

# **POWER BOILER AIR EMISSION COMPLIANCE WITH NEW SCRUBBER TECHNOLOGY**

## **A CASE STUDY**

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### **ABSTRACT**

Emission standards for power boilers are becoming difficult to meet without the most up to date environmental controls. Therefore, investing in the optimum air pollution technology is crucial. Flexibility in fuels being fired in the boiler with minimum impact to the environmental emissions increases the mill's ability to adjust fuel mix and stay competitive in a changing economical climate. In the past, the standard solution has been assumed to consist of a combination of particulate removal using a dry ESP followed by SO<sub>2</sub> removal using a wet scrubber. This is not necessarily the best option, however .

This paper describes a unique multi-stage wet scrubber installed on a 420,000 lb/hr (MCR) coal/oil swing boiler burning high sulfur coal (as well as collected Non-Condensable Gases from the Pulp Mill). This system accomplishes the goals of very high removal efficiencies (equaling that of a traditional Wet ESP) for both PM and SAM plus SO<sub>2</sub>/HCl removal - all in one wet scrubber. This new scrubber operates at low pressure drop as well as minimizes the typical hazards associated with high voltage or the handling of dry ash seen in an ESP. Corrosion problems are minimized through the application of conservative metallurgy in the wet-dry interface and control of pH in the scrubber stages.

This paper will share the results and provide qualitative insights in regards to this unique wet scrubber technology as a feasible alternative to meet the most stringent air pollution control requirements regardless of the fuels used.

### **INTRODUCTION**

Traditionally low particulate emissions have been associated with using an ESP, Wet ESP, or baghouse technologies. At the same time high efficiency acid control technologies has been limited to wet scrubbers.

For more complicated emission requirements, the standard alternative of installing various air pollution control equipment in series is costly and results in a complex system in terms of operation and maintenance.

Moreover, in certain processes, particulate can be formed by condensation downstream of the ESP or baghouse. Examples of such emissions are sulfuric acid mist (SAM), ammonium chloride and potassium sulfate. In many cases these reactions require that a 3<sup>rd</sup> emission control stage be added to ensure compliance.

This paper describes an "all-in-one" newly installed scrubber on a large coal and oil fired swing boiler where flexibility and low emission requirements were required. The paper will also discuss the operating results of the system as well as control of pH and chemical addition to minimize operating cost and potential corrosion issues.

## ABOUT THE PLANT

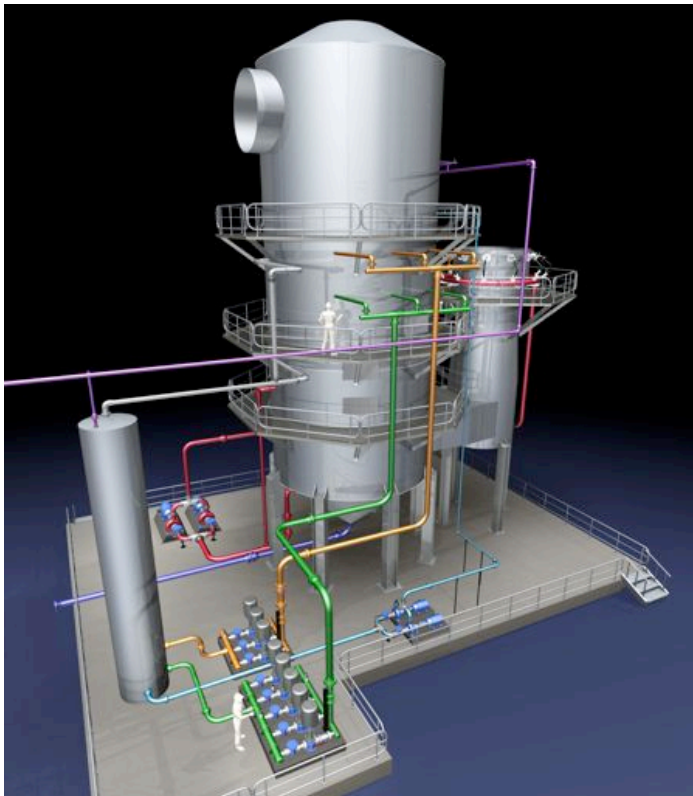
This boiler is primarily coal and oil fired with an MCR of 420,000 lb/hr steam and provides steam and power for a 1900 ton/day white-top linerboard mill. The coal is sourced from numerous suppliers in the eastern US and the coal quality (sulfur, ash, etc) can vary significantly so great operating flexibility is required. The mill has operated this boiler with only a multi-clone dust collector followed by an ESP but due to tightening SO<sub>2</sub>, H<sub>2</sub>SO<sub>4</sub> and PM requirements, instead of adding an SO<sub>2</sub> scrubber downstream of the ESP, the mill decided to install a multi stage wet scrubber to entirely replace the ESP then in use.

