

In-Duct Scrubber (IDS) – A Commercially Available Technology for Removal of Gaseous Pollutants from an Industrial Facility

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Abstract

Alcoa has conducted multi-year concept validation, pilot and full-scale demonstration studies to assess the technical feasibility of an energy efficient, horizontal gas-flow, co-current in-duct scrubber (IDS). More recently, Alcoa has completed a two year testing of the scrubber at its Lake Charles Carbon facility demonstrating an average SO₂ removal efficiency of 93 %, an average fluoride removal efficiency of 85 % and a total particulate removal efficiency > 55 %. Based on Lake Charles performance, IDS technology has been submitted for State MACT (Maximum Achievable Control Technology) permit replacing the age old electro-static precipitator at the facility. State MACT designation is expected during 4Q 2016. This paper will provide detail operational data from the performance validation testing at Lake Charles facility and will also touch upon the various scrubber blowdown management options that can be designed and commercially implemented at industrial facilities. IDS is targeted for worldwide commercialization in the area of small to medium size coal fired boilers, smelters, calciners and bake furnaces.

1. Introduction

Alcoa developed and patented an in-duct scrubber (IDS) technology that removes acid gases such as sulfur dioxide (SO₂) and particulate matter from flue gas, and is now installed for commercial operation at Alcoa's Lake Charles Carbon Plant in Louisiana. The technology, developed by the Alcoa Technical Center (ATC) is designed to remove greater than 90 % of the sulfur dioxide, over 80 % hydrogen fluoride and over 60 % fine particulates contained in the flue gas of smelters, anode baking furnaces, petroleum coke calciners and industrial boilers in the 50 - 120 MW/unit range.

Most smelters worldwide have been able to meet current SO₂ emission regulations without having a scrubber system in place. During the last ten years, SO₂ standards are becoming increasingly stringent in many parts of the world. In addition, the aluminum smelting industry is moving toward using petroleum coke with higher sulfur contents due to the reduced supply and higher cost of low-sulfur anode-grade petroleum coke. This results in increased SO₂ emissions from potrooms and anode bake plants at a time when emission limits are decreasing. To address these growing challenges, Alcoa's researchers developed this innovative horizontal co-current sodium based wet scrubbing technology, which has a smaller physical footprint, lower capital costs, and 30 – 40 % lower energy consumption. This is achieved by increased process and energy efficiencies for equal removal rates compared to conventional sodium or calcium based wet flue gas desulfurization (FGD) technologies. The system schematic is shown in Figure 1, which relates the simplicity of the system, e.g., no contactors or other mass transfer devices that consumes energy or contributes to scaling and increased maintenance.

2. Process Description

In the basic application a single bank of spray headers is installed in a horizontal duct after an optional pre-cooling spray (Figure 1). A clear alkaline sodium based scrubbing solution is

introduced into the flue gas through the spray headers, further cooling the gas stream and neutralizing/removing the SO₂ from the flue gas stream. A large part of the reaction products, unused sorbent, and excess water fall to the bottom of the duct and drain into the recycle tank. Droplets remaining in the gas stream are removed by a mist eliminator in the duct from which the collected liquid also drains into the recycle tank. Additionally, the IDS can be operated in multiple regeneration modes. In one mode, caustic make-up is added to the recycle solution based on the pH in the Recycle Tank, which will ultimately render a sodium-sulfate laden waste stream. In another mode, blowdown from the recycle tank can be regenerated with lime using a dual alkali chemistry process, thereby producing a gypsum byproduct (Figure 1). In the dual alkali mode the blowdown from the recycle tank is sent to a regeneration tank and mixed with fresh lime. The lime reacts with the sodium salts, regenerates sodium hydroxide (which is pumped back to the Recycle Tank) and produces calcium sulfate/sulfite. The addition of forced oxidation can convert the sulfite salts to sulfate and produce high quality gypsum that can be filtered and washed and potentially used as raw material for the cement or wallboard industry.

