High Efficiency SO2 Scrubber Design to Reduce Caustic Consumption

Paper # 35

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ABSTRACT

An industrial facility located in Southern California operates a thermal oxidizer to treat vapor recovery and waste gas streams containing sulfur compounds. The facility has an available source of alkali waste water which could be a potential scrubbing solution. Several technologies were evaluated to replace the existing control equipment for reducing SO_2 emissions. Incentives exist for similar facilities with the South Coast Air Quality Management District (SCAQMD) Regional Clean Air Incentives Program (RECLAIM) to reduce SOx emissions below the facilities operating permit limits. The RECLAIM program is requiring plants to achieve less than 5 ppmv SO_2 stack emissions and greater than 99% SO_2 removal.

Plans are currently underway to replace the existing control equipment with a two stage packed bed scrubber system. This arrangement enables the plant to achieve very low emission limits and reduce caustic consumption by as much as 28% compared to a single stage scrubber. It also provides flexibility for the future use of available alkali waste water to reduce caustic consumption by as much as 75% compared to a single stage caustic scrubber. This reduction will save an estimated $165,000 per year in operating cost. This paper will discuss the system design and how it achieves low outlet emissions while reducing overall chemical consumption. It will also discuss several other design considerations and benefits. The design approach provides a viable alternative for other Southern California facilities impacted by the SOx RECLAIM program as well as facilities in other regions.

INTRODUCTION

An industrial facility located in Southern California operates a thermal oxidizer to treat vapor recovery and waste gas streams containing sulfur compounds. The facility has an available source of alkali waste water which could be a potential scrubbing solution. Several technologies were evaluated to replace existing control equipment for reducing SO_2 emissions. Incentives exist with the South Coast Air Quality Management District (SCAQMD) Regional Clean Air Incentives Program (RECLAIM) for similar plants to reduce SOx emissions below operating permit limits. The reclaim program is requiring plants to achieve less than 5 ppmv SO_2 stack emissions and greater than 99% SO_2 removal.

Plans are currently underway to replace existing control equipment with a two stage packed bed scrubber system. This arrangement enables the plant to achieve very low emission limits and reduce caustic consumption by as much as 28% compared to a single stage scrubber. It also provides flexibility for future use of available alkali waste water to reduce caustic consumption by as much as 75% compared to a single stage caustic scrubber. This reduction will save an estimated $165,000 per year in operating cost. This paper will discuss the main benefits of a two stage scrubber design including:

Main Benefits of Two Stage Scrubber

- Capability to meet low emission limits below 5 ppmv and greater than 99% removal efficiency.
- Ability to minimize caustic consumption.
- Flexibility to use available alkali waste water as a potential scrubbing solution to reduce operating cost.
- Reduced risk of fouling and the need for softened water related to calcium scaling.

In addition to the main benefits of a two stage system, there are several other considerations for designing an SO2 scrubber system. These will also be discussed in the paper, including:

Other Scrubber Design Considerations

- Particulate Tolerance
- Ability to suppress a visible steam plume.
- Maintaining 24/7/365 operation and maximizing system uptime.
- Minimizing down-time during start-up and commissioning.
- Installation into limited space while providing adequate maintenance access for operators.
- Maintaining close cooperation with plant personnel during system design, installation, and start-up.

Facilities considering new or upgraded SOx controls need to weigh a wide range of factors. These can include the possibility of tighter emission limits in the future and local incentives to reduce emissions beyond permit limits. The two stage approach provides a viable alternative for Southern California facilities impacted by the SOx RECLAIM program as well as facilities beyond California.

SYSTEM DESIGN

Figure 1 shows a schematic of a 2-stage scrubber system. Hot gas from the thermal oxidizer is first cooled in an evaporative quencher using re-circulated water. Water that has not evaporated flows from the quencher into the packed bed absorber.