## PROJECT SCOPE

The project was awarded as “turnkey” and consisted of supply of all required equipment, piping, E&I and erection for a scrubber system to replace the existing ESP. The scope of supply consisted of the following major equipment:

- New ductwork
- Quench
- Multiple venturi scrubber system
- ID Fan
- Stack
- Acid neutralization system
- Scrubber blowdown dewatering system (belt filter presses)
- MCC

Figure 1. Scrubber System



## PROCESS SPECIFICATIONS

The minimum mill requirement was that the scrubber would remove at least 93% of the SO<sub>2</sub> emissions generated by the Boiler and that emissions of Particulate matter (PM) from the scrubber would comply with the Industrial Boiler MACT limit of 0.07 lbs./MMBTU of heat input with the boiler operating within the MCR limits. The Process Specification is summarized in Table 1 below.

Table 1. Project Specification

		Maximum	Minimum
MCR Steam(Coal),	lbs. Steam /hr	420,000	
MCR Steam(Oil),	lbs. Steam/hr	350,000	
Inlet SO <sub>2</sub> rate	lb per million Btu Heat Input	3.42	0.86
	lb/hr	1891	478
Inlet H <sub>2</sub> SO <sub>4</sub> rate (@5% SO <sub>2</sub> )	lb /hr	30	
Inlet Flue Gas Volumetric Flow Rate	DSCFM	160,000	80,000
	ACFM	295,000	93,000
Inlet Flue Gas Temperature	deg F	500	275
Inlet Flue Gas Moisture	% by volume	8.8	5.9
Inlet HCl	Lb/hr	12.6	2.1
Inlet NOx	lbs NOx per million Btu	0.43	
Inlet Particulate (fly ash loading) From Multiclone Dust Collector	grains per dscf	5.0	
Scrubber Performance requirements			
Outlet SO <sub>2</sub> rate	lb per million Btu Heat Input	0.24	
	Lb/hr	132.7	
SO <sub>2</sub> removal Efficiency	(%)		93
Outlet Particulate	Lb/hr	27.65	
Outlet H <sub>2</sub> SO <sub>4</sub>	Lb/hr	8.0	

# THE MICROMIST™ SCRUBBER

The scrubber consists of the following major stages:

## Quench System

Removal of coarse PM (particulate matter) and some SO<sub>2</sub> and HCl (see Fig.2).

Hot flue gas from the multi-clones are ducted to a high efficiency atomized spray quench. In the quench, fine droplets are generated creating a relative droplet-particle motion resulting in saturation of the gas and removal of the vast majority of coarse particles from the flue gas stream. The dirty quench water is collected in the sump of the scrubber and recycled through the quench pump set with addition of water draining from later stages (countercurrent washing). The amount of water used for the quench is approximately 5-7 times the theoretical amount for cooling (a 5-7 to 1 L/G ratio).

Approximately 100 GPM is lost through evaporation in this stage.

## Scrubber Section

The quench section transitions into the scrubber separator vessel. The vessel is 21' dia. x 60' tall and contains the remaining stages of the scrubber system. The stages are shown in the diagram below;

Figure 2. Process Flow Sheet.