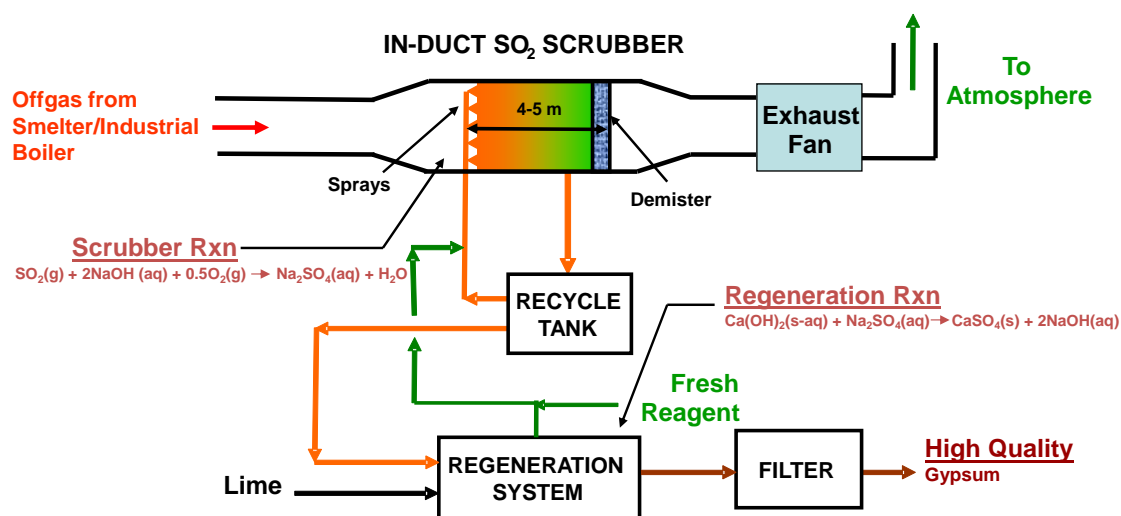


Figure 1. In-Duct Scrubber process diagram.

A 1/15th scale pilot IDS system is housed in the campus of the Alcoa Technical Center, the largest light metals research facility in the world. Another 1/15th scale unit was used for demonstration purposes at the Alcoa Massena smelter treating a slip stream of exhaust gases from the dry HF scrubber. Also, a 1/5th scale system is operated at test location in Canada. More recently, a full scale IDS system has been installed in Alcoa's Lake Charles Carbon plant and has been put to operation since April of 2014. This facility calcines green petroleum coke and then bakes carbon anodes that are sent to smelters. Figure 2 shows the IDS unit that has been installed in Lake Charles, LA. Demonstration testing over an 18 month period has shown superior performance of the scrubber unit in treating acid gases, including SO₂ and HF, as well as organics and particulates.

3. Results

Figure 3 shows the test results from 2014 and demonstrates that the IDS system consistently performed with average SO₂ removal efficiencies in the 90 – 95 % range. Figure 4 shows the performance data from 2015. The scrubber continues to perform efficiently with SO₂ removal efficiencies between 92 – 98 %. In addition to the SO₂ removal, the scrubber has also been effective in removing HF as well as particulate matter 2.5 μm in size or less (PM 2.5) and particulate matter 10 μm in size or less (PM 10).



Figure 2. IDS system at Lake Charles.

