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Wet Flue Gas Desulfurization (WFGD) Upgrade at the Trimble County Generating Station Unit 1

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ABSTRACT

The Trimble Unit 1 WFGD system, originally supplied by Combustion Engineering circa 1980, was originally designed for 90% removal while operating three absorbers (one spare) each with four of five recycle pumps operating. As of February 2005, the system was capable of operation close to or at 98% removal but was typically operating around 93-94% SO_2 removal while operating all installed equipment. This removal efficiency was insufficient to meet the 2006 emission requirement of 97% SO_2 removal of a 5.5 lbs/MMBtu inlet (0.17 lbs/MMBtu outlet).

Babcock Power Environmental Inc. (BPEI) was contracted to upgrade the existing WFGD system to meet the future compliance limit while limiting additional pressure drop. This upgrade was to be designed such that the WFGD system could consistently maintain a 98% SO_2 removal while operating all installed equipment. By using previous experience, and guidance from E.ON U.S., BPEI utilized multiple tools including CFD and physical modeling to optimize the inlet gas distribution, slurry spray generation, and gas-liquid interaction.

The results of the upgraded system exceeded expectations by removing over 99% of a 6.5 lb/MMBtu SO_2 inlet. This removal was not only achieved during the start-up period, but was also maintained for extended operation. This paper presents the design development and results of the Trimble WFGD upgrade.

INTRODUCTION

The wet flue gas desulfurization (WFGD) upgrade project at E.On U.S.'s Trimble County Generating Station Unit 1 is an excellent example of the application of current technology to an existing system. This paper presents an overview of the process that involved the evaluation of the current system and the design and installation of materials necessary to upgrade the existing WFGD system. In addition, the performance of the installed enhancements as well as the system without them is reviewed.

Upgrading an existing WFGD system has many areas of potential difficulty, as the entire system needs to be evaluated to determine the best course to bring the process to an optimal efficiency. This can be increasingly difficult when the system was originally designed and installed over 20 years ago and limited design data are available. Additional consideration also needs to be made toward the current operation and the desired future operation. If the desired performance increase requires the purchase and installation of numerous pieces of additional equipment (recycle pumps, oxidation air blowers, etc...), upgrading the existing system may be less cost effective than installing a new WFGD.

From proposal to installation, the Trimble Unit 1 upgrade was accomplished in a 9-month period. All phases (design, requisition, purchase, fabrication, and installation) of the project schedule were compressed in order to deliver the material for a planned outage. In addition, the increased removal efficiency needed to be met by January 1st, 2006 with the release for the project in late February 2005. Each phase of the project contributed to and was instrumental in achieving this goal, and demonstrated that the solution designed for the system was cost effective.

Both physical and CFD flow modeling were utilized to optimize the inlet gas distribution to the absorber and to limit the amount of slurry deposition on the inlet duct. Slurry spray nozzle tests were conducted to characterize the existing nozzles so that new nozzles could have similar flow and pressure criteria. Dual direction nozzles were installed with a wider-angle spray cone to ensure complete coverage of the spray zone, as well as, increased gas-liquid interactions. A header pad or saddle was designed and installed around the branch pipe connections to the spray header to reduce erosion and provide additional reinforcement. Wall baffles were designed and installed in each absorber to direct and better distribute flue gas over the entire cross section of the absorber, as well as, reduce "gas sneakage" along the absorber walls and corners. The combination of all these items will improve the gas flow distribution and liquid-to-gas contact and therefore increase the absorbers' effectiveness to remove SO_2 from the flue gas.

BACKGROUND

Trimble County Generating Station Unit 1 is a 550 MWG, subcritical, tangential-fired, pulverized coal boiler designed by Combustion Engineering. The unit is a balanced draft, pulverized coal fired, drum type boiler with single reheat. The boiler is equipped with six levels of burners located in the corners of the unit. The original steam side operating conditions at full load are 3,800,000 lbs/hr of main steam at a design outlet temperature of 1005 °F and a pressure of 2500 psig.

In addition, Trimble 1 also has electrostatic precipitators (ESP) and in 2002 was retrofitted with a selective catalytic reduction (SCR) system. While the ESP was originally installed with the boiler, the SCR was supplied by Riley Power (A Babcock Power Inc. company) and was designed to remove 90% of the inlet NO_x.

Combustion Engineering also supplied the existing WFGD system, which was originally designed in the 1980's. The discharge from the two induced draft fans is fed to a common plenum, which then feeds four absorber modules. The discharge of the absorbers is again fed to a common duct before exiting through the stack. There are two reaction tanks supplied for the plant, each having two of the four absorber modules located above such that the absorbed SO_2 is directed into the tanks. Each absorber has five installed recycle pumps, each feeding a dedicated spray level. The original design condition for the WFGD system was to remove 90% of a 7.0 lbs/MMBtu SO_2 inlet while operating three of the four absorbers and four of the five installed recycle pumps per absorber.