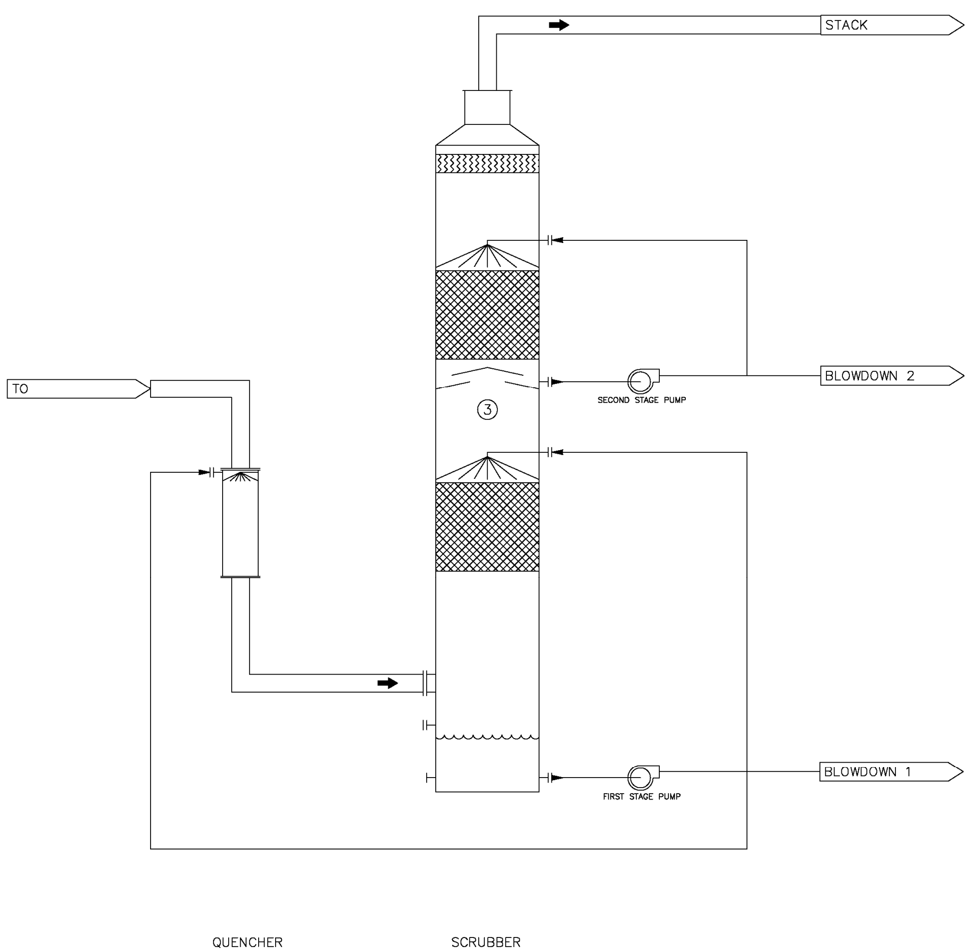
The gas passes through the first stage packed bed to remove the majority of SO_2 in the gas stream. The scrubbing water is collected in the sump and is re-circulated back to the top of the first stage packed bed and to the quencher. A dilute solution of sodium hydroxide is metered into the scrubber recirculation line to neutralize acid gases in the gas stream. The addition rate of sodium hydroxide is controlled by the pH of the liquid in the absorber sump.

After the first stage, the gas passes though a second stage packed bed. The second stage acts as a polishing step to achieve the low outlet SO_2 concentration limit. The first and second stages are separated by a trap-out tray. A dilute solution of plant-supplied sodium hydroxide is metered into the second stage re-circulation line and is controlled based on the pH in the 2nd stage sump. A blowdown stream is taken from the re-circulation line to purge the system of absorption products. Water is added to the system to make up for blowdown and evaporative losses.

After passing through the packed bed the gas passes through a mist eliminator at the top of the scrubber vessel. The entrainment separator collects any water droplets that were entrained in the gas stream during scrubbing. The gas then passes through an interconnect duct, fan, and stack before being discharged into the atmosphere.

An option is available to sub-cool the gas using a plate-and-frame heat exchanger and a source of cooling water. Sub-cooling condenses the moisture in the gas stream to supply a clean source of water in the scrubber and to suppress the steam plume under most meteorological conditions. The potential benefits of sub-cooling and other design considerations are discussed later in the paper.

Figure 1: Two Stage Packed Bed Scrubber Arrangement.