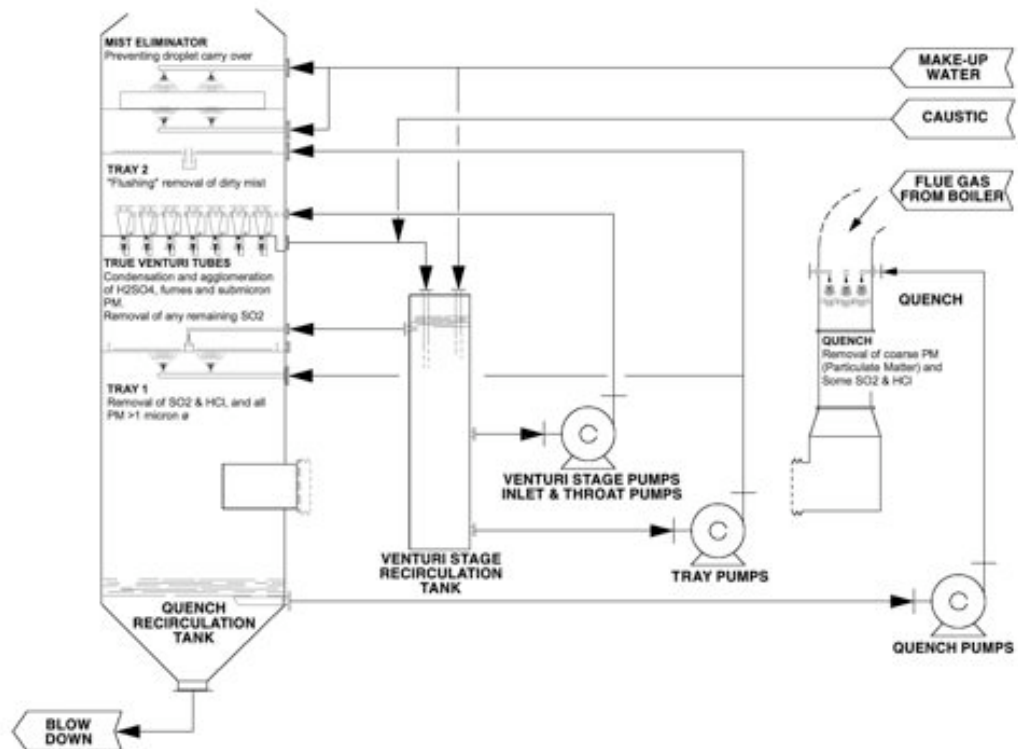
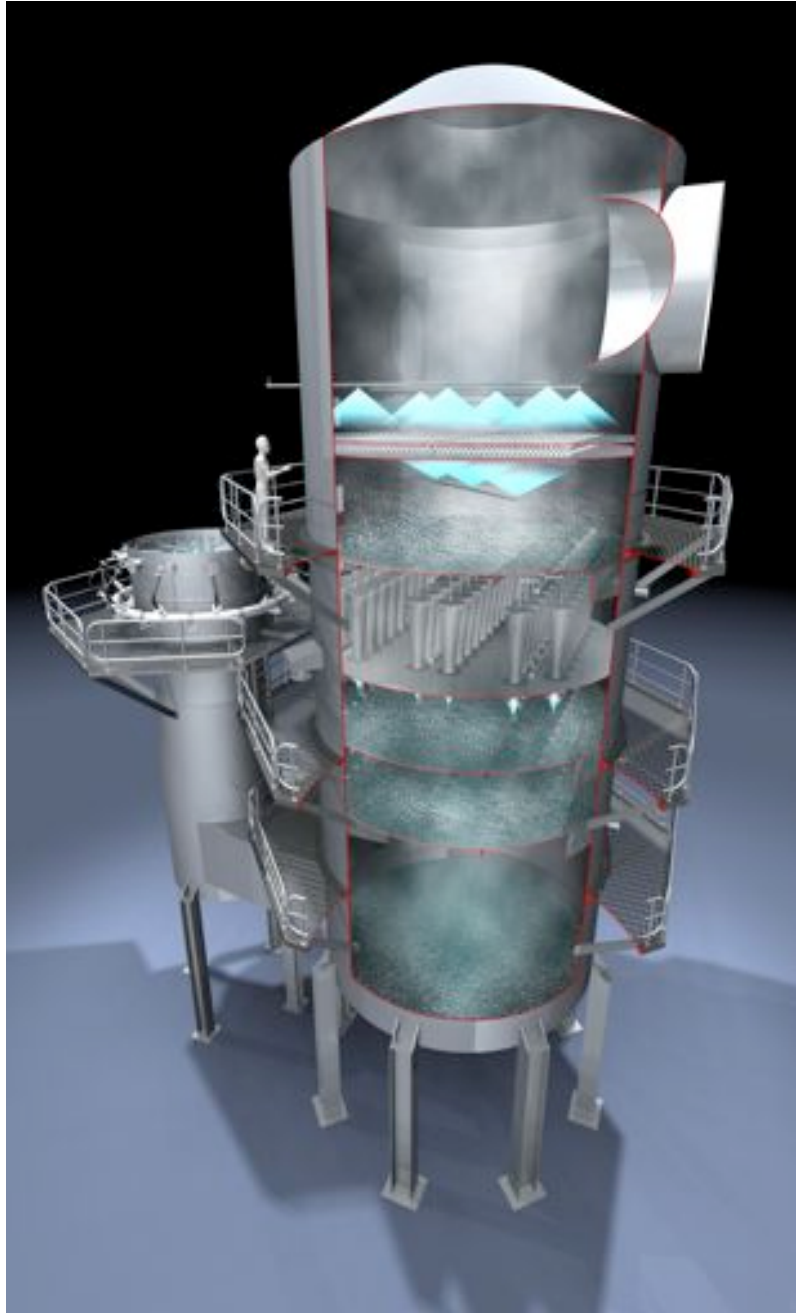


Figure 3. Scrubber Cut-Away



## Dual Orifice impingement tray stage –Flue Gas Conditioning

Removal of SO<sub>2</sub> and HCl and all Particulate larger than 1 (one) micron (see Fig.2).

A Dual-Orifice Impingement tray is located below the venturi tubes and acts as the first conditioning stage in the scrubber. The dual orifice tray is flooded with gravity fed overflow water from the external venturi recirculation tank, this conditions the flue gas and reduces the particulate/dirty droplet loading in the gas stream. To ensure the tray stays clean, it is also irrigated with under-sprays with recirculated water from the tray pumps.

## Multiple Venturi stage

Condensation and agglomeration of H<sub>2</sub>SO<sub>4</sub>, fumes and submicron particulate matter. Removal of any remaining SO<sub>2</sub> (see Fig.2).

This stage consists of two integral elements, about 40 parallel true venturi tubes each preceded by a high-pressure liquid atomizer. Gas flow and injected droplets are in an up-flow mode. The two components, in tandem, affect a high relative motion between the micro-fine injected scrubbing droplets and the fine sub micron particulate that has escaped the quench and tray section. It should be noted that in many cases, the pre-quenching section effects growth of otherwise smaller particulate, resulting in more efficient capture of the sub micron particulate. It also condenses numerous gaseous species whose dew points are in the range where condensation can occur.

To control and to modulate a constant pressure drop across the scrubber, the venturis are equipped with throat atomizers that provides flexibility under different operating conditions.

About a two thirds of the water used here is recirculated water, the other third is make-up water.

Figure 4: Venturi Tubes shown inside vessel



Figure 5: Circulation Pumps installed in one location for maintenance access



## Dual orifice impingement tray stage

“Flushing” removal of dirty mist (see Fig.2).