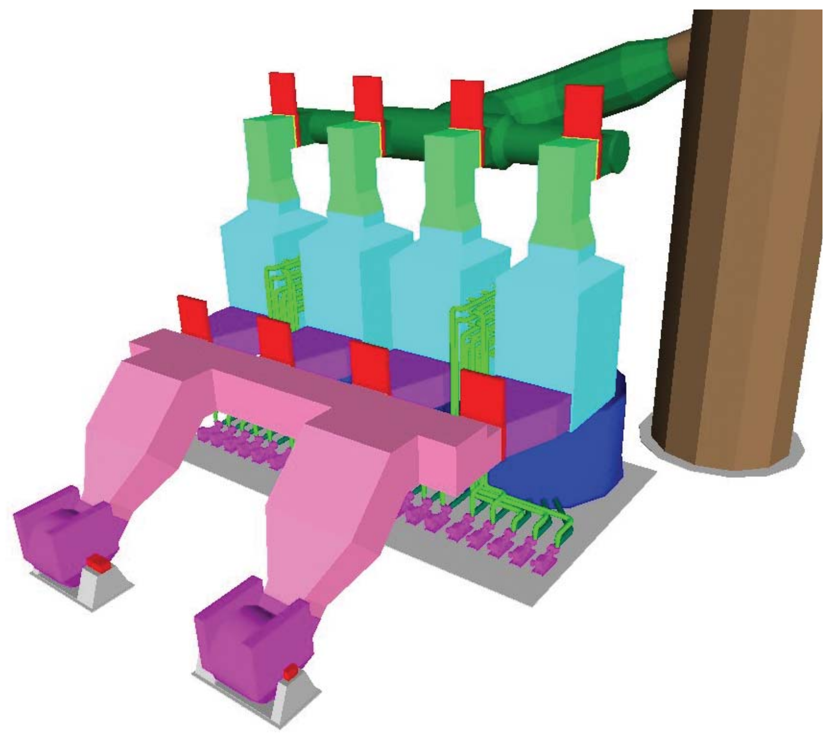

Figure 1. Trimble 1 WFGD Arrangement

Because of operational issues with the absorber inlet dampers and a desire for higher SO_2 removal efficiencies, the WFGD system has been and is currently operating with all four absorbers in service and with all five recycle pumps per absorber in service. This arrangement was the design basis for the WFGD upgrade.

WFGD UPGRADE DESIGN

During the initial design of the Trimble 1 WFGD upgrade, it was important to understand the dynamics of the installed WFGD to determine a suitable solution. The original request for quote had suggested many potential areas of improvement including the addition of wall baffles, modifying the inlet ducts to eliminate solids buildup, and spray header repair. However, it was necessary to learn the operational history of the WFGD system so that additional design issues and potential solutions could be identified. Through interactions with the plant, it was discovered that removal efficiencies greater than 97% up to 98% were achievable for short periods of time. However, items such as equipment maintenance outages would result in a significant drop in efficiency. In addition, the scrubber had experienced quite extensive solids deposition on the inlet duct, and during outage inspections, it was noticed that there were a considerable number of plugged spray nozzles and spray headers. All of these items were viewed to be linked to unstable removal efficiency. Therefore, they were considered in the design and scope provided for the upgrade.

Operating History

In characterizing the existing WFGD the first step was to document the operating history. To do so, the hourly emission data on the Environmental Protection Agency's website was used for the characterization.[1] By using the data directly from the EPA, all graphs and results are reproducible from data that is publicly available.