MAIN BENEFITS OF A TWO STAGE SCRUBBER

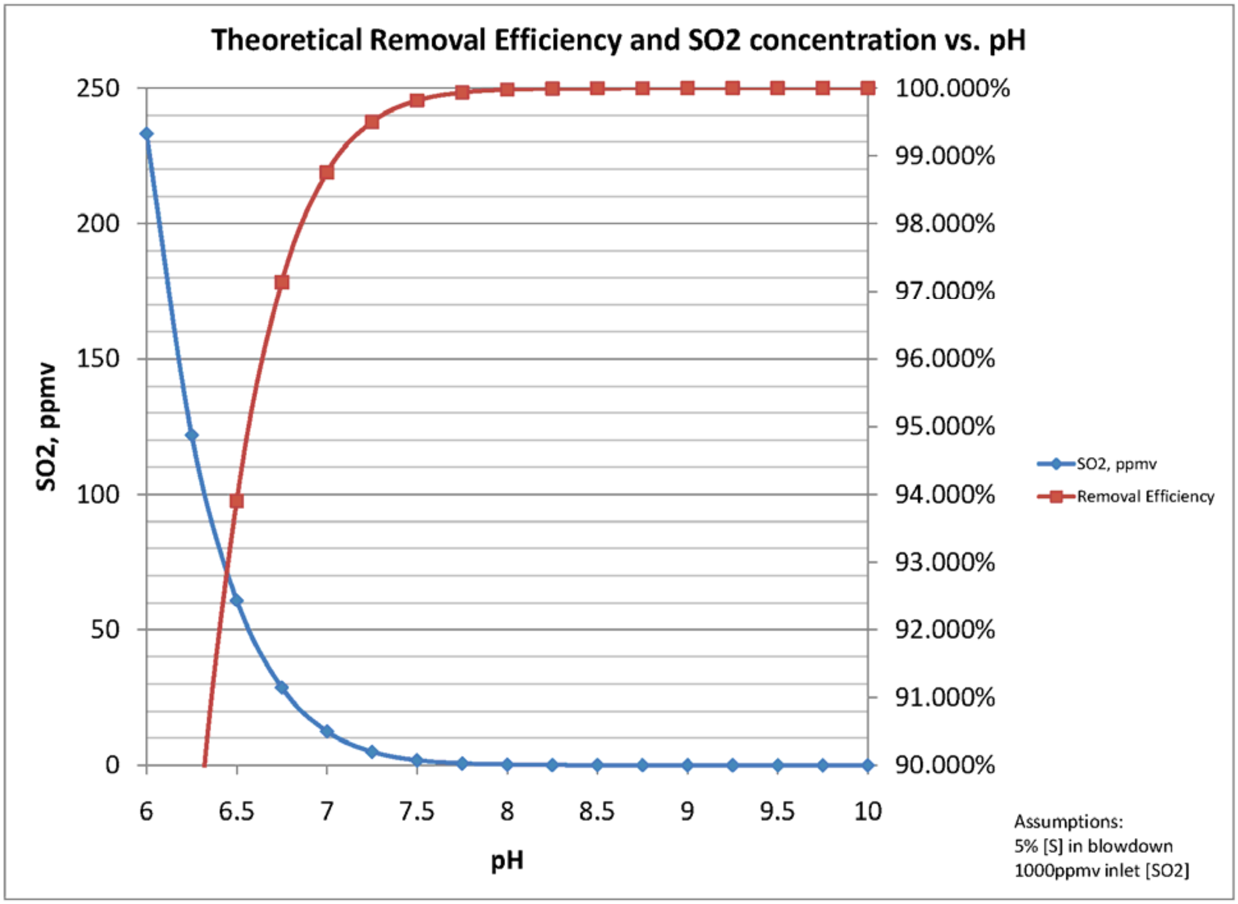
The section will address the benefits of a two stage scrubber design.

Achieving Low Outlet Emissions

One of the primary driving forces for a two stage scrubber is the capability to achieve lower outlet emissions than a conventional single stage scrubber. The specific sizing and operating parameters of the scrubber depend on many variables including gas flow rate, composition, temperature, moisture content, inlet SO_2 concentration, and outlet emission limits. Figure 2 shows the theoretical performance of a single stage scrubber versus pH based on Henry's law. The data is for a scrubber operating with an inlet SO_2 concentration of 1,000 ppmv and 5 wt. % sulfur in the blowdown. The performance curve is dependent on these variables. As the blowdown is reduced (higher sulfur content in the blowdown), the curve shifts to the right (higher pH is required). Likewise for lower inlet SO_2 concentration, the curve shifts to the left (lower pH is required).

