulfate while simultaneously cooling the flue gas. The cooled flue gas leaves the absorber and enters the particulate collection system, such as a fabric filter or electrostatic precipitator.

Circulating fluidized bed scrubber. The circulating fluidized bed (CFB) scrubber is growing in popularity with plants up to approximately 600MW. Indian plant owners who are highly sensitive to the construction cost will be pleased to learn that the CFB scrubber has an installed cost approximately 60% of a similarly sized wFGD system. In India, the average installed cost of a wFGD system has averaged $65/kW, this would translate into immediate savings of almost $25/kW in favor of a CFB scrubber.

The operating essentials of the CFB scrubber and its up flow absorber are substantially different from the SDA process **(Figure 1)**. Flue gas with fly ash enters the bottom of the absorber, flowing upward through multiple venturis to accelerate the gas causing turbulent flow.There is no need for external lime preparation so all the slurry mixing and handling equipment are eliminated. Instead, dry hydrated lime, $Ca(OH)_2$, is directly injected into the CFB absorber along with the boiler flue gas and fly ash. An optional dry lime hydrator produces hydrated lime on-site from lower cost quick lime.

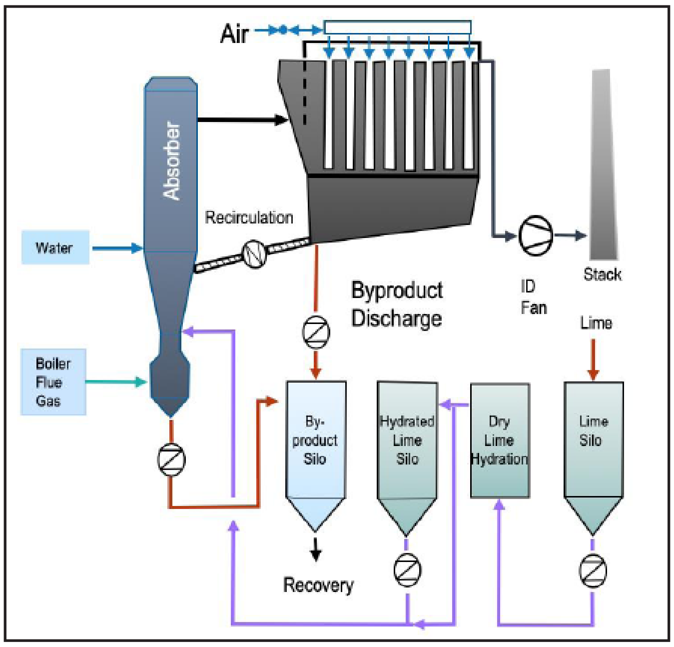

***Figure 1**. The CFB dry desulfurization process. **Source**: Sumitomo SHI FW*

Recycled solids, reagents, and water mix with the turbulent flue gas providing gas cooling, reactivation of ash, and capture of pollutants. In short, unlike the other technologies, the sulfur removal process in a CFB scrubber is independent of water usage.

The design of the absorber produces high turbulent mixing of the flue gas, solids, and water to achieve high capture efficiency of the vapor phase acid gases and metals contained within the flue gas, unlike the wFGD or SDA processes. The gas and solids enter the fabric filter where solids are captured and recycled back to the absorber to capture more pollutants. Unique to the CFB scrubber, reactive absorbents, such as sodium carbonates, hydrated lime, and activated carbon, may be added to target specific pollutants such as acid gases and organic compounds for capture first within the CFB absorber vessel and then again in the fabric filter as the flue gas passes through the filter cake.

There are other important cost advantages with the CFB scrubber. Because there are no high-speed rotary atomizers within the absorber requiring a high frequency of maintenance since they are prone to erosion, scale formation, and plugging or lime slurry preparation equipment in a CFB scrubber so annual maintenance is reduced by a factor of four compared to the SDA and even more compared to the wFGD.

