DYNAWAVE WET GAS SCRUBBING: A NEW ALTERNATIVE FOR CLAUS UNIT TAIL GAS CLEAN-UP

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Introduction

Sulfur recovery units built or operated in the United States, must install a tail gas treatment unit (TGTU), in order to reduce sulfur emissions. Currently, Refinery MACT II requires that SO_2 emissions from sulfur recovery units (in refineries) be kept below 250 ppm, corrected to 0% oxygen on a dry basis. This usually equates to an overall sulfur recovery/removal rate of 99.8%, or higher.

Regenerable amine type tail gas treatment units are most often utilized to achieve 99.8% sulfur recovery. In an amine type unit, the Claus tail gas sulfur compounds, including SO_2, CS_2, COS & elemental sulfur, are converted to H_2S with a hydrogenation/hydrolysis reactor. The H_2S is then absorbed in a selective amine solvent, concentrated, and recycled to the front end of the SRU. This approach typically increases the overall sulfur recovery efficiency of the Claus unit to 99.8%, or higher. However, the fresh acid gas feed rate to the SRU is reduced by the amount of the recycle stream, which reduces the SRU fresh acid gas capacity by approximately 5%. The residual H_2S not recycled to the SRU is incinerated to convert it to SO_2 prior to emitting it to the atmosphere.

Until recently, there were few viable alternatives to this approach to SRU tail gas treatment, which could also provide an overall sulfur recovery/removal of 99.8%. However, recently a wet gas scrubber was shown to be a viable, alternate approach for SRU tail gas treatment. When using a wet gas scrubber, the sulfur compounds present in the tail gas from the Claus Unit are first oxidized to SO_2. The SO_2 is then captured by contacting the gas stream with an alkaline reagent such as sodium hydroxide in the wet gas scrubber, producing a concentrated brine waste stream. Residual SO_2 not captured in the scrubber is discharged to the atmosphere. With this approach, there is no H_2S recycle to the sulfur recovery unit, and the overall sulfur recovery/removal efficiency is increased to 99.95%. In addition, equipment costs are less than conventional amine absorption type systems. Finally, wet gas scrubbing systems can operate over a wide range of feed conditions, as is often found in refineries.

Background

Sinclair Oil Corporation operates two refineries in Wyoming. The "Sinclair" Refinery is located just outside of the city of Rawlins in Sinclair, Wyoming and is rated at 72,000 bpd. The other refinery is located just outside of Casper and is rated at 22,500 bpd. The Sinclair Refinery operates two three-stage sulfur recovery units, with a combined capacity of 47.7 LTPD, while the Casper Refinery operates one three-stage sulfur recovery unit, with a total capacity of 18 LTPD.

Throughout 2003, Sinclair investigated several options that would bring the sulfur recovery units at both sites into compliance with the newly promulgated Refinery MACT II standards.

In early 2004, Sinclair decided that their preferred approach was to treat the tail gas from the SRUs at their Sinclair and Casper refineries with incineration/wet gas scrubbing technology. The decision was based on an economic review of the competing technologies as well as the fact that Sinclair had successfully operated a wet gas scrubber on their SRU at their Tulsa Refinery for several years.

After evaluating several different wet gas scrubbing technologies, Sinclair settled upon DynaWave Wet Gas Scrubbing Technology (supplied by MECS, Inc.). The DynaWave was selected for its ability to handle a wide range of upstream operational scenarios, while still reducing SO_2 in the off gas to levels required by MACT II, as well as its ability to reduce COD (chemical oxygen demand) in the scrubber effluent. This paper will describe the installation and subsequent performance of the DynaWave system.

System Description

Sinclair worked with CEntry Constructors & Engineers to develop the project scope, process design basis, and engineering specifications for the units. CEntry had assisted with the previous technology studies, and was selected as the EPC firm for the project. As the Sinclair Refinery has two SRUs, a main process requirement was that the DynaWave performance would not be compromised when only one of the SRUs was in operation. On the other hand, the Casper refinery only has one SRU. Therefore, the Casper Refinery wanted to have the capability to send a large percentage of the feed stream that would normally be sent to the front end of the SRU, directly to the TGTU, should the SRU need to be taken offline for maintenance. With this arrangement, the refinery could continue to operate, even during periods when the SRU was offline. As the Casper Refinery required the ability to operate a portion of the refinery when the SRU was down, the tail gas systems at both the Casper Refinery and the Sinclair Refinery were designed to handle similar amounts of sulfur throughput.