A two stage scrubber achieves higher removal efficiency by operating 2 packed beds in series, each operating at a lower removal efficiency than the overall removal efficiency that is required. The overall removal is the product of the two individual removal efficiencies. For example, the removal efficiency of a 2 stage scrubber operating at 90% removal in each stage is calculated as: 1-(1-.90)*(1-.90) = 99% removal. Operating the individual packed beds at lower removal efficiency enables each bed to operate at a lower pH or blowdown rate than a single stage scrubber. At some point the ability to achieve high removal efficiency with a single stage scrubber may be limited by the cost of caustic consumption or scaling issues associated with operating at high pH. Two stages provide a greater operating window for achieving very high removal efficiency.

Figure 2: Theoretical scrubber performance versus pH.



Minimizing Caustic Consumption

Another main driver for a two stage scrubber is the ability to reduce caustic consumption for removal efficiencies greater than 95%. This reduction becomes greater as the scrubber is operated to achieve higher removal efficiency. This occurs for a couple of reasons. At a lower pH the water will absorb less CO_2. More importantly, the scrubber will favor the 1:1 salt reaction to sodium bisulfite. This can be understood by Figures 3 & 4. Figure 3 shows the SO_2 scrubber reactions as the 2:1 salt reaction to sodium sulfite (Na_2SO_3) and the 1:1 salt reaction to sodium bisulfite ($NaHSO_3$).

Figure 3: SO2 Scrubber Reactions.

2:1 Salt: $SO_2 + 2NaOH \rightarrow Na_2SO_3 + H_2O$

1:1 Salt: $SO_2 + NaOH \rightarrow NaHSO_3$

The scrubber equilibrium curves in figure 4 shows the sulfur species in water as a function of pH. The curves show that lower pH favors the 1:1 salt reaction (HSO_3) and higher pH favors the 2:1 salt reaction (SO_3).

Because the two stage scrubber can operate at lower pH, the 1:1 reaction is favored, resulting in lower caustic consumption. That is because 1 mole of caustic is consumed to reduce 1 mole of SO_2 compared to 2 moles of caustic to reduce 1 mole of SO_2.

Figure 4: Sulfur concentrations versus pH.