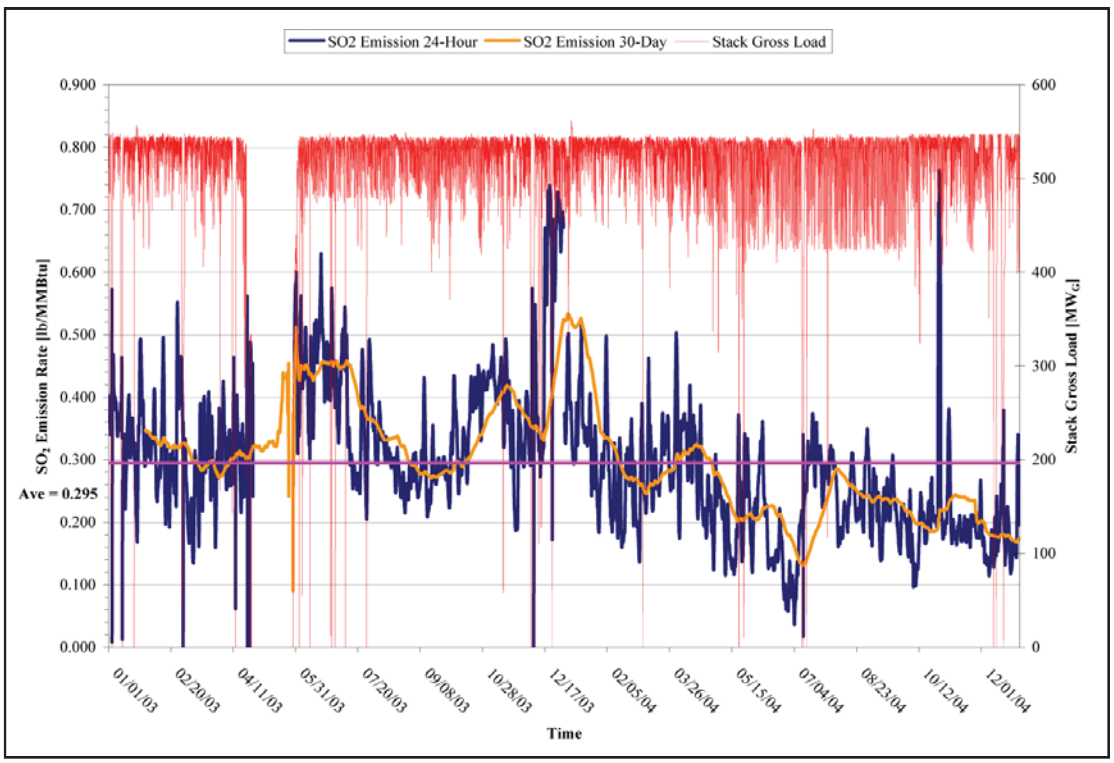

Figure 2. Trimble County 1 Rolling SO_2 Emissions Data (2003 & 2004)

Rather than plotting the raw data from 2003 and 2004, Figure 2 shows the 24-hour and 30-day rolling averages of the SO_2 emissions data. These rolling averages were used to better illustrate the overall operation of the scrubber instead of the hourly operation that may be misleading when a process variable changes for a short period of time. In addition to the cumulative graphs for 2003 and 2004, rolling averages for the individual years were also made.

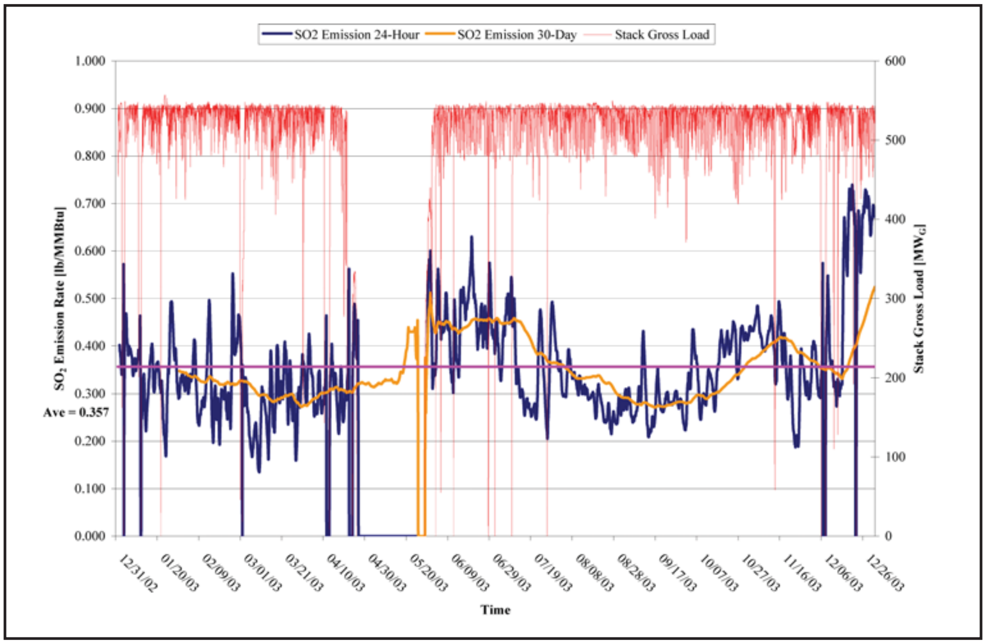

Figure 3. Trimble 1 SO_2 Emissions Data (2003)

