Multi-pollutant control technology assessment: Circulating fluidised bed scrubber vs. spray dryer absorber

Matthew Fischer and Greg Darling

Kurzfassung

Minderung von Multi-Emissionen: zirkulierender Wirbelschichtwäscher oder Sprühtrocknungsabsorber?

Strengere Auflagen zur Minderung von Emissionen setzen Kraftwerksbetreiber zunehmend unter Druck. Kohlebefeuerte Anlagen sind daher mit Rauchgasentschwefelungsanlagen (REA) nachzurüsten. Am Markt gibt es zahlreiche Systeme zur gleichzeitigen Minderung einer Reihe von Emissionen (Multi-pollutant control). Derartige Systeme sind einer klassischen REA bei weitem überlegen.

In vorliegenden Beitrag werden die Unterschiede zwischen modernen Wirbelschichtwäschern und fortschrittlichen Sprühabsorptionstrocknern dargestellt.

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Introduction

The converging US Environmental Protection Agency (EPA) rules for reducing mercury, metals, acid gases and organic compounds (Mercury and Air Toxics Standards or MATS), Regional Haze (RH) and SO_2, NO_x as well as particulates (Cross-State Air Pollution Rule or CSAPR) have ratcheted up the pressure on coal-fired generators to quickly reduce a variety of pollutants. The EPA estimates that CSAPR alone requires more than 3,000 units at more than 1,000 plants located in 28 states to reduce emissions that cross state lines and contribute to ground-level ozone and fine particle pollution. CSPAR Phase 1 compliance takes effect this year while MATS and RH reduction are ongoing programmes.

The debate over what limits will be imposed has now shifted to how individual units will comply with the prescribed deadlines. There are as many technical approaches to meeting new emission limits as there are differences in plant designs. Adding to the complexity of any solution is the uncertainty of future rules that will require further reductions of an expanding range of pollutants.

In the past, SO_2 capture on a large scale was the province of wet flue gas desulphurisation (WFGD) technology. It has the advantage of relatively low operating cost and uses readily available limestone as the reagent, which can be recycled into a number of useful products to offset operating costs. However, WFGD scrubbers do have disadvantages, such as large capital and high maintenance costs. By design, many WFGD systems require periodic discharge of the scrubber liquor to maintain solids and/or chlorides. This effluent requires additional treatment which adds capital and operating costs. Also the uncertainty of future regulations, specifically the Steam Electric Power Generating Effluent Limitation Guidelines (ELG), may require additional discharge treatment.

WFGD is also limited in its ability to capture mercury and SO_3. Some plants have reported increased mercury removal as a desirable, but expensive co-benefit when a selective catalytic reduction (SCR) system for NO_x removal was installed upstream of the WFGD scrubber. Other plants have also added injection of one or more proprietary reagents into the furnace, such as dry sorbent injection (DSI), as a means to increase the mercury removal co-benefit. Stacking technologies is not a cost effective long-term strategy to reduce pollutants – it is unnecessarily expensive and reduces the overall reliability of the entire unit. A more holistic solution is preferred.

Technology comparison

Interest in dry or semi-dry FGD scrubbers is increasing due to its ability to capture mercury, acid gases, dioxins, and furans, in addition to SO_2 and particulates. These multi-pollutant technologies also have added benefits: no liquid discharge and significantly reduced water consumption, which is increasingly important to power plants that are under pressure to reduce water consumption.

Two multi-pollutant technologies dominate the utility sector. The fundamental difference between the two technologies is the manner in which the reagent is mixed with the incoming flue gas to remove the desired pollutants. The first technology is the spray dryer absorber (SDA), which sprays atomised lime slurry droplets into the flue gas. Acid gases are absorbed by the atomised slurry droplets while simultaneously evaporating into a solid particulate. The flue gas and solid particulate are then directed to a fabric filter where the solid materials are collected from the flue gas. Amec Foster Wheeler has installed 60 SDA units representing over 4,500 MW of plant capacity. The second is the circulating fluidised bed scrubber (CFBS, which circulates boiler ash and lime between a scrubber and fabric filter). Amec Foster Wheeler has install 78 CFB scrubber units representing over 7,000 MW of capacity in the power and industrial industries.