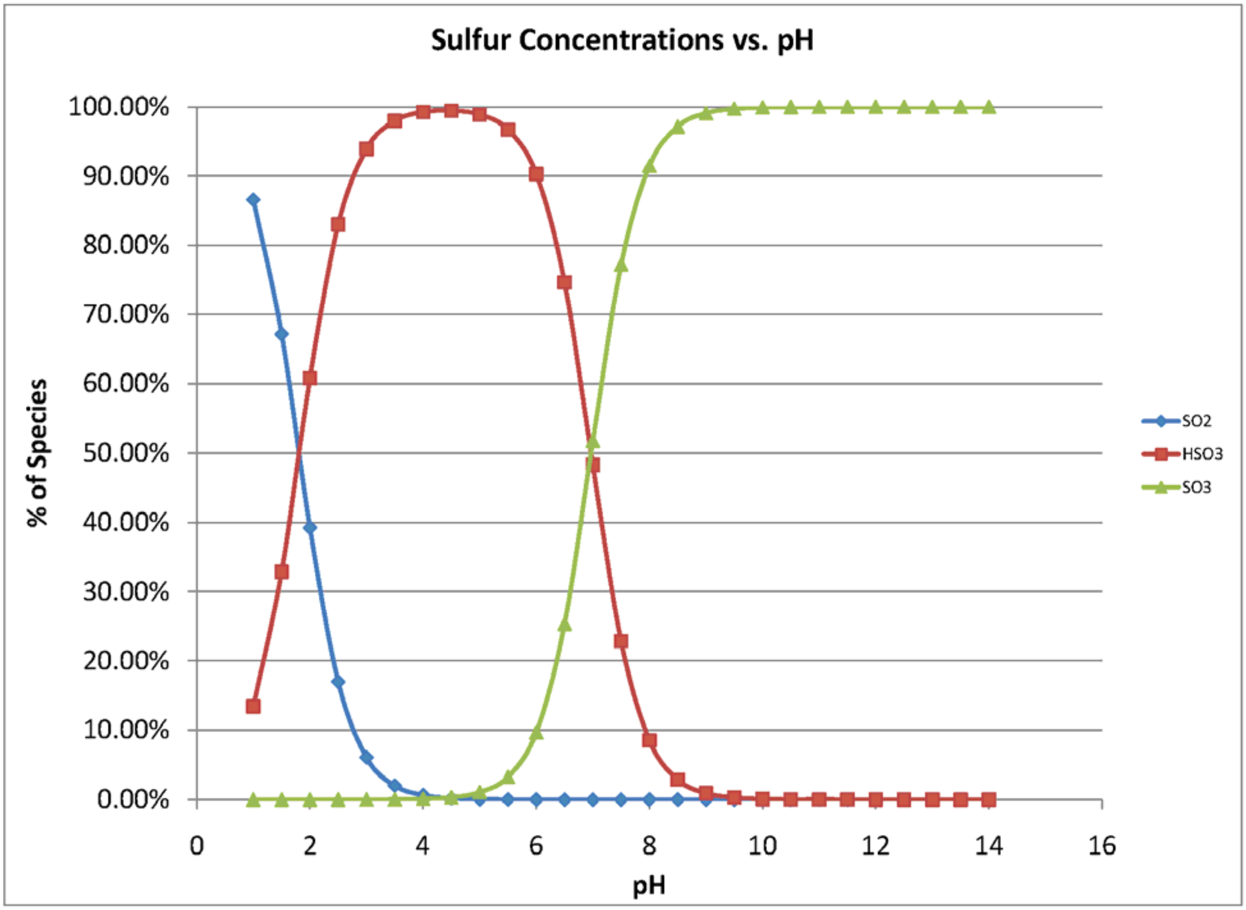
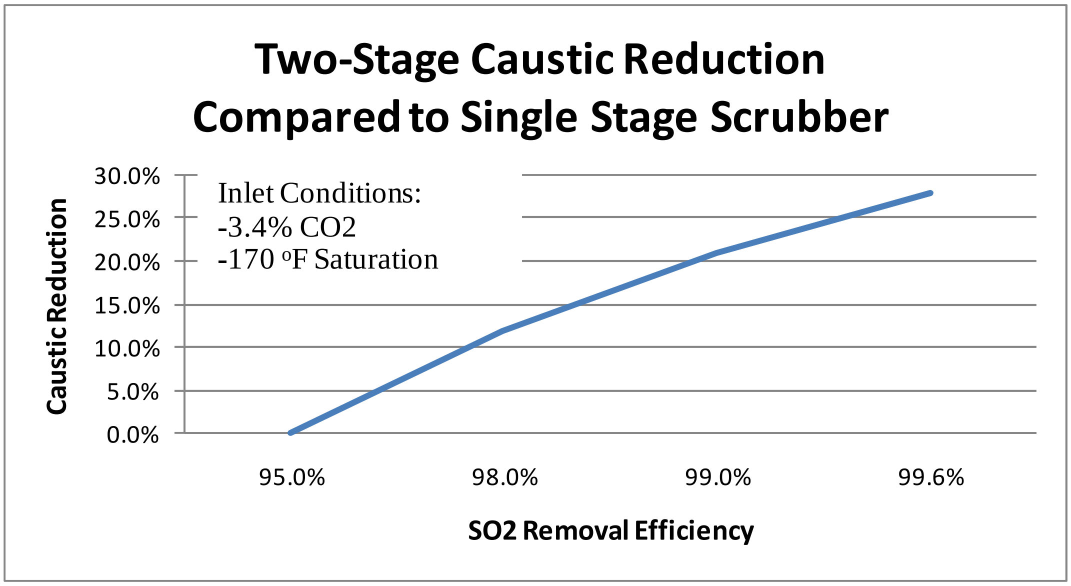


Figure 5 shows the reduction in caustic consumption ranging from 95% to 99.6% SO_2 removal for a scrubber with an inlet SO_2 concentration of 1,050 ppmv and 3.4% CO_2. The curve shows that caustic is reduced 28% for a removal efficiency of 99.6% compared to a single stage scrubber. This achieved by operating the scrubber at a pH of 5.5 to 6.0 compared a pH greater than 8.0 for a single stage scrubber. From Figure 4, the 1:1 salt reaction is dominant at this pH range resulting in few moles of caustic consumed.