A second level of dual orifice impingement trays are located just downstream of the venturi array. The impingement trays are flooded with water “falling” back from the mist eliminator under wash sprays. The recirculated make-up water is used to further reduce the particulate loading in the gas stream. The impingement trays are, in turn, followed by a high efficiency mist eliminator pack designed to collect all droplet carryover from the scrubber.

## **Mist eliminator stage**

Preventing droplet carry over (see Fig.2)..

The mist eliminator is located above the dual orifice and is designed to capture any residual droplets that may 'spit' off the upper tray prior to the gases exiting the scrubber. The mist eliminator is washed continuously from below and intermittently back washed from above with clean makeup water. This wash water will drain onto the tray stage which is directly below supplementing the liquid that is flooding the upper tray.

## **Neutralization Stage**

The venturi stage captures any residual SO<sub>2</sub> and most of the H<sub>2</sub>SO<sub>4</sub> (as sub-micron aerosol and as what has condensed onto sub-micron particulate). Therefore the drain of the venturi stage will be very acidic unless caustic is added to keep the pH near neutral. The venturi drain liquid pH is measured to immediately measure and predict the caustic requirement and to keep the pH probe in the 'cleanest' near acidic/non-scaling environment.

The caustic is added after measurement of the pH but before the recycle tank. This prevents scale deposits by preventing the high concentration caustic from contacting sensitive surfaces like pump impellers or pH probes before it is thoroughly mixed and diluted. The drain pH set point is usually 6.5 to 7.5 for control of the caustic injection to maximize SO<sub>2</sub> scrubbing.

The overflow solution from the venturi recycle tank is directed to the lower tray. It mixes with recycled liquid from the lower recycle tank/loop and is injected into the hot inlet gases through the quench nozzles. The residual caustic present in the venturi drain is consumed in the neutralization of absorbed SO<sub>2</sub> gas and some condensed H<sub>2</sub>SO<sub>4</sub> present on the larger flyash particles captured by the quencher stage. Any alkalinity in the captured flyash particles also neutralizes the captured SO<sub>2</sub> and H<sub>2</sub>SO<sub>4</sub> in the recycled scrubbing liquids. The drain pH of the lower/primary recycle tank BD from the quencher recycle loop is dependent on the equilibrium of inlet SO<sub>2</sub>/SO<sub>3</sub> and the alkalinity in coal flyash but it is usually near neutral or slightly acidic.

This strategy uses the lowest possible pH for the two recirculation loops to achieve the required outlet SO<sub>2</sub> emissions. Therefore the use of caustic is minimized by maximizing the effectiveness of the flyash alkalinity to neutralize the captured SO<sub>2</sub>/SO<sub>3</sub> at low pH. In this two loop recirculation system, any alkaline cations in the captured flyash (Ca, Mg, Na, K) are used first to neutralize and 'fix' the captured SO<sub>2</sub>/SO<sub>3</sub> as a salt in the lower/inlet stages *before* supplementing with caustic in the upper/outlet stages of the scrubber.

## **ID Fan**

The new ID Fan is a radial tip fan rated for 230,000 acfm at 145 deg F at 27 inches SP.. The design operating HP is 1,495 BHP and is controlled by a variable frequency drive. The fan actually runs with much lower dP and BHP due to the scrubber system not requiring the maximum dP to maintain emission levels significantly below target.

## **Stack and Duct:**

A new 181' single wall stack was installed. The stack was constructed of 316LSS. New carbon steel duct was installed from the boiler multi-clone dust collectors to the scrubber quench. The remaining duct between the scrubber, IF fan and stack was 316L stainless steel.

## **Belt Press System**

Two belt filter presses 2 meters in width were supplied for dewatering the scrubber blowdown. Each filter press was rated for a hydraulic capacity 200gpm and a solids capacity of 8000lb/hr. The cake dryness was guaranteed at 50% TS using polymer. Each filter was designed to handle the required capacity alone.

## START UP, OPERATION & INITIAL TESTING

Equipment checkout presented a few minor challenges. Initial operation began when the boiler was brought on line firing oil. While on oil the boiler was held at steady state operation and all process controls could be tuned and process parameters could be monitored and adjusted as needed. After establishing steady state operation the venturi countercurrent throat sprays were started in manual to set the initial operating scrubber differential pressure.

The boiler fuel was switched from oil to coal after having established fully automatic control of the scrubber system. No significant operational differences were noted in scrubber operation after the switch was made. The process variable set points were optimized and tuned during this process.

Initial operating data:

Boiler production rate	220-430,000 lbs/hr steam
Scrubber inlet temp.	450-600°F
Pressure	-0.4 W.C. inlet ~19" W.C. total $\Delta$ P across the scrubber (controlled)
Quench flow	1200 gpm
Tray flow	900 gpm
Venturi flow	1100 gpm @260 psig
Venturi throat flow	425-900 gpm modulating to control scrubber differential pressure
Make-up flow	330 gpm (added mostly to the venturi circulation tank)
Caustic flow	0.8 gpm
Blow down pH	4.2

### Initial operation—Lessons Learned

#### Water Balance and pH:

Several control adjustments had to be done to optimize water levels and flows in the scrubber. It was found that the majority of the acid in the flue gas was absorbed in the first tray resulting in potentially very low pH swings if tight controls were not used for pH neutralization. Even though SO<sub>2</sub> absorption was nearly 100%, operating at these very low pH levels (<4.0pH) was considered risky in terms of long term life of the equipment.