Spray dryer absorber (SDA)

SDA technology operates using absorption as the predominant collection mechanism. In general, the acid gas dissolves into the alkaline slurry droplets and then reacts with the alkaline material to form a filterable solid. Intimate contact between the alkaline sorbent (hydrated lime) and flue gases make the gas removal process effective.

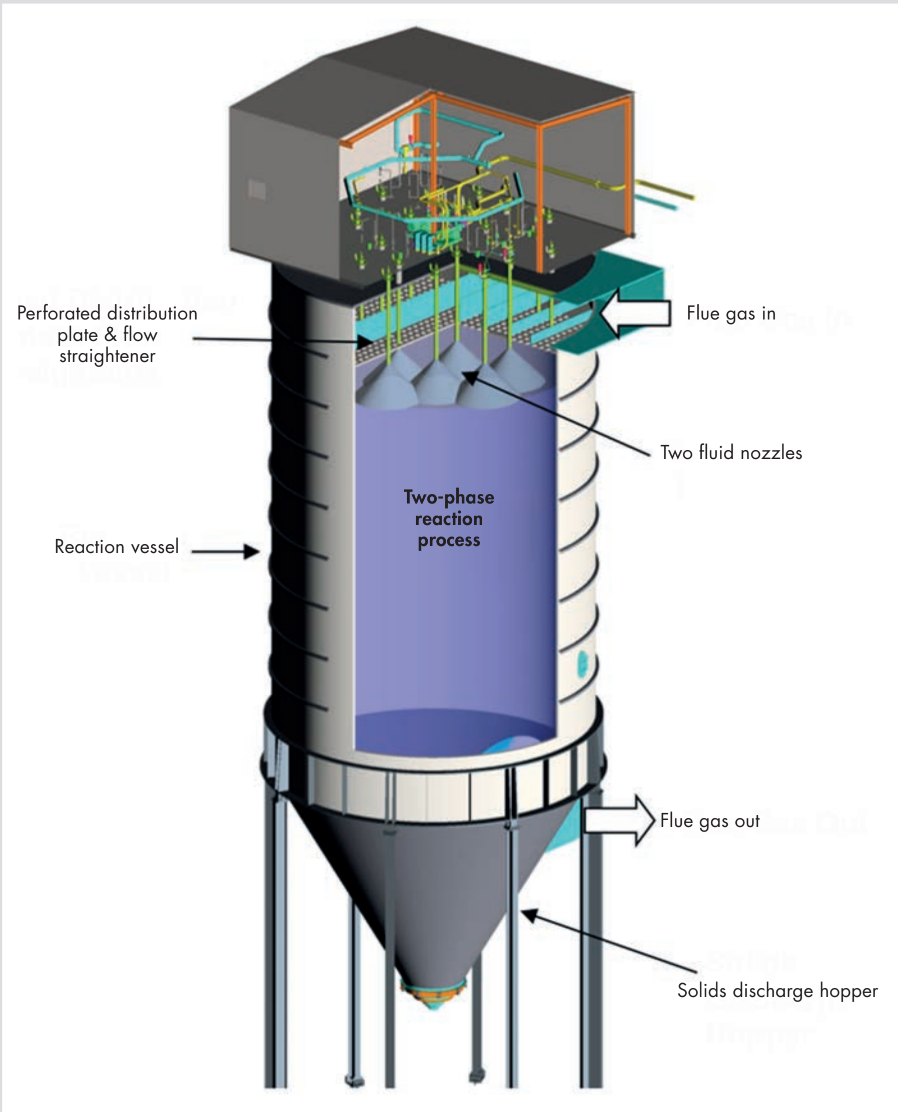

Fig. 1. SDA design details. The SDA uses hydrated lime to treat flue gas. The heat of the flue gas evaporates the droplets which cools the flue gas. Cooled flue gas containing the dried products is directed to a fabric filter. Source: Amec Foster Wheeler.

The key to efficient performance is the means used to atomise the lime slurry into droplets within the gas stream. The SDA offered by Amec Foster Wheeler utilises a two-fluid nozzle to atomise the lime slurry. The fine spray provides increased contact area in order for gas absorption to occur compared to the CFBS (it is easier to mix a gas with a liquid than with a solid). Acid gases are then absorbed onto the atomised droplets. Evaporation of the slurry water in the droplets occurs simultaneously with acid gas absorption. The cooled flue gas carries the dried reaction product downstream to the fabric filter. This dried reaction product can be recycled to optimise lime use (Figure 1).