Figure 5: 2-stage reduction in caustic consumption compared to single stage scrubber.



Flexibility to use Alkali Waste Water

The plant has an available source of alkali waste water that could be a potential scrubbing solution and reduce operating costs. The waste water has an incoming pH of approximately 9.0 and is non-scaling at a pH < 7.

Although the scrubber will initially operate using caustic only, the plant requested the flexibility to use waste water to reduce caustic consumption even further. Because SO_2 is a weak acid, a single stage packed bed must operate at a pH above the waste water non-scaling point. Scaling caused by elevated pH would cause the packed bed to plug and result in significant downtown. For this reason, it was determined a single stage scrubber is not capable of using the plant waste water.

For reasons discussed earlier regarding pH versus efficiency, a two stage scrubber provides the flexibility to use the waste water. The majority of SO_2 would be removed in the first stage by re-circulating the waste water at a pH well below the non-scaling point. The 2nd stage would be a polishing step using water and caustic injection to achieve the final SO_2 removal required. Making use of the waste water would reduce caustic consumption approximately 75%, saving an estimated $165,000 per year.

Reduced Risk of Fouling and Need for Softened Water

An important consideration for packed bed scrubbers is the tolerance for calcium in the recirculation water. Low calcium tolerance results in scaling caused by reactions in the water of carbonate and calcium. This is a function of both pH and recirculation temperature. The calcium tolerance is lower for higher pH and temperature. This will generally be observed first in fouling of instruments used to control the scrubber, but can also lead to plugged nozzles. In an extreme case an increase in pressure drop might occur from plugging the bed. However, instrument fouling and plugged nozzles usually occur well before an impact to the bed is observed. In some cases, softened water may be required for make-up water to combat this effect. The two stage scrubber provides an advantage because the pH in each bed is lower compared to a single stage scrubber. This results in greater tolerance for calcium scale. In many cases, a two stage scrubber will eliminate the need for a water softener.

OTHER SCRUBBER DESIGN CONSIDERATIONS

In addition to the main benefits discussed above, there are several other considerations for designing an SO_2 scrubber system. These are further discussed below.

Particulate Tolerance

A design consideration for scrubber systems is tolerance for low concentrations of particulate during normal operating conditions or higher concentrations during unexpected upset conditions. Because the inlet gas from the thermal oxidizer is at a high temperature, it must first be quenched to saturation using an evaporative quencher. A proprietary low pressure drop quencher is used to rapidly quench the gas. The quencher uses open pipe injection ports with large orifices to eliminate the potential for plugging. In other words, there are no nozzles in the quencher. The internal design creates a small pressure drop which promotes water-gas mixing to fully saturate the gas. Because the quencher is essentially a low pressure drop Venturi, large particulate will be collected and entrained in the water. Figure 6 shows the predicted particulate removal as a function of particule size. This shows the quencher will remove 99% of particulate greater than 3 microns and approximately 90% of particulate greater than 1.5 micron in size. The quencher therefore serves the dual purpose to cool the gas to saturation and to collect particulate before the gas passes through the packed bed.

Figure 6: Quencher particulate removal performance.