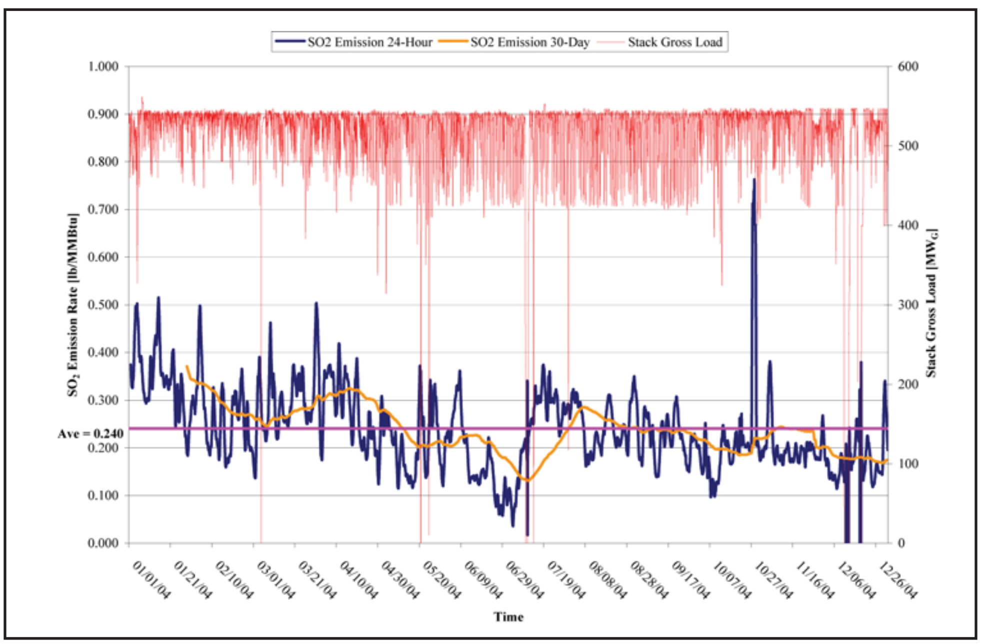

Figure 4. Trimble 1 SO_2 Emissions Data (2004)

Figures 3 and 4 show the rolling averages (24-hour and 30-day) for the individual years of 2003 and 2004. While 2004 had a lower overall average emission rate than 2003, 0.240 and 0.357 lbs/MMBtu respectively, maintaining a 24-hour average or 30-day average emission below 0.200 lbs/MMBtu was inconsistent. While there are a few periods below 0.200 lbs/MMBtu and even 0.100 lbs/MMBtu over these two years, consistent operation at these levels with the existing absorber configuration seems improbable.

Boiler Performance and Baseline Test

After the system history had been established, it was necessary to evaluate the boiler performance and perform a baseline test for the WFGD system. The baseline test would verify that the data provided during the initial design were valid, or it would establish a new set of operating conditions to compare to the EPA emission data. This operating data could then be used to fine-tune the performance calculations to establish a better picture of the existing system's performance.

The results from the baseline test indicated that the flue gas flow rates provided from the original WFGD design were rather conservative. The design gas flow provided was approximately 7.5 MMlbs/hr where as the tested flows were only about 6.0 MMlbs/hr. In addition, the test confirmed that the removal of the WFGD was operating less than its best efficiency of 97 — 98% and was approximately 90%.

CFD and Physical Model Study

With the WFGD system experiencing solids deposition on the inlet duct and concern about ID fan capacity, a physical model and a CFD model were constructed in an attempt to optimize the gas side of the WFGD system. The goals of the CFD and physical model studies are defined below:

1. Evaluate absorber inlet duct modifications to move the wet/dry interface away from the inlet duct. These modifications include adding a "false roof" and sidewalls to the flared inlet duct as well as an inlet hood over the inlet duct penetration.

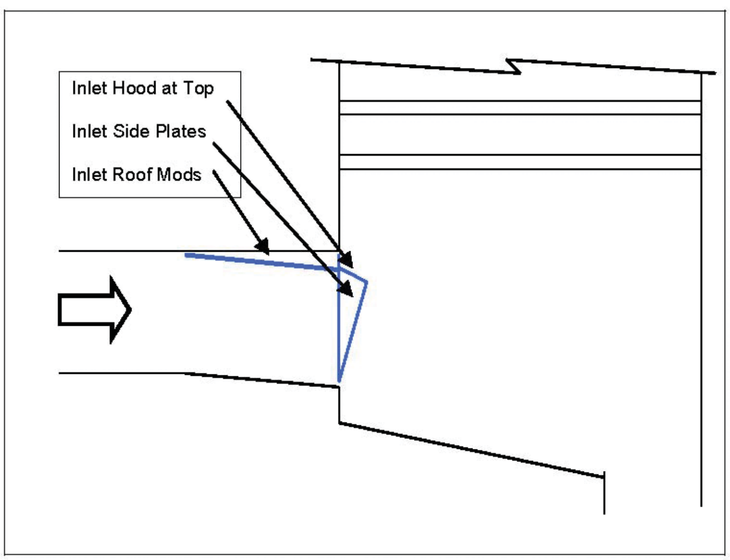

Figure 5. BPEI Proposed Inlet Duct Modifications

2. Evaluate the existing and new flow controls for the inlet plenum to improve flow distributions to the absorbers and reduce the overall gas side pressure drop. This is to include an evaluation of the installed perforated plates to see if they can be removed or replaced with a more open plate.