The final scope for the Sinclair and Casper Refineries each consisted of a single tail gas treatment train with a forced draft thermal incinerator, a waste heat boiler, and a single DynaWave Scrubbing System. The Sinclair Refinery also included a single ID fan downstream of the TGTU waste heat boiler to avoid imposing the TGTU pressure drop on the two SRUs.

Under CEntry's direction, MECS upgraded the standard DynaWave Scrubber System engineering specifications in order to provide a final design that met Sinclair Corporations' Refinery Engineering Standards. The result is a robust design that provides the redundancy and safety features required in a refinery environment. These systems were placed on order in the summer of 2004, and were operational by April of 2005.

Oxidation of Sulfur Compounds in the Tail Gas

The first major piece of equipment in each system is the forced draft thermal incinerator, also known as a thermal oxidizer, which was supplied by John Zink. The incinerator combusts the tail gas stream from the SRU with sufficient oxygen, at the proper temperature, for a given residence time. Based on the tail gas composition from the SRUs and allowing for 10 ppm of H_2S in the incinerator tail gas, the incinerators at the Sinclair and Casper Refineries were designed to be operated at 1250°F to 1350°F with a minimum residence time of 1.0 second. Normal operation requires fuel gas to maintain the incineration temperature. The

Sinclair Refinery incinerator is rated at 10 MMBTU/hr, while Casper's incinerator is rated at 4 MMBTU/hr.

A two fan arrangement provides the motive force for the thermal oxidizer combustion air. One fan is required for normal operation and the second fan is an installed spare. An electrically ignited pilot is used for light-off.

The burners are constructed of carbon steel while the burner tile is a high temperature refractory capable of handling the flame zone service. The thermal oxidation furnace itself is a brick lined carbon steel vessel. A rain shield is also provided in order to minimize corrosion, which could occur as a result of ambient cooling due to wind, rain and snow.

Flue gas from the incinerators flows into a waste heat firetube boiler. The flue gas is cooled to 500°F while making 300 to 350 psig saturated steam.

In order to accommodate the SRU acid bypass case, the Casper incinerator was designed with a center fired acid gas gun and the capability of operating at 2000°F, by controlling the temperature with quench air from the combustion air blowers. In addition, the fans were equipped with variable frequency drives so that they would not have to continuously run at the higher air flow and pressure required when acid gas was being sent directly to the incinerator.

Based on samples taken after unit start-up with the incinerator operating at 1250 deg F, the gas stream composition, exiting the incinerator at the Sinclair Refinery is as shown in Table 1. There was a great deal of initial concern regarding the amount of SO_2 that would be further converted to SO_3 in the incinerator. SO_3 will combine with water in the scrubber, and form H_2SO_4, which is a submicron mist. At high enough concentrations, H_2SO_4 will form a distinctive blue plume that will trail from the scrubber stack. The opacity caused by this plume must typically be kept below 20% (as measured by EPA Method 9). In addition, SO_3/H_2SO_4 will add to overall sulfur emissions, thus reducing the overall recovery efficiency of the TGTU. However, as shown below, SO_3 formation in the incinerator at the Sinclair Refinery was minimal. In addition, the plant reports that there is little to no opacity out of the stack.

Table 1. Sinclair Refinery Incinerator Outlet Gas Stream Composition, Fixed Gas Analysis

Compound	Percent (Dry Basis)
Nitrogen	91.0 %
Oxygen	6.0 %
Carbon monoxide	Non Detectable
Carbon dioxide	2.2 %
Sulfur dioxide	7097 ppm
SO_3 (reported as H_2SO_4)	21 ppm
Dimethyl sulfide	11 ppm
Carbonyl sulfide	8 ppm
Carbon disulfide	Non Detectable
Dimethyl disulfide	Non Detectable
Hydrogen	Non Detectable
Hydrogen sulfide	Non Detectable
Methane	Non Detectable
Methyl mercaptan	Non Detectable

DynaWave Operation

After incineration, the tail gas is sent to the DynaWave scrubber, for SO_2 removal. Scrubbing of SRU tail gas presents several challenges specific to SRUs. In addition to SO_2 removal, provision for SO_3/H_2SO_4 removal may be required. Finally, oxidation of the liquid effluent may be required in order to reduce chemical oxygen demand (COD) to levels acceptable by wastewater treatment facilities.

Wet gas scrubbers circulate a liquid reagent throughout the system, which absorbs SO_2. The amount of liquid circulating throughout the system versus the gas flowrate through the system is referred to as the liquid to gas ratio, or L/G ratio. The L/G ratio is typically expressed in gpm divided by the quenched gas flow through the scrubber, in acfm, divided by 1000. The L/G ratio is a key process parameter for a scrubber and must be high enough to fully quench the hot gas and to absorb the SO_2 without suppressing the pH in the absorber reaction/contact zone. In general, higher liquid to gas ratios will result in higher SO_2 removal efficiencies.