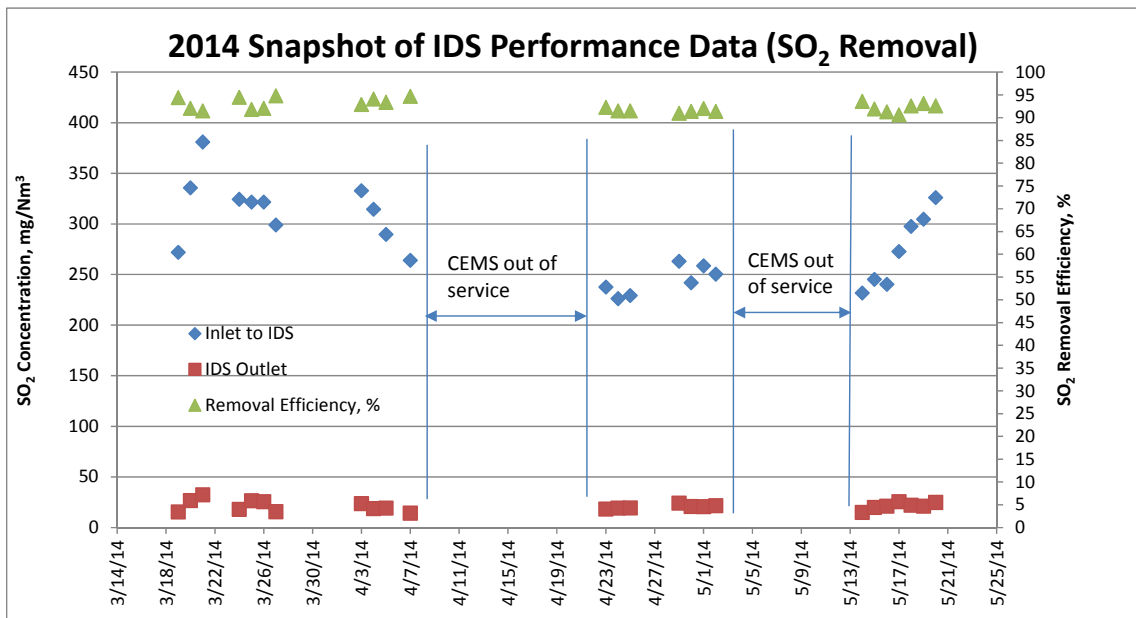


Figure 3. IDS test results from 2014 time period.

Table 1 provides a summary of inlet and outlet concentration ranges during the course of two years of testing for SO₂, fluoride and total particulates.

Table 1. Critical pollutant removal performance data

	Inlet Range, mg/Nm ³	Outlet Range, mg/Nm ³	% Average Reduction
SO ₂	25 - 320	6 - 15	96.5
Fluoride	10	0.33	96.7
Particulates	80 - 120	16 - 37	74

IDS is able to maintain > 90 % scrubbing efficiency over a wide range of inlet SO₂ concentrations (140 mg/Nm³ to 5500 mg/Nm³) with a high turn down ratio. This is illustrated in

Figure 4 which shows the SO₂ profile at the inlet and outlet of the Lake Charles unit as well as in Figure 5 which depicts the SO₂ removal from pilot testing at the test facility in Canada.