To prevent possible long term corrosion issues, the pH setpoint in the venturi circulation tank was increased to “cascade” additional caustic to the quench loop. To ensure sufficient pH in the blowdown, a separate caustic supply line was added bleeding a constant 0.5 gpm of caustic to the lowest tray loop ensuring a constant level of neutralization for potential pH upsets in the lower scrubber loops due to changing HCl levels.

#### Belt Presses:

The mill opted to burn a coal that contains very little ash. The low ash content of the coal has resulted in a very low suspended solids level in the scrubber blow-down (<0.5%). This low solids level makes it impractical to operate the belt presses. In addition, the scrubber has been optimized to run lower pH levels than originally designed. This pH level will keep a majority of the sodium and calcium salts as dissolved solids further reducing the suspended solids in the blow-down. The belt presses are kept on standby in case the coal source changes.

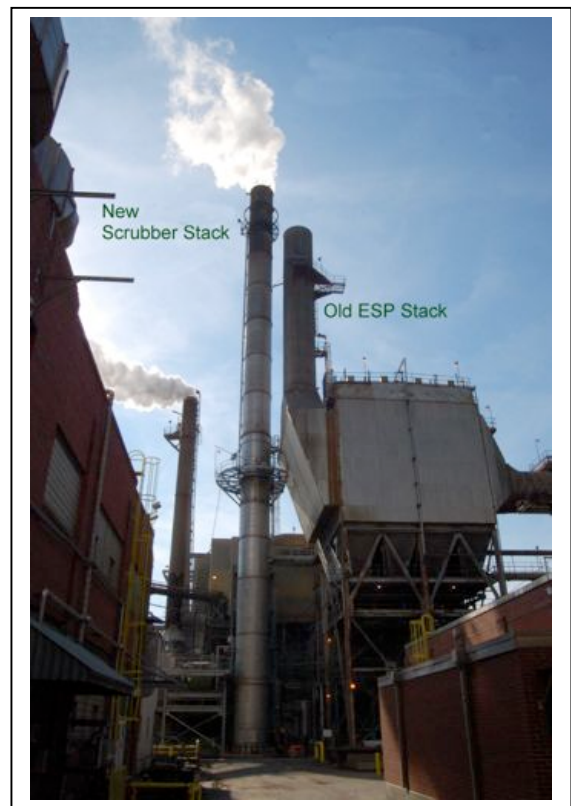
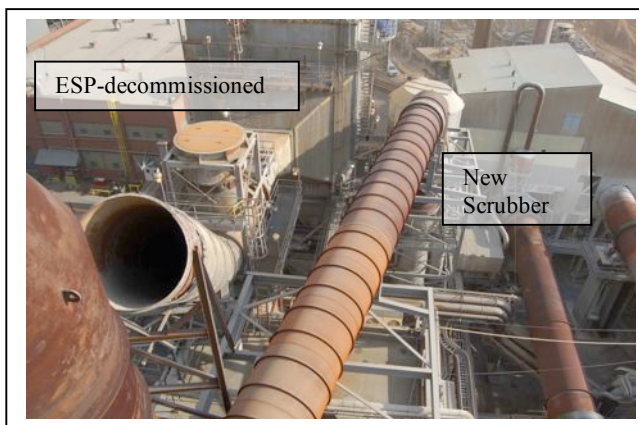


## INSTALLATION

The scrubber system was installed adjacent and between to the existing ESP and lime kiln area. As can be seen from the photos below, the footprint for the entire system was very small and was required to fit inside a very tight area. This made equipment layout critical to allow maintenance and operating access. As an example, all circulation and process pumps were installed together along one side of the layout to allow each pump and motor to be easily removed for maintenance.

Installation of the system was completed in approximately 6 months. The switchover from the existing ESP to the new scrubber was accomplished during a two-week boiler outage. The scrubber system was started up and reached maximum capacity during the first week. The system was tested under full “swing boiler” mode four weeks after startup.

Fig.6 and 7 Switch from ESP to new scrubber



## MATERIAL SELECTION AND METALLURGY

Most FGD applications have either experienced issues with thermal fatigue cracking and corrosion in the wet-dry zone of the scrubber or have been very careful or conservative at the start in selecting steel alloys that are very resistant to corrosion. Installing high nickel alloys such as C-22 and C-276 may have been an acceptable option in the past but since these high nickel based alloys have increased dramatically in price, minimizing the use of these expensive alloys is now very important. However, from a corrosion standpoint, 316L by itself is not expected to survive long term in the wet-dry zone of a system where high chloride levels are found so other alloys have to be considered.

The quench zone is a particularly severe application because the alternating wet-dry conditions in this area will concentrate chlorides in a very narrow region. The two corrosion mechanisms commonly seen here are chloride-assisted stress corrosion cracking and pitting from the sulfuric acid.