The pH of the circulating liquid decreases as acid gas is absorbed. As lower pH inhibits SO_2 absorption, the pH of the circulating solution is continuously monitored. When the pH drops below a given set point, reagent is added to the circulating liquid in order to maintain an acceptable pH range (typically somewhere between 6.5 and 7.5) for further SO_2 absorption. A high enough L/G ratio is required to prevent momentary pH depression in the reaction zone.

Reagent Selection and Cost Comparison

Reagents are typically grouped into two categories: sodium based, such as caustic (NaOH) and soda ash (Na_2CO_3), and calcium based, such as lime (CaO) or limestone ($CaCO_3$). Any reagent can be used in the DynaWave system. However, each reagent has advantages and disadvantages associated with its use. In general, reagent selection will play the biggest factor when it comes to system capital and operating cost, removal efficiency, and operability.

Most refiners prefer to use sodium based reagents, such as caustic, as all of the products and reactants are soluble, making scrubber operation simple and straightforward. Sinclair initially investigated two sodium based reagents: soda ash and caustic. Both sites ultimately decided to use caustic, as the on-going savings gained by using soda ash was not significant enough to compensate for the additional capital costs incurred with a soda ash system. In addition, caustic was available as a fifty percent solution, which could be pumped directly to the scrubber without further dilution or mixing. On the other hand, soda ash was only readily available as a powder and would have required the installation of a reagent preparation system.

The reaction between SO_2 and caustic is a strong acid-base reaction and is, for all practical purposes, instantaneous. Once the SO_2 is in solution, the reaction proceeds as follows:

SO_2 (v) + NaOH (l) → $NaHSO_3$ (soluble salt)

SO_2 (v)+ 2NaOH (l) → Na2SO_3 (soluble salt) + H_2O

At the normal operating pH value of 6.5 to 7.0, 90% to 98% of the reaction products are sodium sulfite, with only 2% to 10% being sodium bisulfite.

One of the major advantages of using caustic as the reagent is that the above reactions are relatively fast compared to the reaction of SO_2 with calcium based reagents, such as lime or limestone. Therefore, higher removal efficiencies can be achieved with caustic, as shown in Figure 1.

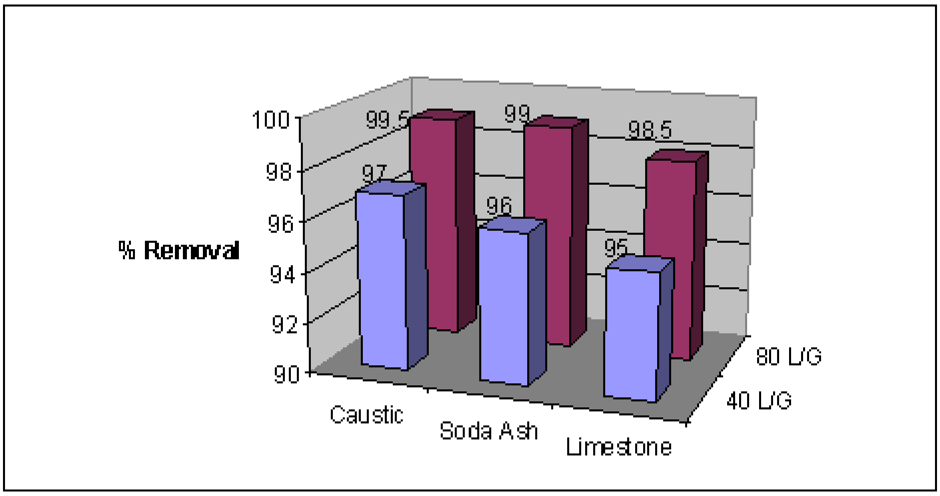

Figure 1. Typical SO_2 Removal Efficiencies of a DynaWave Scrubber

In most cases, the sodium sulfite/bisulfite salts formed in the above reactions must be further oxidized to sodium sulfate, as shown below, in order to reduce the Chemical Oxidation Demand (COD) in the scrubber effluent to acceptable levels.

$NaHSO_3$ (soluble salt)+ ½ O_2 + NaOH → Na_2SO_4 (soluble salt) + H_2O

Na_2SO_3 (soluble salt)+ ½ O_2 → Na_2SO_4 (soluble salt)

Once the COD has been reduced to acceptable levels, the scrubber effluent can be sent to an evaporation pond (as with the Sinclair Refinery), or the local municipality's wastewater treatment plant (as with Casper Refinery). Some customers choose to send the effluent to their plant wastewater treatment system or inject it into a disposal well.