At the beginning of SDA application, industry experienced that they were expensive to operate and maintain regardless of the atomisation mechanism used. Amec Foster Wheeler has redesigned its two-fluid nozzle to improve the distribution and mixing of atomising air with lime slurry, which improves mixing efficiency and decreases operating and maintenance costs (Figure 2). The optimised nozzle design delivers even atomising air distribution to produce a consistent droplet size while providing longer nozzle life. In 14 field applications, the optimised nozzle has demonstrated low cleaning frequency (1 to 3 weeks continuous operation), reduced cost of operation (20 to 25 % less compressed air consumption) and longer life with its new tungsten carbide inserts. In addition no special tools are required for routine maintenance.

The SDA design also provides additional operating flexibility for the entire plant. For example, any two-fluid nozzle can be removed for maintenance without decreasing boiler load. Emission control performance is maintained even when multiple two-fluid nozzles are taken out of service. The SDA is also capable of high unit turndown, down to 25 % of rated flue gas flow without recirculation of the flue gases while maintaining emission requirements. The design of the unit also provides for fast load response enabling unit cycling or load following. An added advantage is low absorber pressure drop that keeps the parasitic fan power loss to a minimum.

Circulating fluidised bed scrubber

Boiler flue gas enters the CFBS (with or without ash) at the bottom of the up-flow vessel, flowing upward through a venturi section that accelerates the gas flow rate, causing turbulent flow. The turbulator wall surface of the vessel causes highly turbulent mixing of the flue gas, solids, and water for 4 to 6 seconds to achieve a high capture efficiency of the vapour phase acid gases and metals contained within the flue gas. The gas and solids mixture then leaves the top of the scrubber and the fabric filter removes the solid material. (Figures 3 and 4).

Recycled solids/hydrated lime and water mix with the turbulent flowing gas moving vertically through the vessel, which provides gas cooling, reactivation of recycled

Tab. 1. Key technical characteristics of SDA and CFBS (Source: Amec Foster Wheeler).

Performance characteristic	SDA	CFBS
Fuel sulphur content	<2.5 %	<3.5 %
SO_2 removal %	95 to 97 %	95 to 98+ %
Capacity per vessel	40,000 to 1,000,000 acfm	75,000 to 1,800,000 acfm
Turndown capability, % of MCR flue gas flow	25 % without FGR	50 % without FGR 25 % with FGR
Sorbent	Calcium hydroxide slurry	Dry calcium hydroxide
Sorbent treatment	Slaker	Dry hydrator
Sorbent utilisation (molar Ca/S ratio)	1.4 to 1.5 (without recycle) 1.15 to 1.25 (with recycle)	1.3 to 1.4
Control flexibility	Temperature limited	Temperature independent
Water quality	Medium	Low
Capital cost	Slightly lower	Slightly higher
Footprint, includes fabric filter	Larger diameter vessel, smaller fabric filter, equal overall footprint	Smaller diameter vessel, larger fabric filter (lower A/C ratio), equal overall footprint

Notes: MCR = maximum continuous rating; FGR = flue gas recirculation; acfm = actual cubic feet per minute