 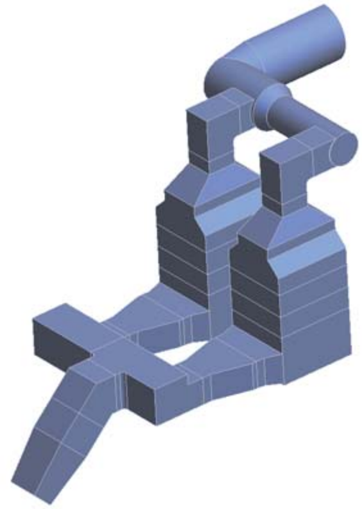

Figure 6. Physical and CFD Models

3. Model the BPEI designed wall baffles for pressure loss and flow distribution.

After the completion of the models and nine model modifications between the two, the study produced the following results.

1. The proposed inlet redesign by BPEI with a false roof and an inlet hood reduces the amount of flow bouncing off of the floor and recirculating back to the inlet duct.

2. There still exists a small backflow zone on the floor of the absorber inlet duct, most likely due to the unequal flooring which creates a low pressure zone above the drain into the reaction tank.

3. A flow bias exists within the absorber with higher flows on the outboard and rear walls. This is most likely due to the unequal floor, which is shallow along the outboard wall and deep along the inboard wall.

4. The installed perforated plates provided the best distribution of gas flow between the four absorbers as well as the best rms % for velocity distribution at the absorber inlet.

5. The installed wall baffles were successful in diverting gas from the walls to the center. The test cases with baffles also showed an increase in flow along the front wall when compared to the test cases without baffles. In addition, the measured pressure loss of the baffles was 0.06 iwg.

Spray Nozzle Characterization and Selection

One of the major components was to install new dual direction (up and down on the bottom 4 levels and a double orifice down on the top level) wider-angle spray nozzles in all of the absorbers. By providing a nozzle with the same flow and pressure loss characteristics, but with twice the orifices, the number of droplets increases creating more surface area and, therefore, increased overall mass transfer. To ensure complete coverage of droplets within the vessel, the new interior nozzles would also have a 120° spray angle instead of a 90° angle.

To design a new spray nozzle that does not impact the recycle pump operation, a spare existing nozzle was independently tested. The results produced the required pressure and droplet size for the appropriate flow. These values could then be provided to design the new replacement nozzles so that the recycle pump operation would remain the same. This was particularly important as it was not desirable to increase the velocity in the recycle lines above the design velocity of 9 ft/s and introduce additional sprayed liquid that would lead to higher gas-side pressure drop through the absorber.

Wall Baffle Design

All open spray towers are designed such that there is some degree of spray overlap to optimize the liquid-gas interaction. However, due to the absorber geometry and spray nozzle layout, this level of overlap is not achievable along the walls. This lack of overlap leads to a less dense spray zone at the wall, which in turn leads to less resistance and higher gas flows along the perimeter of the absorber. The increased flow causes the spray along the wall to be less efficient and, therefore, lead to a decrease in overall removal efficiency. This effect is known by multiple names, which include “gas sneakage” and “wall effect”.

Based on BPEI’s previous experience and success with the Culley WFGD upgrade[2], wall baffles were designed and installed in Trimble Unit 1’s four absorbers. These baffles were designed such that the gas from the walls and the corners of the square absorbers would be deflected back to the denser spray coverage of the interior spray zone. This design would ensure that 100% of the flue gas would be treated.

Process Audit and Chemistry Evaluation

One of the last items to be completed in the upgrade of the Trimble 1 WFGD was an evaluation of the absorber chemistry. With all installed equipment operating, a small interruption in operation or an equipment failure can be devastating to the system removal efficiency. In an effort to prevent such events from happening, BPEI performed an audit of the existing system, which included a process chemistry evaluation.

To properly evaluate the absorber chemistry, a compilation of the plants’ chemical analyses for the absorber slurry, make-up water, and limestone slurry for the previous five years was reviewed. In addition, an Oxidation-Reduction Potential (ORP) meter was used so that as future absorber slurry samples were taken; the ORP of the absorber slurry could be measured. This measurement is useful in qualitatively verifying sufficient oxidation air flow as well as good distribution throughout the reaction tank. While these items were done in parallel to the absorber and duct modifications, they produced results that would benefit future operation.

1. Overall the installed equipment is sufficient to meet the removal requirements. However, as indicated in the model study results, the layout and design of the floor of the absorber may cause some continued solids deposition in the inlets. Solids deposition could cause problems, as the drains from the absorbers are located directly above the recycle pump suctions. With this relative location, any deposited solids that are blown into the absorber drains are likely to be taken in by the recycle pumps. This could lead to excessive wear or even spray nozzle pluggage.

2. The reaction tank chemistry is in good standing. Both chemical analysis and ORP measurements indicate that the absorber slurry is well oxidized and that both the oxidation air and agitation systems are sufficient for future operation.

3. While the absorber chemistry is good, it was discovered that the water used for washing the mist eliminators was of poor quality and had a high potential for scaling. The water used was saturated with many dissolved salts some of which were predicted to plate out during the wash cycle. To remedy this problem, an existing fresh water connection on the mist eliminator wash tank was used to provide better quality wash water.