In selecting the reagent, both the on-going reagent cost and the capital cost associated with using a particular reagent should be considered. Reagent consumption is a function of the scrubber inlet sulfur loading, and the efficiency of the sulfur recovery unit. Maximizing the recovery efficiency of the upstream SRU minimizes on-going reagent cost. Therefore, optimization of the SRU design and operation should be considered in developing the scope of the TGTU project. As a minimum, the SRU should have three catalyst beds and state-of-the-art ratio and temperature control systems. The Claus catalyst should be kept in good operating condition. For existing 2-stage Claus units that are not amenable to adding a third stage, reagents such as limestone could be used to minimize the reagent costs, as shown in Table 2.

Other more costly SRU modifications may also be cost effective in minimizing the life cycle cost of a SRU/TGTU train. These include the use of enhanced Claus catalysts, modifications to the Claus unit design to provide a sub-dewpoint process, or a direct oxidation step. These modifications can boost the SRU recovery efficiency to 99%, or more.

Sinclair did consider modifying the SRUs at the Sinclair location to increase their sulfur recovery efficiency. Cost studies were done during 2003 comparing capital and operating costs for the proposed SRU/Incinerator/Scrubber train with the SRUs as is and with the SRUs modified with separate or a combined sub-dewpoint Claus final stage. The scrubber operating cost comparison was based on soda ash reagent. In this case, the savings in reagent realized by installing a sub-dewpoint Claus stage were not sufficient to justify the additional capital cost required to modify the SRUs.

Table 2. Relative Reagent costs vs. number of stages

	Sulfur Recovery	Reagent	Yearly Reagent Costs 100 LTPD Unit
2 Stage Unit	95.5%	Caustic	100%
3 Stage Unit	97.0%	Caustic	66.7%
Enhanced SRU Recovery	99.2%	Caustic	17.7%
2 Stage Unit	95.5%	Limestone	0.036%
3 Stage Unit	97.0%	Limestone	0.024%

In any event, as can be seen in the above table, using limestone (also known as calcium carbonate) can also result in significant savings over the lifetime of the installation. However, limestone, is less reactive than caustic as it must first be dissolved into the liquid before the acid-base reaction can take place. Therefore, limestone may not be a viable reagent for all scenarios, and needs to be evaluated on a case-by-case basis.

As was previously mentioned, most refiners decide that limestone is not an acceptable reagent for their operations. This is for several reasons.

Compared to caustic scrubbing, the reactions of limestone and SO_2 are much more complex. Since limestone is basically insoluble, the dissolution of limestone into water is often the limiting step in the overall conversion of SO_2 to calcium sulfate ($CaSO_4$). Although there are many intermediate reactions, once the limestone is in solution, the net reaction between SO_2 and limestone can be summarized as follows:

$SO_2 + CaCO_3 \rightarrow$ $CaSO_3$ (insoluble salt)+ CO_2

Just as with caustic systems, the calcium sulfite must be further oxidized to calcium sulfate (CaSO4), also known as gypsum, in order to reduce the COD in the scrubber effluent to acceptable levels. The oxidation reaction is shown below.

$CaSO_3$ (insoluble salt) + ½ O_2 $\rightarrow$ $CaSO_4$ (insoluble salt)

It should be noted that because of its crystal structure, calcium sulfite ($CaSO_3$), which is the product produced when SO_2 is first absorbed into a limestone solution, is not easily removed from the scrubber effluent. Therefore, even in cases where COD is not a concern, oxidation is still required with limestone systems in order to facilitate the filtration, disposal, and handling of the reaction by-products, and prevent scale formation in the scrubber.

Calcium based systems will require more operator attention and will cost more than caustic based systems, for several reasons. First, lime and limestone are often only available in a dry form, which means that a reagent preparation system must be installed and attended to on a regular basis. Secondly, calcium sulfite and calcium sulfate (also known as gypsum) are both insoluble salts. These salts can be erosive to the piping and recirculation pumps, resulting in more maintenance. Finally, the system effluent must typically be gypsum free before it can be disposed of. Therefore, rotary drum vacuum filters or filter presses are required in order to remove the gypsum from the effluent as well. On the positive side, as the gypsum can be filtered from the scrubber effluent, the water can be recirulated to the scrubber, resulting in a zero liquid effluent system.