The generally accepted corrosion resistance of 316L is as follows:

5% H<sub>2</sub>SO<sub>4</sub> - resistant up to 146°F  
5% H<sub>2</sub>SO<sub>4</sub> – resistant up to 144°F (with 200 ppm Cl)  
5% H<sub>2</sub>SO<sub>4</sub> – resistant up to 135°F (with 500 ppm Cl)  
5% H<sub>2</sub>SO<sub>4</sub> – resistant up to 102°F (with 2,000 ppm Cl)

1% H<sub>2</sub>SO<sub>4</sub> - resistant up to 185°F (pH>3 with 200 ppm Cl)  
1% H<sub>2</sub>SO<sub>4</sub> – resistant up to 170°F (pH>3 with 1100 ppm Cl)  
1% H<sub>2</sub>SO<sub>4</sub> – resistant up to 155°F (pH>3 with 2000 ppm Cl)  
(source: Rolled Alloys)

Since the coal type and well water used at this facility resulted in an equilibrium chloride level of ~500 - 800 ppm (mg/L) the use of 316L is not out of the question but potentially risky in the quench zone where the operating temperature is ~165°F. This combination of temperature and Cl level should be “safe” but is certainly not without risk resulting from process upsets. An upset could easily place the wet-dry zone in the quench into an environment where the chloride concentration can be well above 2000 ppm. This is where there is significant potential degradation of 316L SS.

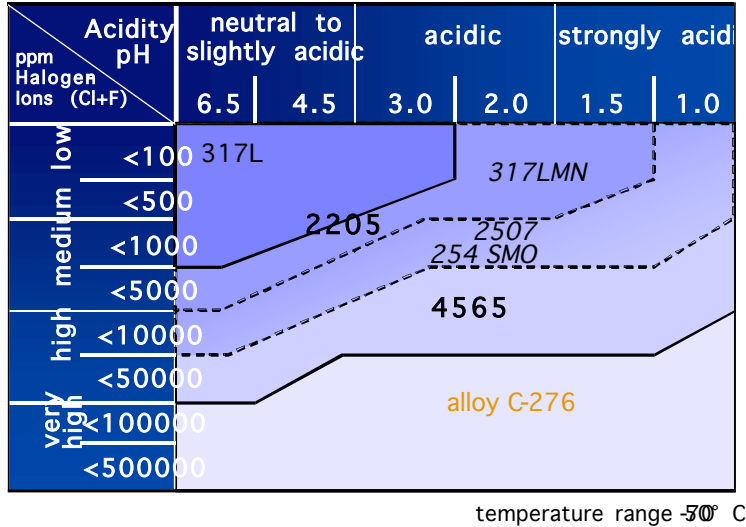
So what material should be used?

In order of increasing resistance to corrosion in this environment, the list of materials commonly considered for use are 316L – 317L – 317LMN – 2205 – 6%Mo (AL-6XN or 254 SMO) – C-276 - C-22 (see Diagram . Duplex stainless steel (2205) is a practical alternative because it is readily available as sheet and plate. 2205 has equivalent acid pitting and crevice corrosion resistance as 317LMN, is not susceptible to stress corrosion cracking and is less expensive than 317LMN.

An even more conservative approach is to install a section of AL-6XN, a 6% Mo alloy, in the wet-dry region of the quench. This was the option selected at this facility. A 5 ft. “band” of ¼” AL-6XN was installed in the quench section at the location (above and below) the quench spray lances. The quench spay nozzles themselves were made of Hastelloy to prevent any issues with potential erosion since this is the “dirtiest” circulation loop. In the scrubber after the quench section, all the walls are washed/irrigated with neutral pH solutions and are well below 150°F so the 316L base metal is adequate even with potential high chlorides concentrations. After ~24 months of operation, this unit has experienced only minor crevice corrosion in some spot welds located in the first impingement trays. This was resolved by replacing the mounting clips with a different design which eliminated areas where concentration gradients could occur. Good control of system pH at the impingement tray and venturi is also important to prevent all corrosion issues. In this facility, pH measurement is redundant to ensure good pH control.

Figure 8. Corrosion resistance of commonly used alloys in scrubber systems (source:Tom Spry, SSSC, email Aug.2007)

## FGD Limits of Corrosion Resistance



## RESULTS

Several engineering tests were conducted to show if any further tuning was required of the system before conducting official tests. These preliminary tests showed the following:

### SO<sub>2</sub> Initial Testing

The mill had CEMS (Continuous Emission Monitoring System) for SO<sub>2</sub>. From startup, the SO<sub>2</sub> capture was measured in excess of 99% removal, substantially above the required 93% removal.

### PM (Particulate Matter) Initial Testing

The PM testing proceeded measured the combined total of “front” and “back” catch. During tuning, it was found that accurate pH control in the tray and venturi stages had a significant effect on the PM “back” catch as well as the absorption of SO<sub>2</sub>.

### H<sub>2</sub>SO<sub>4</sub> (Sulfuric Acid Mist) Initial Testing

After the initial testing it was determined that even if the total “back catch” was counted for as H<sub>2</sub>SO<sub>4</sub>, the scrubber unit would pass well below the requirements. To further ensure that all H<sub>2</sub>SO<sub>4</sub> was counted for the testing company measured the front catch as Method 5B allowing all H<sub>2</sub>SO<sub>4</sub> to condense and be measured as “back catch”.

Conservative estimates indicated SAM removal in excess of 95%.

Based on the excellent results from the initial tests, the scrubber system was officially tested for compliance.