UPGRADE RESULTS

In November of 2005, the Trimble 1 WFGD system started up with the new modifications for the first time. After the system completed its start-up, the performance of the upgrades was to be tested. However, since the reaction tanks were empty and the system started up from a tank with only water with small concentrations of limestone, the reaction tanks had to come to equilibrium first. To verify the system was in equilibrium, extensive amounts of control room as well as local data were collected. After it was determined that the system had reached equilibrium, the system was tested so that the performance of the upgrades could be verified.

Initial Performance Testing

The initial performance testing of the upgraded unit was done to verify that the installed modifications met the guaranteed performance when operating under the design conditions. To do so, BPEI conducted multiple tests that met the plants' requirements and were in compliance with EPA 40 CFR 60 Test Method 193 to determine the removal efficiency of the upgraded WFGD.

Table 1

Initial Performance Testing Results of the Trimble 1 WFGD Upgrade

Test Description	Fuel Bound SO_2	CEMs Emission	WFGD SO_2 Removal Efficiency
5 Level Operation (All Levels on All Absorbers)	6.61 lbs/MMBtu	0.049 lbs/MMBtu	99.3%
4 Level Operation (Bottom 4 Levels on Each Absorber)	6.42 lbs/MMBtu	0.190 lbs/MMBtu	97.0%
4 Level Operation (Top 4 Levels on Each Absorber)	6.64 lbs/MMBtu	0.135 lbs/MMbtu	98.0%
Unbalanced (1 Bottom Level Out on 1 Absorber)	6.64 lbs/MMBtu	0.071 lbs/MMBtu	98.9%
Unbalanced (1 Top Level Out on 1 Absorber)	6.64 lbs/MMBtu	0.086 lbs/MMBtu	98.7%

As Table 1 illustrates, when operating with all installed equipment (the upgrade design basis), the WFGD not only met the required 98% removal, it exceeded it while operating with a higher than design inlet SO_2. In addition to the performance case, multiple other tests were conducted to verify the operation should there be recycle pump failures. Since the design of the system is to operate with all installed equipment, any loss of recycle pumps will cause the emissions to increase. These tests will be essential in predicting emissions for such periods. As the data show, only one test case, the lower four levels on each absorber operating, is below 98% reduction.

90-Day Performance Testing

The next step in verifying the performance of the upgrade was to once again test the system after 90 days of operation. This test would verify that the initial operation data was not biased with little operating history. The 90-day performance test was a more concise test but was conducted in a similar fashion to the initial performance testing.

Table 2

90-Day Performance Test Results for the Trimble 1 WFGD Upgrade

Test Description	Fuel Bound SO_2	CEMs Emission	WFGD SO_2 Removal Efficiency
5 Level Operation (All Levels & All Absorbers)	6.61 lbs/MMBtu	0.052 lbs/MMBtu	99.2%

Like the initial performance test results, the 90-Day performance test results showed a performance of the WFGD upgrade exceeding expectations. While the performance decreased slightly, the overall removal efficiency well exceeded the required 98% reduction of a 5.5 lbs/MMBtu SO_2 inlet.

Long-Term Performance (EPA Reported SO_2 Emission Data)

As was done previously in determining the system's operating history, SO_2 emission data from the EPA website was compiled. This time, the data were collected for a comparison of the "before and after" WFGD performance and so that the long-term performance could be viewed.