DynaWave Description

As can be seen in Figure 2, tail gas from the waste heat boiler enters the scrubber inlet duct and collides with the circulating scrubber liquor, which contains excess reagent and reaction byproducts. The liquor is injected countercurrent to the gas flow through a large bore, open throat nozzle, also known as a reverse jet nozzle. This area of the DynaWave scrubber is generally referred to as the inlet barrel. The inlet barrel is typically made of a high alloy material such as AL6XN or Duplex 2205.

As can be seen in the figure, the typical DynaWave contains two stages of scrubbing, or froth zones, in the inlet barrel. The primary function of the first froth zone is gas quenching and initial acid gas absorption. The gas exits the first scrubbing stage at its adiabatic saturation temperature (typically between 150 and 180 deg F) and passes to a second scrubbing stage, which is located below the first scrubbing stage. In the second scrubbing stage, liquid is again injected upward into the incoming gas, removing additional contaminants.

In a typical system, after the gas exits the inlet barrel it flows through the top portion of the vessel, through a set of chevrons, and exits to the atmosphere through an integral stack. The chevrons maximize liquid droplet removal from the gas stream; however, as soon as the gas enters the vessel most of the liquid disengages from the gas stream and accumulates in the bottom of the vessel. The bottom of the vessel is used as a reservoir for the scrubber solution, which ensures continuous feed to the recirculation pumps. In addition, in-situ oxidation of sulfite salts to sulfate salts occurs in this area.

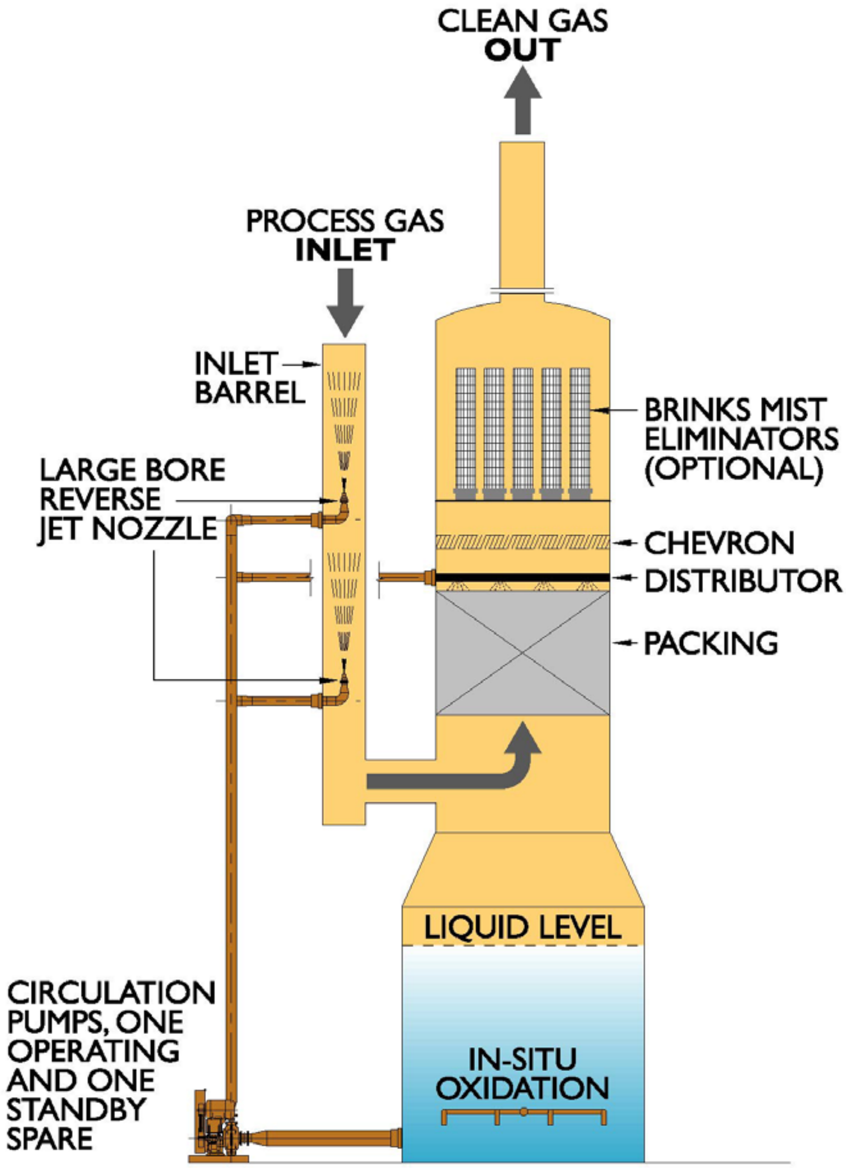

Figure 2. DynaWave Wet Gas Scrubber used for SRU Tail Gas Treatment

More water leaves the scrubber, due to evaporation, than enters the system with the reagent. Therefore, the liquid level in the sump is continuously monitored. When the liquid level drops below a given set point, liquid is added in order to prevent the system from running dry. The scrubber solution is discharged from the system when its specific gravity reaches a given set point, typically between 1.07 and 1.20.