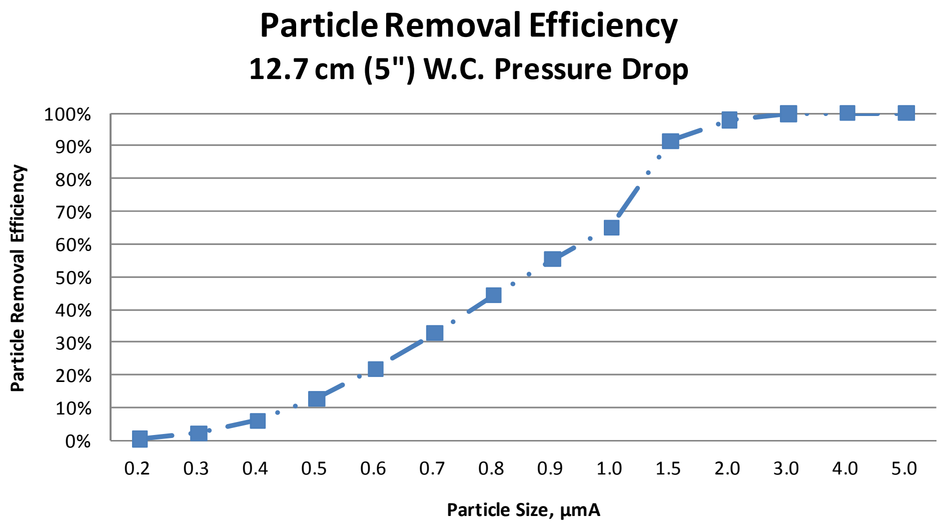


Figure 7 shows a picture of typical packing material used in the packed bed. The packing is a newer design than older style pall rings. The packing has a low pressure drop, high mass transfer, and large void spaces free of wide surfaces for material to collect on. The large void space provides additional tolerance for particualate in the gas stream. Although this application has a low inlet particulate concentration, the approach of an upstream low pressure drop Venturi Quencher followed by a packed bed has been used on many solid waste incinerators with much higher particulate loads ranging from 0.1 to 2.0 gr/dscf. The arrangement is capable of tolerating particulate in the gas stream.

Figure 7: Packing material showing large void space and free of wide surfaces.

Visible Steam Plume

Because a packed bed scrubber cools the gas to the saturation temperature, the stack will have a visible steam plume. An option can be provided to suppress the plume under most meteorological conditions by sub-cooling the gas. This is achieved using a liquid cooling circuit comprised of a plate & frame heat exchanger and cooling tower on the recirculation loop to the packed bed.

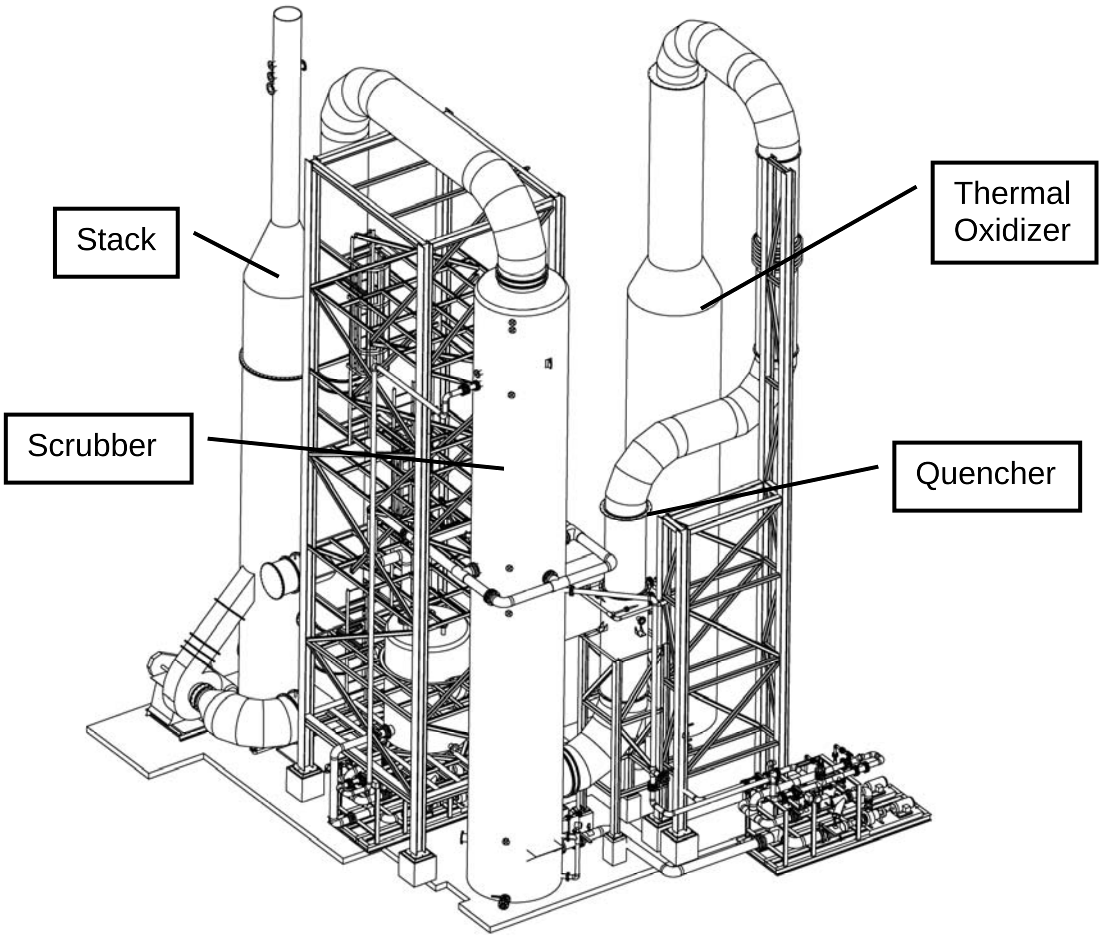
As the gas passes through the packed bed, the water vapor will condense and be collected in the sump. Sub-cooling provides the additional benefit of minimizing the potential for fouling from calcium scaling. That is because condensed water vapor is a clean source of make-up water which makes less calcium available to react with carbonates and cause scaling.