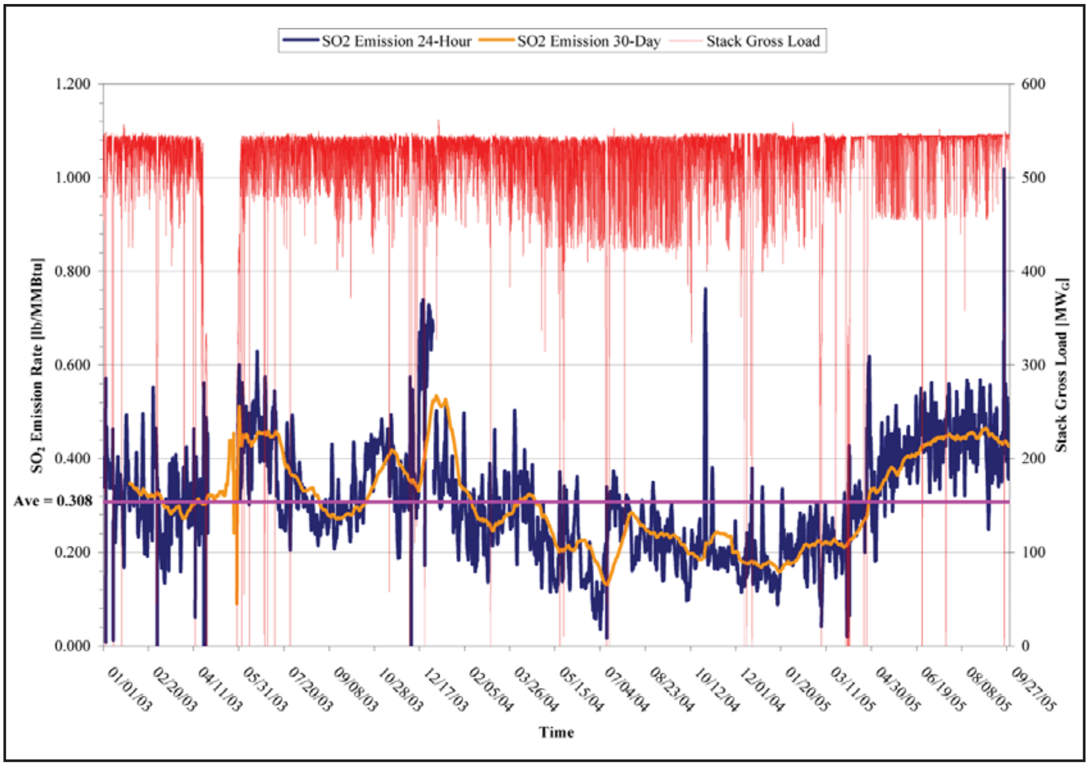

Figure 7. Trimble 1 SO_2 Emissions Data (2003 — 2005)

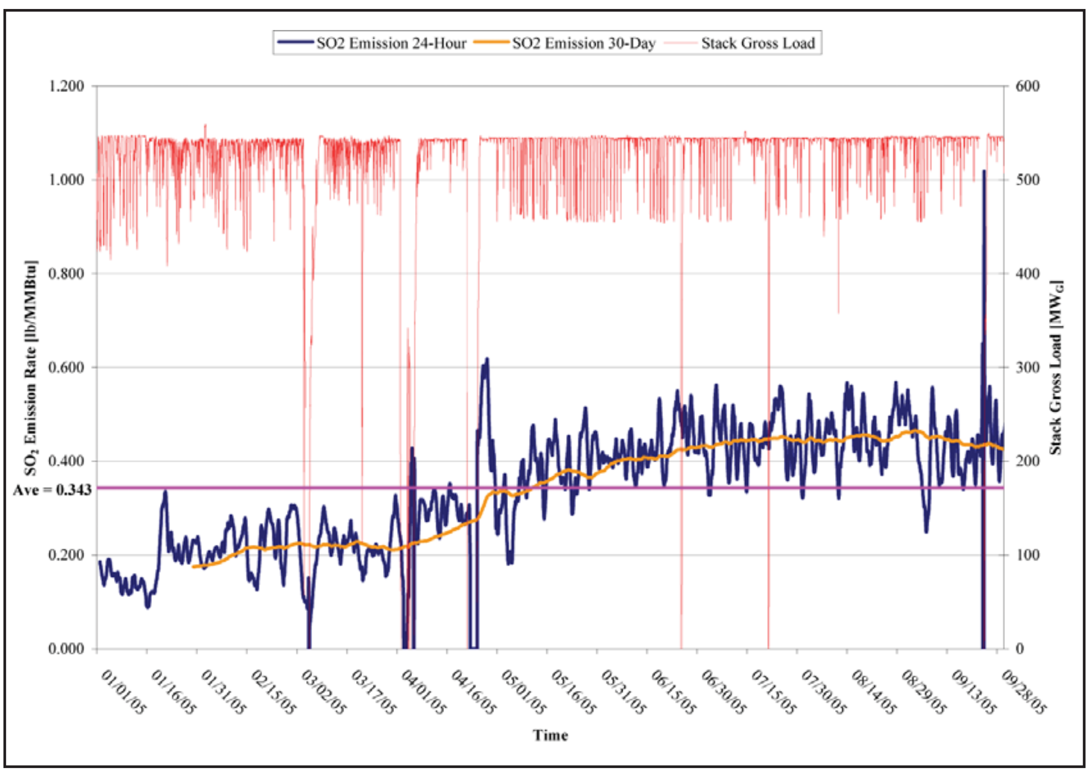

Figure 8. Trimble 1 SO_2 Emissions Prior to Upgrade (2005)