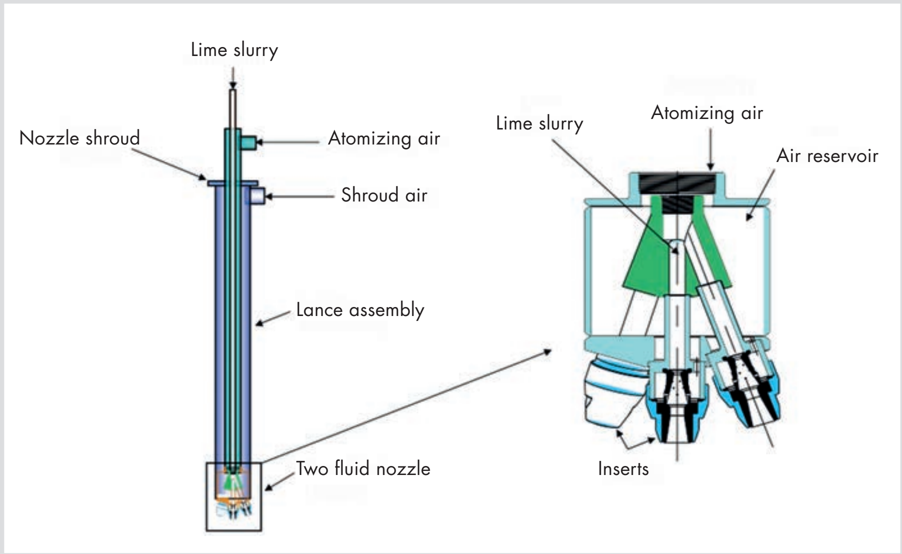

Fig. 2. Two-Fluid nozzles released. The optimised two-fluid nozzle design ensures balanced atomising air distribution in order to produce a consistent droplet size and reduced compressed air consumption by a quarter. Also, tungsten carbide inserts have significantly reduced nozzle wear. Source: Amec Foster Wheeler.

ash and capture of pollutants. The CFBS process achieves a very high solids-to-gas ratio, which dramatically improves the ability of vapour phase pollutants to find adsorption sites on the colliding solid particles. The water plays the important role of cooling the gas to enhance the adsorption of the vapour phase pollutants onto the solid particles.

The gas and solids mixture exit at the top of the scrubber and enter the fabric filter where solids entrained in the flue gas are captured and recycled back to the scrubber to capture additional pollutants. A portion of the recycled solids is removed from the fabric filter in order to maintain the right quantity of material in the circulating loop.

The effectiveness of the sorbent is largely a function of residence time. A CFBS can keep solids in the system from 20 to 30 minutes. This is a sufficient period of time for the sorbent to react with the acid gases. Two independent control systems maintain the dry flue gas at optimum temperature and at adequate removal efficiency by controlling the amount of water added and the amount of fresh sorbent added separately. As a result, unlike the SDA scrubber, pollutant capture is not limited by inlet flue gas temperature.

Circulating fluidised bed scrubber vs. spray dryer absorber

Table 1 summarises the important technical differences between the SDA and CFBS options. Table 2 shows the performance differences. In general, the CFBS is slightly better at SO_2 control, with up to 98+% capture with high amounts of sulphur in the fuel. Plant turndown capability is equivalent, when the CFBS is equipped with flue gas recirculation.

In general, the CFBS offers slightly greater SO_2 removal flexibility when compared to SDA. The amount of fresh lime injection is not limited by flue gas temperature thus allowing greater SO_2 scrubbing performance over a wider range of fuel sulphur content (Figure 5). SDA systems are temperature limited because fresh lime is introduced as slurry (lime and water). In addition, due to water being introduced independently and purely for temperature control, the CFBS can utilise lower quality water, as it is not used for pebble lime hydration.

The CFBS has the ability to effectively treat more flue gas volume than an SDA. The multiple venturis present allow a single CFBS vessel to be scaled up to almost twice that of the SDA vessel option.

Turndown capability is built into the SDA design, where a CFBS requires a flue gas recirculation system in order to achieve equivalent turndown. An SDA utilising the two-fluid nozzle design can maintain