## The Test Data

Below table shows a summary of the official test results. The test consisted of 24 one-hour sampling periods that were conducted over several days. A sample of the flue gas test data can be found in Appendix A. As can be seen, the performance of the system well exceeded the requirements, even at significantly lower scrubber pressure drops than designed.

**Table 2. Emissions Summary**

Flue gas flow	168,000 acfm average	The boiler load varied 62-100% of design capacity during testing based on Steam Load (this is a swing boiler)
Steam Flow	355,000 lbs/h (~ 486 MMBTU/h)	
Scrubber Pressure Drop	Ranged from 12" to 19" H <sub>2</sub> O	dP variation due to mill experimenting with system performance limits
<b>Emission Rates</b>		
PM (particulate matter)	3.0 lbs/h average (filterable) 2.4 lbs/h average (condensable) 5.4 lbs/h total average equivalent to 0.0120 lbs/MMBTU average	Based on mill conversion "factor" of 553MMBTU = 420,000lb steam production  This is 17% of the guarantee value
SO <sub>2</sub> (Sulfur Dioxide)	2.3 lbs/h average  99.7% average	This is 33% of the guarantee value
H <sub>2</sub> SO <sub>4</sub>	Based on the 8.0 lbs/h emission limit in ratio to the condensable part of the total PM it was determined that testing was not required to verify performance	

## **WHAT'S NEXT?**

In 2004, the EPA administrator promulgated the Industrial Boiler MACT Rule. Under this rule, all affected existing sources were to be in compliance by spring of 2007. The rule identified 4 major categories of Hazardous Air Pollutants (HAP): Organic HAP, Inorganic HAP, Mercury and Selected Metals. Instead of requiring monitoring specific HAP's, the Rule allowed monitoring of "Surrogates" in the flue gas. These surrogates were: for Organic HAP – surrogate was CO, for Inorganic HAP – surrogate was HCl, and for Selected Metals (arsenic, beryllium, cadmium, chromium, lead, manganese, nickel, selenium) – the surrogate was Particulate Matter (PM). Mercury did not have a surrogate.

In 2007, the EPA vacated the regulation and left behind a great uncertainty in the pulp and paper industry. What is going to be next for power boilers in the industry?

As of the time of writing this paper, no new official ruling has been published. However, indications are that specific levels for PM, Hg and HCl will be included in the upcoming BoilerMACT. Also SO<sub>2</sub> and NO<sub>x</sub> have been discussed.

High efficiency scrubber technology will be an attractive "one system" solution for any power boiler in the future in its ability to meet stringent PM emissions as well as Acid gases. For wet scrubbers as well as dry systems, more work needs to be done in regards to Mercury. High efficiency scrubber perform well capturing ionic mercury. The capture of ionic mercury is about equal to the sub micron PM removal efficiency. Several additives and possible new technologies will be available to address elementary mercury. At this time everyone is waiting to see what provisions will be required to dispose of mercury once captured.

The results seen from this scrubber system prove the concept that a good high efficiency scrubber is a practical or even a preferred alternative to achieve the combined requirements of particulate and acid control. The emissions results show levels exceeding those found from many ESP and baghouse applications. The ability to condense and capture acid mists and alkali salts eliminates the potential of secondary plumes potentially seen in ESP and baghouse applications.

As good as a scrubber of this type is capable of performing, additional removal of fine particulate and acid mist can be attained by incorporation of a final Wet ESP stage after the last impingement tray. The Wet ESP in this design can be smaller because it is designed to work as a nearly perfect mist eliminator. Emissions levels significantly even below the results presented in this paper are easily achievable. This is the "ultimate" scrubber system for future compliance.

## **ACKNOWLEDGEMENT**

The authors are grateful to all people that provided input to this paper, especially James Schwab, Director Technology, EnviroCare Intl.

**APPENDIX-  
Test Results**

Test Day 4: 16 October 2007

TABLE 5 SUMMARY OF PARTICULATE AND SULFUR DIOXIDE DATA ON NO. 1 BOILER SCRUBBER				
Run Number	13	14	15	16
Time Particulate Run Began	0830	1030	1205	1335
Time Particulate Run Ended	0935	1135	1310	1440
<b>Process Data</b>				
Steam Flow, K lb/hr	407	389	406	400
<b>Outlet Volumetric Flow Data</b>				
Velocity, ft/sec	40.7	40.8	40.7	40.6
Flow Rate, ACFM	180,000	181,000	180,000	180,000
Flow Rate, DSCFM	136,000	136,000	136,000	137,000
<b>Outlet Particulate</b>				
Filtrable Rate, lb/hr	3.9	5.8	3.4	2.7
Condensible Rate, lb/hr <sup>1</sup>	1.4	1.7	<del>15.6</del>	1.6
Total Rate, lb/hr <sup>2</sup>	5.3	7.5	<del>19.0</del>	4.3
<b>Inlet CEM<sup>2</sup></b>				
Oxygen, % dry <sup>3</sup>	6.5	7.0	6.4	6.5
Sulfur Dioxide, ppm dry	429	472	497	473
Sulfur Dioxide, lb/mmBtu	1.011	1.152	1.163	1.115
Sulfur Dioxide, lb/hr <sup>4</sup>	582	640	674	646
<b>Outlet CEM<sup>1</sup></b>				
Oxygen, % dry	6.3	6.9	6.2	6.3
Sulfur Dioxide, ppm dry	2.3	2.4	0.3	0.1
Sulfur Dioxide, lb/mmBtu	0.005	0.006	0.001	0.000
Sulfur Dioxide, lb/hr	3.1	3.3	0.4	0.1
<b>Sulfur Dioxide Capture</b>				
% utilizing lb/mmBtu data	99.5	99.5	99.9	100.0
% utilizing lb/hr data	99.5	99.5	99.9	100.0

<sup>1</sup> Suspect sample contamination for Run 15. Data discarded.