If membrane grade caustic is used as the reagent, the circulating liquid will contain low levels of chlorides, allowing the gas/liquid disengagement vessel to be constructed of 316 S/S. Membrane caustic can be more expensive than diaphragm grade caustic because of the fact that it contains lower levels of chlorides. However, the use of diaphragm caustic requires a higher alloy material of construction for the vessel such as Duplex 2205, in order to prevent stress corrosion cracking.

The reverse jet nozzle used to inject the scrubber liquor into the inlet barrel is a proprietary piece of equipment, supplied by MECS. The nozzles are non-atomizing, operate at low pressures, and are fabricated of abrasion resistant silicon carbide. Two nozzles (one per froth zone) are typically required for most SRU applications. A picture of a reverse jet nozzle is shown in Figure 3.

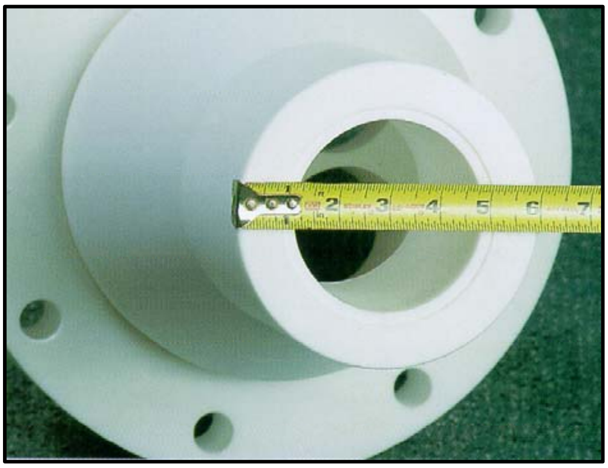

Figure 3. Typical Reverse Jet Nozzle for SRU Tail Gas Treatment Applications

The reverse jet nozzle is critical to scrubber operation, as it creates the full cone liquid flow essential to producing the froth zone, the region in the DynaWave system where gas/liquid contacting occurs. A froth zone is simply an energetic flow regime comprised of a mixture of gas and liquid. The design of the froth zone is customized for each particular application and set of process requirements, and is defined by a plot of the gas flow rate and the liquid to gas ratio.

SO_2 Removal

Most DynaWave systems typically only consist of two stages of gas/liquid contacting in the inlet barrel and an open gas/liquid disengagement vessel with chevrons. However, due to the high levels of SO_2 entering the Dynawave during various operating scenarios (e.g. SRU acid gas bypass) a third scrubbing stage, consisting of 2" diameter metal packing rings, was added in the gas/liquid disengagement vessels at both sites. This additional stage of mass transfer is used as a polishing stage to achieve SO_2 levels of less than 100 ppmvd, corrected to 0% oxygen in the stack. In some cases, the liquid circulation to the packing can be turned off, if the SO_2 removal across the froth zones is determined to be acceptable.

Results of testing at the Sinclair Refinery show that SO_2 levels have been reduced to non-detectable levels. The results below were obtained with both of the froth zones in operation and liquid circulating over the packing, in November of 2005.

Table 3. Full Scale SO_2 Removal Results, based on EPA Method 6

	Run 1	Run 2	Run 3	Average
SO_2 Inlet (lb/hr)	276.11	259.13	249.50	261.58
SO_2 Outlet (lb/hr)	0.01	0.01	0.01	0.01
SO_2 Outlet, ppm basis	0.3[1]	0.3[1]	0.3[1]	0.3[1]
SO_2 % Removal	***99.99***	***99.99***	***99.99***	***99.99***

Note 1: The above outlet SO_2 value of 0.3 ppm represents the lower detection limit for stack testing.

It should be noted that Sinclair has found that a certain level of operator attention must be given to the system in order to ensure proper pH levels are maintained during sulfur plant upsets.

Chemical Oxygen Demand

The extent to which a refinery must treat their effluent is very specific to each site. Effluent treatment can range from no required treatment to total treatment and discharge of potable water. At a minimum, most refiners want to make provisions for oxidizing the sulfite in the scrubber effluent to sulfate, thereby reducing the effluent COD. COD is simply the amount of oxygen (in milligrams) required to oxidize the chemical compounds in a liter of liquid to a stable, non-oxygen consuming, form.