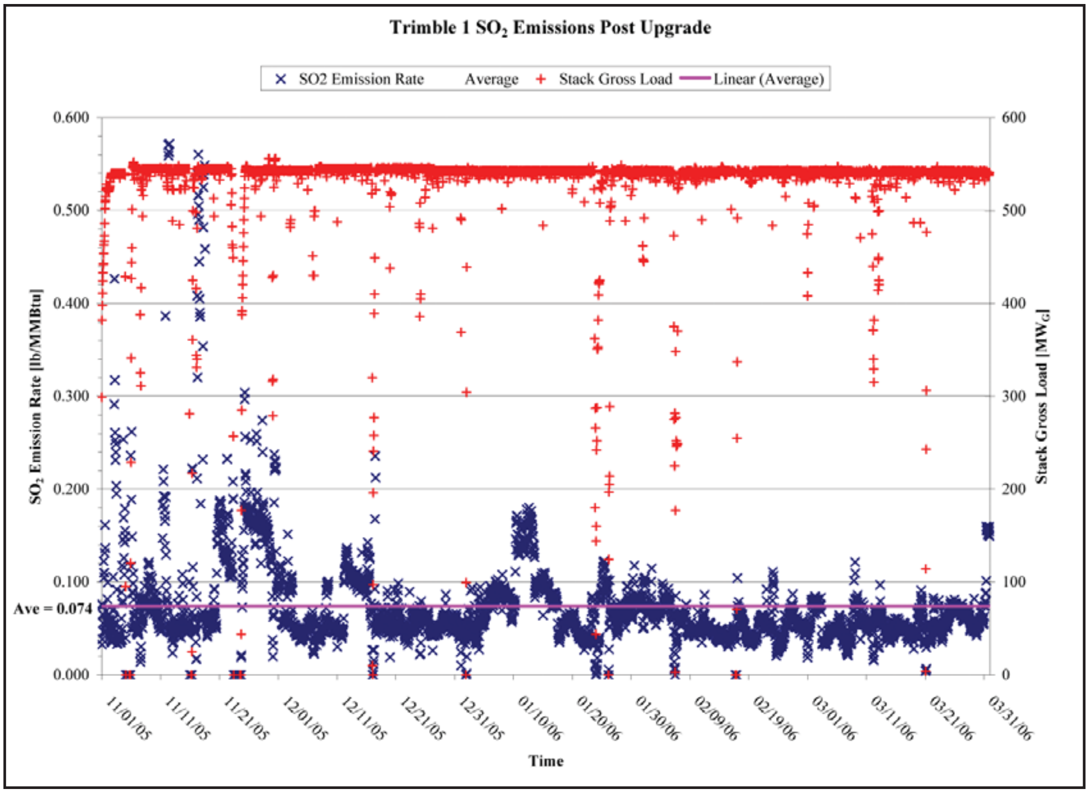

Figure 9. Trimble 1 SO_2 Emissions Post Upgrade

Figures 7 and 8 both show the operating history from 2003 up to the installation of the upgrade, as well as, the 2005 operating history prior to the upgrade. Figure 9 shows the SO_2 emission history of the upgraded WFGD system. As it can be seen in Figure 9, the start-up of the WFGD system was unstable as is typical after an outage. This instability is primarily due to additional required maintenance in one reaction tank. Because of this, the WFGD was started up with only two absorbers and one reaction tank in operation instead of four absorbers and two reaction tanks. After approximately one month of operation and all absorbers operating, the system settled out and with the exception of two excursions, the emissions remained between 0.05 and 0.1 lbs/MMBtu. It should be noted that after the system stabilization, neither the 24-hour average nor the 30-day rolling average exceeded the 0.17 lbs/MMBtu limit with the overall average for the upgraded scrubber being 0.074 lbs/MMBtu.

Table 3

Trimble 1 SO_2 Emissions Data

Period	Average SO_2 Emissions
2003	0.357 lbs/MMBtu
2004	0.240 lbs/MMBtu
2005 — Prior to Upgrade	0.343 lbs/MMBtu
2003 to 2005 — Prior to Upgrade	0.308 lbs/MMBtu
Post Upgrade	0.074 lbs/MMBtu

As illustrated in Table 3, the WFGD performance has been maintained at a consistent high efficiency level. Prior to the upgrade, small periods of exceptional performance could be seen as the emissions at times were below 0.1 lbs/MMBtu. However, this performance was not maintainable as the averages for the analyzed periods all exceed 0.2 lbs/MMBtu. The post-upgrade data shows the opposite effect. The majority of the data is well below 0.1 lbs/MMBtu with only brief periods of less efficient performance.

CONCLUSIONS

The Trimble 1 WFGD upgrade project was successful in meeting its performance goals. Not only did it achieve sustainable high removal efficiency, but it also allows for a high efficiency when one or more spray levels are inactive. While only five months of operating data were available at the time of this paper, it is expected that with the current maintenance and continuous improvement efforts, good results will continue to be achieved. It should be noted that this testing period occurred immediately following a planned maintenance outage. The unit will remain in continuous operation until the next planned outage. Although some performance degradation may occur during this long period of run, it appears that the unit should be able to achieve a long-term removal efficiency of 98% or better. The achievements of this project were made possible by a careful evaluation of a problem with a foreign system and applying current technology and knowledge in developing a solution.

Future Recommendations

Throughout this paper, multiple areas of improvement have been identified. As the Trimble 1 WFGD continues to operate, ensuring recycle pump operation and maintenance, as well as nozzle and spray header cleanliness are vital to continued peak performance. With potential problem areas in the design of the absorber inlet floors and relative location to the recycle pump this area could cause the performance of the system to decrease. Investigating solutions such as pump suction screens, or drain relocation will help to maintain the pumps and spray levels operating at optimum operating efficiency.

ACKNOWLEDGEMENTS

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