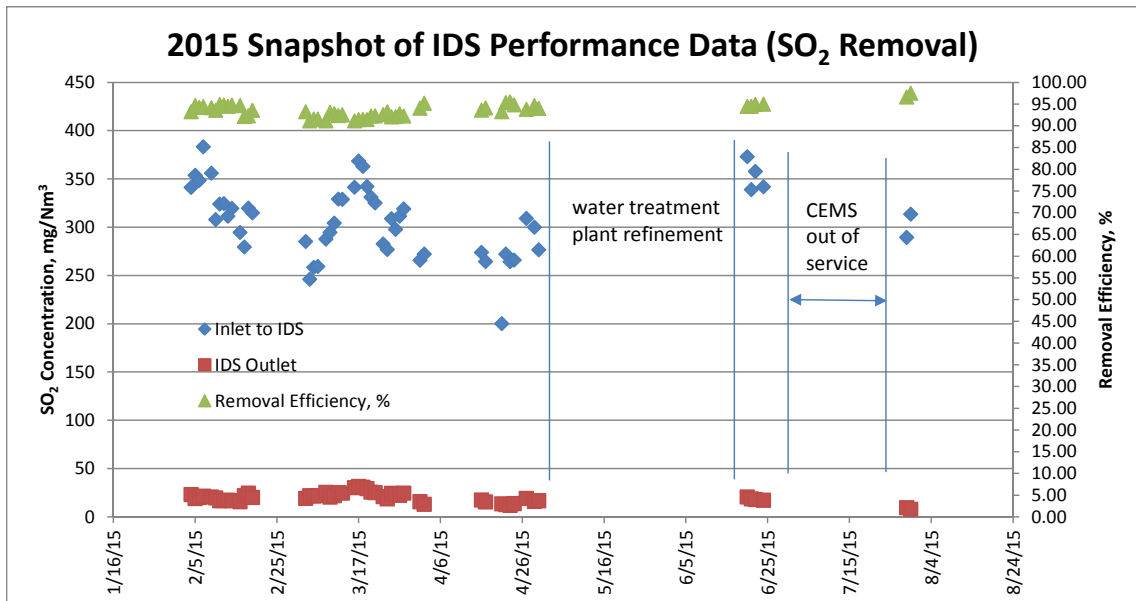


Figure 4. IDS test results from 2015 test period.

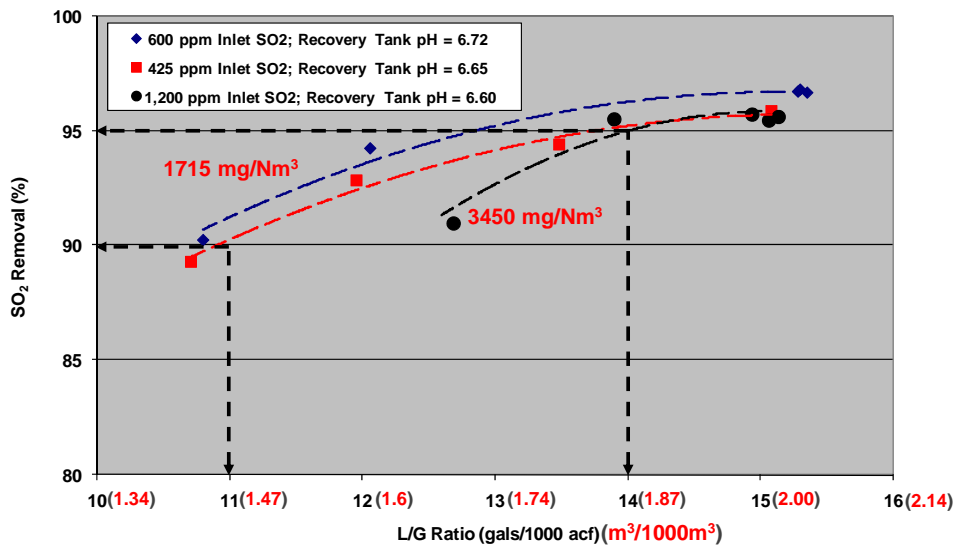


Figure 5. SO₂ removal plot as a function of liquid to gas (L/G) ratio under wide range of SO₂ inlet levels (data from pilot testing) (SI units are in red font).

The type and orientation of the spray nozzle arrays contributes to optimum gas-liquid contact in terms of mass transfer surface area and mixing as well as the co-current placement of the nozzles that contributes to the so called “aspiration effect”, whereby the gas is pulled into the liquid spray zone along with a pressure rise, thereby resulting in lowering the overall pressure drop across the scrubber system. This is an advantage of a horizontal co-current spray system over conventional vertical counter-current scrubbers leading to lower overall energy

consumption and smaller physical footprint. This may allow the use of existing Induced Draft fans when retrofitting this technology to existing installations.

Considerable testing has been conducted at the pilot test facility at Alcoa Technical Center, PA, where the dilute mode dual alkali process has been integrated with the in-duct scrubber. This process has the ability to further optimize the regeneration chemistry by adding lime to the scrubber blowdown to regenerate the caustic soda with minimum sodium losses while generating gypsum crystals with acceptable particle size and aspect ratio for easy dewatering. The key performance metrics that have been achieved in the course of this testing are as follows:

- no/low solids scale or buildup in the scrubber;
- efficient mist eliminator performance (expected droplet concentration after mist eliminator < 45 mg/Nm³ outlet droplet concentration);
- high level of oxidation CaSO₃/CaSO₄ < 2 %;
- absorber liquor pH – 12.2 – 12.5;
- maximum gypsum crystal – D₅₀ > 80 μm;
- maximum calcium de-supersaturation – calcium relative saturation of ~ 1.2;
- lime utilization > 98 %; and
- thickener underflow solids content of 40 – 50 % attainable.