As was previously mentioned, the DynaWave system employs a unique "in-situ" oxidation system whereby air is injected into the sump of the vessel in order to facilitate oxidation of the sulfite salts. A sparger-piping array in the bottom of the scrubber vessel distributes the air throughout the sump liquid and creates fine bubbles. The vessel sump is sized to maximize contact time with the air and oxygen as the bubble migrates to the surface of the liquid. The sump is also sized to provide adequate retention time of the liquid in order to allow ample time for the oxidation reactions to occur.

$NaHSO_3$ (soluble salt)+ ½ O_2 + NaOH → Na_2SO_4 (soluble salt) + H_2O

Na_2SO_3 (soluble salt)+ ½ O_2 → Na_2SO_4 (soluble salt)

As was previously mentioned, both sites employ the in-situ oxidation system. The Sinclair Refinery sends the scrubber effluent to an evaporation pond, while the refinery in Casper sends their scrubber effluent to the local municipality's waste water treatment plant. COD, which is tested once per day at Casper averages from 50 to 150 mg/l. In order to keep COD levels within these levels, it is critical that a refinery manages the COD and TOC (Total Organic Carbon) content of all sources of make-up water and anti-foam used in the scrubber.

SO_3 Removal

As was previously mentioned, SO_3 in the tail gas can be a concern, as it will condense in the scrubber, form H_2SO_4 (sulfuric acid mist), and create opacity at the outlet of the scrubber. It is generally accepted that sulfuric acid mist produces a visible plume when it is present in the stack gas at significant enough concentrations. In addition to mist concentration, opacity is also dependent upon stack diameter and the particle size of the mist.

During the design phase of the project, both facilities questioned the quantity of SO_3 theoretically predicted to be formed in the incinerator. This is because the mechanisms for SO_2 to SO_3 conversion in an incinerator are not completely understood. An extremely conservative approach is to assume that equilibrium between SO_2 and SO_3 is attained in the incinerator, which would mean that nearly 10% of the sulfur would be converted to SO_3, while the remaining 90% of the sulfur species would remain SO_2. Most engineering firms and incinerator vendors agree that this level of conversion is rarely, if ever seen. In most cases, the general rule of thumb is to assume that 1 to 3% of the sulfur in the gas will be converted to SO_3 in the incinerator.

On the other hand, experience has shown that even SO_3 levels of 1 to 3% (as a percentage of SO_2 in the gas stream) are very conservative. For example, a study of H_2SO_4 emission levels from 47 scrubbers downstream of FCC units (OGJ, Jan. 17, 2005, pp 62-64) concluded that there was little correlation between the amount of SO_2 and SO_3. In fact, the study concluded that in 90% of the cases, H_2SO_4 in FCC scrubber exhaust was less than 10 ppm, on a dry basis. This data has relevance as a higher level of SO_2 to SO_3 conversion is expected in a FCC, than an incinerator, as it operates at lower temperatures and higher pressures than an incinerator (conditions which favor SO_3 formation), and in the presence of vanadium.

In any event, given the unknown regarding the amount of SO_3 that would be produced in the incinerator, especially during the acid gas bypass phase of operations, Casper elected to go ahead and install Brink™ Fiberbed Mist Eliminators, supplied by MECS, in the upper portion of the gas/liquid disengagement vessel. Figure 4 shows how these fiberbeds work.

Mist eliminator operation is simple and straightforward. The mist laden gas flows horizontally through vertically mounted fiber beds. The collected mist coalesces into larger droplets and films inside the collecting layer of the fiberbed. Gas drag and capillary forces cause the liquid to migrate horizontally, to the interface between the collecting and drainage-fiber layers. The drainage layer, consists of fibers or filaments that reduce the gas drag and capillary forces on the collected liquid, and facilitates drainage of the collected liquid to the bottom of the fiberbed. The mist eliminators are made of Alloy-20 and glass fiber, and are virtually 100% efficient.