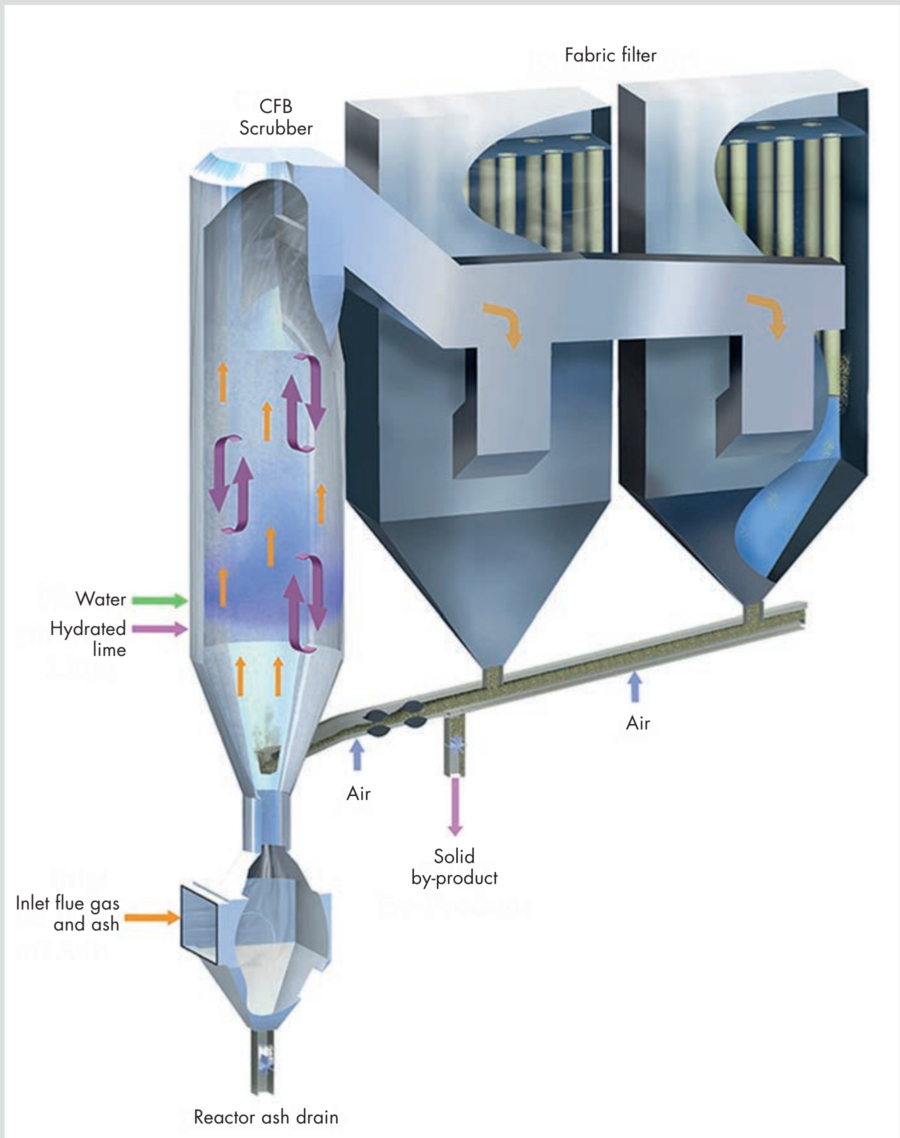

Fig. 3. CFBS design details. The principal operating steps is recycling a solids/hydrated lime and water mixture in the flue gas flow to capture pollutants, cool the gas and then capture solids in a fabric filter. Other reactive absorbents like activated carbon can be added to target specific pollutants. Source: FWEC.

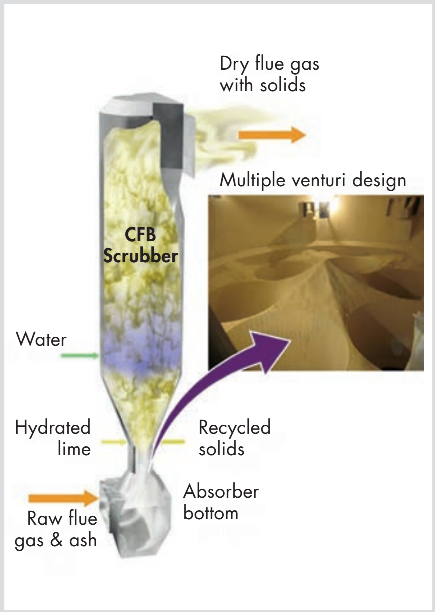

Fig. 4. Turbulent mixing. Flue gas enters vertically upward into the scrubber and through a set of venturis that accelerate the gas flow. Wall turbulators increase flue gas and reagent mixing efficiency. Multiple venturis allow a single scrubber to be scaled up to 600 MW in unit capacity. Source: FWEC.