4. Benefits

Table 2 provides a comparison between a conventional Limestone Forced Oxidation Technology and the Alcoa’s In-Duct Scrubber system. This example comparison tries to capture the key facets between the two technologies and how the In-Duct scrubber differentiates itself from conventional vertical wet scrubbers.

Table 2. Comparison of LSFO and In-Duct Scrubber.

	Limestone Forced Oxidation	In-Duct Scrubber
SO₂ Inlet Design	<ul style="list-style-type: none"> • Generally >2 800 mg/Nm³ 	<ul style="list-style-type: none"> • 140 – 5 500 mg/Nm³
Operation	<ul style="list-style-type: none"> • Counter-current limestone slurry spray • Gas side pressure drop of 12.7 – 25.4 cm water column 	<ul style="list-style-type: none"> • Co-current clear solution/slurry spray • Gas side pressure drop of 2.5 – 5.2 cm • Lower ID fan power • Reduced OPEX
Liquid to Gas Ratio (L/G)	<ul style="list-style-type: none"> • ~4 – 12 m³/1000 m³ • High pump HP due to flow & height of spray headers 	<ul style="list-style-type: none"> • ~1.6 m³/1000 m³ • Low pump HP due to lower flow and pump heads
Footprint	<ul style="list-style-type: none"> • Moderate to large footprint • Retrofit could be complicated due to space constraints • Gas velocity 4.0 – 4.6 m/s 	<ul style="list-style-type: none"> • Small footprint • Easier retrofit • High gas velocity (> 8.2 m/s) • Significant CAPEX reduction
Other Contaminant Removal	<ul style="list-style-type: none"> • Acid gases (HCl, HF) • PAH’s • Particulate matter 	<ul style="list-style-type: none"> • Acid gases (HCl, HF) • PAH’s • Particulate matter

The testing at the Alcoa Lake Charles, LA plant included measurement of the energy needed to operate the IDS system. The inlet gas flow rate of 70.8 actual m³/s is equivalent to the flue gas flow from a 60 MW Utility boiler. Consequently it is possible to express the power consumption as a percentage of the gross power production from such a boiler. Based on the power measurements during the 2014 - 2015 testing, the energy requirement by the IDS system is shown in Table 3.

Table 3. Energy consumption of IDS system at Lake Charles.

IDS	QTY	HP Rating	HP Usage	KW				
1 Compressor	1	200	5	3.7				
2 IDS Fan	1	500	135	100.7				
3 Main Recirc Pump	1	250	110	82.1				
4 Blowdown Pump	1	7	7	5.2				
5 Main Tank Agitators	2	10	10	7.5				
6 Make-Up Water Booster Pump	1	15	15	11.2				
7 Make-Up Air Damper	1	10	3	2.2				
8 Caustic Pump	1	0.5	0.5	0.4				
Water Treatment								
1 Polymer Pump	1	0.5	0.5	0.4				
2 Ferric Chloride	1	0.5	0.5	0.4				
3 Sulfuric Acid	1	0.5	0.5	0.4				
4 Clarifier Water Pump	1	5	5	3.7				
5 Filtrate Pump (Air)	1	0	0	0.0				
6 Sludge Transfer Pumps (Air)	1	0	0	0.0				
7 Filter Press Sludge Pump (Air)	1	0	0	0.0				
8 Compressor for Supplying Air to Pumps & Agitators	1	200	40	29.8	Same Compressor as Line 1 under IDS			
General								
Instrumentation	-	-	-	3.3	(1.5% of Total Power Usage)			
General Utilities (Lighting & SO ₂ Monitoring)	-	-	-	5.0	(2.0% of Total Power Usage)			
Estimated Power Usage (Assuming Usage - LC Test Data)				255.9	KW			

This estimated power requirement is calculated to be < 0.5 % of the gross power generation of a 60 MW boiler capable. This is indeed quite low, especially when compared to a conventional wet FGD system.