System Uptime, Footprint, and Maintenance Access

High system availability is important in most industrial applications. Many plants operate 24/7/365 days per year with little downtime for scheduled maintenance. To ensure meeting a high uptime demand, redundancy is designed into the system. Each stage has two (2) recirculation pumps, 1 operating and 1 spare. In addition, the exhaust gases are pulled through the system with two induced draft (1) fans, 1 operating and 1 spare.

To save space, the scrubber is designed with both stages vertically integrated in the same vessel separated by a trap out tray. Structural steel is required to support the inlet duct from the thermal oxidizer to the scrubber, the interconnect duct from the scrubber outlet to the inlet of the ID fans, and the stack. Platforms are integrated into the structural steel to provide maintenance access to manways for changing packing, nozzles, and mist eliminator elements. The structural steel is used to provide an access platform to the stack for a CEMS unit and test ports for stack tests. The general arrangement shown in Figure 8 illustrates how the integration was made for this project.

Figure 8: Two stage scrubber general arrangement.



Installation, Start-up and Commissioning

Another important aspect of the scrubber project is to minimize downtime during installation, start-up and commissioning. The scrubber system installation is planned for setting the major pieces of equipment ancillary equipment before making the final duct connections to the thermal oxidizer. The system is provided as a semi turn-key installation. The scope of supply includes all of the engineering including structural, foundations, and electrical as well as submitting the engineering drawings to the city for construction permits. The plant will provide installation of major equipment, foundations and structural steel. Piping and field duct connections for FRP ductwork will also be included in the scope of work. Supplier personnel will be on-site through most of the installation to provide on-site supervision and coordination. The system will be operated and tested prior to making the final connections to ensure the system is fully operational. The last step will be to make the final connection between the thermal oxidizer and inlet duct to the scrubber. Approximately 2 to 3 days are planned to make the final connections and to have the thermal oxidizer back in operation with the scrubber running.

Close Cooperation with the Customer

From the initial scrubber technology selection, close cooperation has been required between the equipment supplier and the customer. This has involved a series of technical design review meetings with key plant personnel including the plant manager, environmental & safety manager, technical project manager, operations manager, and controls engineer. During design review meetings, many issues were evaluated to determine optimum choices and trade-offs for meeting the facilities needs. Some of these issues have included:

- Fan selection and expected noise level.
- Integration of CEMs unit with the stack design.
- Preferences for plant layout and equipment location.
- Optimum material selection for the inlet duct to the scrubber.
- Equipment sizing and trade-offs between performance and operating range.
- Instrument specifications and classifications.

In many respects, the supplier design team becomes an extension of the customer's organization throughout the course of the project. Close communication and cooperation were essential to identify critical issues and address them in the system design.

CONCLUSION

As facilities in California and elsewhere plan strategies for complying with ever more stringent SO_2 or sulfur emission limits, technically feasible solutions are needed to reduce emission levels to very low levels. In many cases SO_2 limits below 5 ppmv will be needed. This may require control technology of greater than 95% removal and in many cases greater than 99%. Some states like California offer financial incentives for plants to reduce their emission below their permit limits.

The two stage packed bed scrubber systems offers a viable alternative that will be applicable for many facilities. The system provides flexibility in achieving efficiency greater than 99% removal while also providing benefits for reducing caustic consumption and operating cost as well as minimizing maintenance and maximizing system uptime.

REFERENCES

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KEY WORDS

SO2 Scrubber, SOx Reclaim, acid gas scrubbing, packed bed absorber