Fig. 5. World's largest CFB scrubber. The 420 MW-rated (500 MW equivalent gas flow at its 4,430 ft. site elevation) coal-fired unit at Basin Electric's Dry Fork Station has operated the world's largest CFBS since it entered service in June 2011. Since it went into operation, the CFBS has exceeded its design performance reducing SO_2 by 95. to 98 % to levels below 0.06 lb/MMBtu (50 to 60 mg/m³). It also passed a 30-day mercury removal compliance test by meeting the permitted emission limit of 20 lb/TWh (2.35 µg/m³) while demonstrating an Hg removal rate in excess of 95 %. Courtesy: Basin Electric Co-Op and Wyoming Municipal Power Agency.

required emission levels down to approximately 25 % of MCR. In a CFBS at lower loads additional recirculated flue gas is required to maintain bed velocities in order to maintain required emission levels. If turndown during non-peak power demands is a consideration the additional parasitic load is an operating cost consideration for the CFBS.

The CFBS provides greater sorbent utilisation compared to a once-through SDA system as reagent recycle is incorporated into the design (Figure 6). However, due to the difference in hydration efficiency, an SDA equipped with recycle offers greater overall sorbent utilisation compared to CFBS. In an SDA, the recycled solids are slurried within a tank providing essentially 100 % hydration. In a CFBS water spray nozzles wet the dry recirculated solids as it passes through the vessel. This hydration process is less efficient due to the quantity of recycled solids and the lack of sufficient wetting time.

All the other performance characteristics are relatively equivalent including net auxiliary power. The pressure drop in the SDA (10 inches H_2O) is much less than the equivalent sized CFBS (16 inches H_2O), which is proportional to ID fan power consumed. However, the auxiliary power used by the SDA, principally for compressed (atomising) air, exceeds that required by the CFBS. The net result is that the total auxiliary power used by the either option is approximately equivalent. However, depending on the unit capacity, pressure drop may have a greater operating cost impact compared to the additional auxiliary power of an SDA.

Both technologies are simple, reliable, and robust. When maintenance of the CFBS is required, the accumulated solids can easily be removed through the bottom of the scrubber. Also, the water nozzles are low maintenance and can be replaced with the unit in operation. SDA two-fluid nozzles may also be removed and maintained during plant operation without loss of unit capacity. No special tools are required for two fluid nozzle maintenance.

Fig. 6. World-class SDA. JEA's Northside Generating Station includes two Amec Foster Wheeler CFB boilers (2 x 300 MW units), each producing 831,000 ACFM of flue gas. Each boiler uses a single SDA followed by a pulse jet fabric filter to treat the flue gas produced by the pet coke- and coal-fired unit. SO_2 emissions are reduced up to 90 % and SO_3, HCl, and HF emissions are reduced up to 99 %. Particulate emissions are 0.011 lb/MMBtu of fuel consumed. The SDA uses CFB fly ash only; no fresh lime addition is required. The plant has been in operation since 2002. Courtesy: Amec Foster Wheeler.

No one size fits all technology

In the past, dry scrubbing technology was typically chosen over WFGD technology for its much lower capital cost and water usage, provided that the boiler size was not too large and the fuel sulphur content was not too high. Today, CFBS technology has broken through these limitations with single unit designs up to 600 MW backed by operating experience on coal-fired units of over 500 MW and on fuels with sulphur levels above 4 % by weight. SDA have also been deployed on equal-sized units but with 2 absorbers and more limited fuel sulphur ranges.

The utility retrofit market has leaned more toward the CFBS technology of late due to the higher SO_2 removal performance.

However, SDA are gaining popularity due to a new generation of SDA nozzles which has significantly reduced cleaning frequency, which was a major criticism by early adopters. In addition the SDA offers greater turndown capability without flue gas recirculation equipment. With extended nozzle life and reduced compressed air consumption, the performance gap between the SDA and CFBS has narrowed. Specific site and environmental permit requirements will be the determining factor.

Tab. 2. Key performance characteristics of SDA and CFBS (Source: Amec Foster Wheeler).

Parameter	SDA	CFBS
SO_2 removal, %	95 to 97 %	95 to 98+ %
SO_3 removal, %	95+	95+
HCl/HF removal, %	99	99
Total PM Removal efficiency, %	99+	99+
Mercury removal efficiency, % (with or without PAC)	Equal	Equal
Pressure drop, inches H_2O	10	16
Auxiliary power consumption	Higher	Lower
Total power consumption (including ID fan)	Equal	Equal
Availability, %	99	99
Water consumption	Equal	Equal
Noise	Equal	Equal

Notes: ID = induced draft; PAC = powdered activated carbon; PM = particulate matter

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