With regards to retrofitting, this technology is ideally suited for retrofitting to existing smelters. The major change is a new section of duct work with a larger cross sectional area so that the flue gas velocity can be reduced from 15.2 – 18.3 m/s down to the 7.6 – 9.1 m/s needed for IDS System operation. The new section of ductwork would contain the inlet and outlet duct sections, the spray system, demisters, and drain and its arrangement (wider/taller than the existing duct work) would depend upon space limitations. Also, due to low line pressure requirement, existing Induced Draft fans may be considered as part of the installation, thereby reducing both CAPEX as well as physical footprint.

Finally, the IDS system is compatible with multiple and proven regeneration options. Figure 6 shows the various regeneration options that can be coupled with an in-duct scrubber based on customer needs and economics.

Regeneration system options

Technology	By - Product	Applicability
iDDA (Improved Dilute Mode Dual Alkali)	Gypsum	<ul style="list-style-type: none"> • All SO₂ levels • To make solid waste OR <ul style="list-style-type: none"> • Commercial grade gypsum
CDA (Concentrated Mode Dual Alkali)	Solid waste	<ul style="list-style-type: none"> • Med to high SO₂ level • Makes waste product • Lower cost than iDDA
Na -Lime (Sodium-Lime)	Waste slurry	<ul style="list-style-type: none"> • All SO₂ levels • Low capital cost - eliminates regeneration system
SWS (Seawater)	Sea water with sulphates	<ul style="list-style-type: none"> • Low to med SO₂ levels • SWS is viable (coastal)
OTS (Once Through Sodium)	Treated waste water	<ul style="list-style-type: none"> • Low to med SO₂ • Lowest capital cost • Coastal other acceptable discharge point

Figure 6. Regeneration options compatible with IDS System.

5. Conclusions

The in-duct scrubber has been proven to be an energy efficient wet scrubbing system for acid gases and particulates for a variety of applications, including aluminum smelters, calciners, boilers and bake furnaces. The scrubber is modular in design, which makes it very suitable for retrofits applications. In addition, the scrubber can also be used in multiple scrubbing modes with different regeneration / treatment schemes.

The key points for the IDS System are as follows:

- small footprint, easy retrofit, less equipment, simple control,
- high SO₂ removal efficiency > 96 %,
- low energy footprint for pumps (low-rise, less head) & blowers etc.,
- scale free operation designed-in (scrubbing zone devoid of internal elements),
- on-the Fly maintenance & replacement of key components (less downtime),
- not tall vertical structures, reduces foundations and construction costs,
- efficient Mist Eliminator performance (< 45 mg/m³ outlet droplet),
- turndown as low as 50 %.

The key points for the addition of a Dual Alkali regeneration option are as follows:

- no/low solids scale or buildup,
- reliable control of absorbent liquor pH – 12.2 – 12.5,
- good de-watering characteristics: Maximum gypsum crystal – D50 > 80 μm,
- low scale/solids buildup potential – Projected 12-year cleanout cycle,
- maximum calcium de-supersaturation – Calcium relative saturation of ~ 1.2,
- lime utilization > 98 %,
- thickener underflow solids content of 40 – 50 % attainable,
- gypsum moisture content ≤ 12 % (beneficial by-product),
- minimize sodium losses (50 % cake wash ~ 2 % loss).

6. References

1. Ghosh, R. S., Bowen, P., Dobbs, C., Nichols, R., Dando, N., Smith, J. R., Lunt, R. R., and Kraft, G. C. Systems and Methods for Removing Gaseous Pollutants from a Gas Stream, *U.S. Patents* 7645430, 7906089, and 8137649.
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