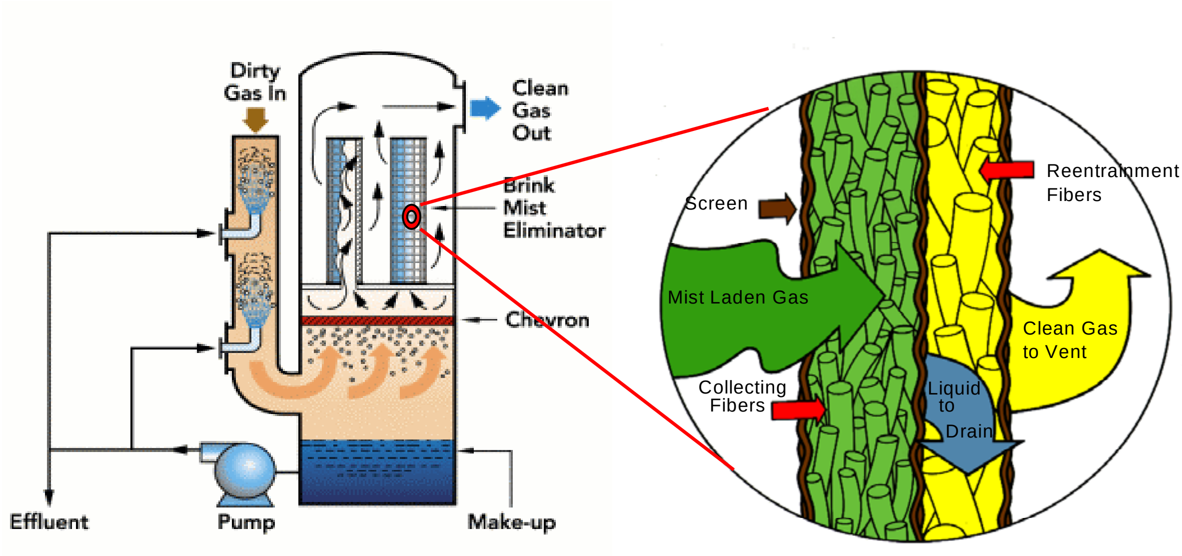

Figure 4. Brink Mist Eliminators Installed in a DynaWave System

The Sinclair Refinery, on the other hand, felt that mist eliminators would not be required for their installation, based on testing they conducted on their existing SRU incinerators before the DynaWave was installed. However, space was left in the vessel for mist eliminators, in case they were required after start-up of the scrubber. Upon start-up testing showed that H_2SO_4 levels out of the incinerator were indeed much lower than predicted by the incinerator vendor, and that scrubber removal efficiency of H_2SO_4 was higher than predicted. As there was no visible plume the plant decided that the installation of mist eliminators was not required. Figure 4 shows the amount of SO_3/H_2SO_4 in the stack gas.

Table 4. Full Scale H_2SO_4 Removal Results without Brink Mist Eliminators

	Run 1	Run 2	Run 3	Average
H_2SO_4 Inlet (ppm, dry basis)	20.85	21.76	21.03	21.21
H_2SO_4 Outlet (ppm, dry basis)	5.74	5.32	5.10	5.38
H_2SO_4 % Removal	***70.3%***	***74.0%***	***74.8%***	***73.0%***

Summary

At the time this paper is published, the DynaWaves at the Sinclair and Casper Refineries will have been operational for nearly a year and a half. Both sites are satisfied with the performance of the units, and report that routine maintenance has been minimal on the scrubber itself. For example, the Sinclair Refinery, reported in November of 2005 that the only maintenance to the DynaWave required in six months of operation was the replacement of a pH meter.

The Sinclair Refinery has made some minor modifications to the system upstream of the DynaWave in order to improve overall system reliability. For example, changes were made to the incinerator pressure taps in order to minimize plugging. In addition, the site insulated the ductwork between the boiler and the ID fan, in order to prevent condensation of SO_3 upstream of the scrubber. However, in July of this year, the plant observed evidence of corrosion on the uninsulated portion of the ductwork downstream of the fan and upstream of the scrubber necessitating a shutdown of the incinerator, waste heat boiler, and scrubber for to make repairs to the corroded section of ductwork. During this time a greenish-yellowish buildup was obtained from inside of the duct, analyzed, and determined to be the byproduct of SO_2/SO_3 attack on stainless steel. The plant plans on preventing this problem in the future by insulating the duct between the ID fan and inlet barrel in order to keep the gas stream above the acid dew point. The scrubber was also inspected during the shutdown and showed no signs of corrosion.

The main issue at the Casper site has revolved around the continuous emission monitor (CEM) installed to monitor SO_2 emissions. The CEM chosen for installation was unable to provide an accurate SO_2 reading at the extremely low concentrations found in the DynaWave outlet. Casper, which by all accounts was overdesigned in order to handle acid gas bypass around the SRU, reduced the liquid circulation rates through the DynaWave, which minimizes the amount of caustic used during normal operations. These changes resulted in reliable CEM readings during normal operations.

In January of 2005, Sinclair Corporation decided to install a third DynaWave on the SRU at their Tulsa refinery. This unit is started up in the late spring of 2006, and is meeting all plant expectations.

References

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