<sup>2</sup> CEM runs started with each particulate run. Each CEM run time was one hour.

<sup>3</sup> Integrated samples collected in 60 liter Tedlar bags.

<sup>4</sup> Outlet DSCFM flow rate utilized to determine inlet SO<sub>2</sub> emission rate.

Test Day 5: 17 October 2007

TABLE 6 SUMMARY OF PARTICULATE AND SULFUR DIOXIDE DATA ON NO. BOILER SCRUBBER				
Run Number	17	18	19	20
Time Particulate Run Began	0750	0920	1105	1235
Time Particulate Run Ended	0855	1025	1210	1345
<b>Process Data</b>				
Steam Flow, K lb/hr	344	379	294	330
<b>Outlet Volumetric Flow Data</b>				
Velocity, ft/sec	35.3	37.9	33.0	39.1
Flow Rate, ACFM	156,000	168,000	146,000	173,000
Flow Rate, DSCFM	119,000	125,000	111,000	131,000
<b>Outlet Particulate</b>				
Filterable Rate, lb/hr	2.5	3.1	1.2	3.0
Condensible Rate, lb/hr	4.9	3.3	4.7	1.2
Total Rate, lb/hr	7.4	6.4	5.9	4.2
<b>Inlet CEM<sup>1</sup></b>				
Oxygen, % dry <sup>2</sup>	7.2	6.6	8.0	7.2
Sulfur Dioxide, ppm dry	616	673	716	648
Sulfur Dioxide, lb/mmBtu	1.526	1.597	1.883	1.605
Sulfur Dioxide, lb/hr <sup>3</sup>	731	839	793	847
<b>Outlet CEM<sup>1</sup></b>				
Oxygen, % dry	7.0	6.3	7.8	7.1
Sulfur Dioxide, ppm dry	3.7	3.2	5.7	0.6
Sulfur Dioxide, lb/mmBtu	0.009	0.007	0.015	0.001
Sulfur Dioxide, lb/hr	4.4	4.0	6.3	0.8
<b>Sulfur Dioxide Capture</b>				
% utilizing lb/mmBtu data	99.4	99.6	99.2	99.9
% utilizing lb/hr data	99.4	99.5	99.2	99.9

<sup>1</sup> CEM runs started with each particulate run. Each CEM run time was one hour.

<sup>2</sup> Integrated samples collected in 60 liter Tedlar bags.

<sup>3</sup> Outlet DSCFM flow rate utilized to determine inlet SO<sub>2</sub> emission rate.

Test Day 6: 18 October 2007

TABLE 7  
SUMMARY OF PARTICULATE AND SULFUR DIOXIDE DATA  
ON NO. BOILER SCRUBBER

Run Number	21	22	23	24
Time Particulate Run Began	0730	0900	1030	1200
Time Particulate Run Ended	0835	1005	1135	1305
<b>Process Data</b>				
Steam Flow, K lb/hr	329	323	298	262
<b>Outlet Volumetric Flow Data</b>				
Velocity, ft/sec	35.4	34.8	33.7	32.3
Flow Rate, ACFM	156,000	154,000	149,000	143,000
Flow Rate, DSCFM	118,000	116,000	112,000	110,000
<b>Outlet Particulate</b>				
Filterable Rate, lb/hr	2.7	2.9	2.8	1.9
Condensable Rate, lb/hr	1.7	1.7	2.3	2.9
Total Rate, lb/hr	4.4	4.6	5.1	4.8
<b>Inlet CEM<sup>1</sup></b>				
Oxygen, % dry <sup>2</sup>	7.4	7.2	7.8	8.0
Sulfur Dioxide, ppm dry	423	422	416	429
Sulfur Dioxide, lb/mmBtu	1.063	1.045	1.077	1.128
Sulfur Dioxide, lb/hr <sup>3</sup>	498	488	465	471
<b>Outlet CEM<sup>1</sup></b>				
Oxygen, % dry	7.1	6.9	7.4	7.7
Sulfur Dioxide, ppm dry	1.1	1.0	1.2	1.0
Sulfur Dioxide, lb/mmBtu	0.003	0.002	0.003	0.003
Sulfur Dioxide, lb/hr	1.3	1.2	1.3	1.1
<b>Sulfur Dioxide Capture</b>				
% utilizing lb/mmBtu data	99.7	99.8	99.7	99.7
% utilizing lb/hr data	99.7	99.8	99.7	99.8

<sup>1</sup> CEM runs started with each particulate run. Each CEM run time was one hour.

<sup>2</sup> Integrated samples collected in 60 liter Tedlar bags.

<sup>3</sup> Outlet DSCFM flow rate utilized to determine inlet SO<sub>2</sub> emission rate.