CFB scrubber systems have been employed at plants worldwide firing coal with a wide range in sulfur levels with no technical limit on the entering fuel sulfur content, unlike the alternative technologies discussed above. Fuel ash content seen in Indian fuels, up to 40-45%, is perfectly acceptable to a CFB scrubber. Also, the flue gas temperature does not limit the amount of lime injection as it does when using an SDA. This feature allows for a significant increase in acid gas scrubbing performance, should future air emissions regulations require. This fuel flexibility is an important performance characteristic for those plants receiving coal from mines with poor coal quality and reduce or eliminate the need to burn imported coal. Sulfur dioxide removal efficiency has been demonstrated in excess of 95% (see below case study) and up to 99% depending on the entering SO_2 loading. Also, unlike wFGD, CFB absorbers can be designed to remove 99% of the SO_3 because of the lime reagent's has a high affinity for SO_3. Other important design features and operating advantages of the CFB scrubber that should be of interest to the Indian power market are shown in **Figure 2.**

Advantage | Neutral | Disadvantage

Capability/requirement	Wet FGD	SDA FGD	CFB FGD
SO_2 capture capable	Advantage	Disadvantage	Advantage
Low water consumption	Disadvantage	Advantage	Advantage
Fuel flexibility, sulfur content	Advantage	Disadvantage	Advantage
Fine particulate capture	Disadvantage	Advantage	Advantage
High SO_3 capture	Disadvantage	Advantage	Advantage
Compact system footprint	Disadvantage	Neutral	Advantage
Low maintenance requirements	Disadvantage	Neutral	Advantage
Includes mercury capture	Disadvantage	Neutral	Advantage
Reduces CO_2 emissions	Disadvantage	Advantage	Advantage
Includes wastewater treatment	Disadvantage	Advantage	Advantage
Uses low-quality water	Disadvantage	Disadvantage	Advantage
Uses limestone reagent	Advantage	Disadvantage	Neutral
Large scale (>350 MW)	Advantage	Disadvantage	Advantage
Necessary for retrofit: ESP improvements	Disadvantage	Advantage	Advantage
Necessary for retrofit: Stack improvements	Disadvantage	Advantage	Advantage
Necessary for retrofit: Flue gas reheater	Disadvantage	Advantage	Advantage

Figure 2. *The advantages and disadvantages of the three desulfurization technologies of interest to the Indian power market are summarized. Source: Sumitomo SHI FW*

CFB Scrubber Case Study

Basin Electric's 420 MW (520 MWe equivalent at sea level altitude) Dry Fork station, located in Gillette, Wyoming, entered commercial service in June 2011 **(Figure 3).** Behind its pulverized coal boiler sits the largest single absorber dry scrubber operating in the world today.

Figure 3. *Basin Electric Dry Fork Unit 1 commissioned by SFW is the largest CFB scrubber in the world with a plant electrical output of 420 MWe or 520 MWe at SL (Courtesy Basin Electric Co-Op and Wyoming Municipal Power Agency)*

The Sumitomo SHI FW CFB scrubber has demonstrated a very high 98% availability while meeting all the strict emission requirements set by the U.S. Environmental Protection Agency and the state of Wyoming. The emission regulations are designed to directly or indirectly limit a broad array of compounds designated as pollutants, such as SO_2, SO_3, HCl, H_2SO_4, HF, PM10, PM2.5, mercury, and other heavy metals. Since it went into operation, the CFB scrubber at the Basin Electric plant has exceeded its design performance reducing SOx by 95% - 98% to levels below 50-60mg/Nm³. It also passed a 30-day mercury removal compliance test by meeting the permitted emission limit of 2.35µg/m3 while demonstrating an Hg removal rate in excess of 95%.

Make the Right Choice

For many plants in the Indian power market, the CFB scrubber is a compelling economic choice particularly for units rated at 600MW or less due to its lower installed cost, auxiliary power and water usage. CFB scrubbers also offer a compact footprint and low maintenance while maintaining high reliability. It's a hard-learned truth that the number of regulated pollutants will increase in the future, particularly in developing countries, so multi-pollutant control capability should be included up front rather as an expensive afterthought. Also, the fuel flexible CFB scrubber allows Indian power plants to purchase lower-cost opportunity fuels, mixes of local fuels, For the Indian power market, 2022 is coming quickly and purchase decisions must be made very soon. Given these important characteristics, the CFB scrubber enjoys distinct and quantifiable advantages over competitive FGD processes.

For details on the Lifecycle Economics of a Wet FGD vs CFBC Scrubber please log into http://www.shi-fw.com/2019/08/31/show-me-the-money-cfbc-vs-wet-fgd-lifecycle-cost-comparison/