Incinerator Optimization –

How to Save Energy and Reduce CO_2 Emissions

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Abstract

Incinerator optimization, if properly done, has the potential to offer operating companies significant natural gas savings, with the added benefit of reducing CO_2 emissions without installing additional equipment for carbon capture.

Using the learnings from multiple site experiences, ExxonMobil has developed best practices for incinerator optimization that are generic enough that they can be applied to any facility; yet they can be customized to a specific configuration, region, and local environmental regulations.

Following a structured approach led by the technology network sharing teams and the site asset improvement specialists, ExxonMobil sites have been optimizing their incinerator operations under different regulatory jurisdictions around the world. In every case, the sites have saved operating expenses on natural gas, reduced CO_2 and NOx emissions, and lowered the site energy intensity index (EII), while complying with environmental regulations and key process objectives of an incinerator downstream of a sulfur recovery unit (SRU) and tail gas treating unit (TGTU).

This paper will provide additional considerations to Sulphur Experts' recent appeal to the industry to look for optimization opportunities in their incinerators. It will describe methodologies that the sites followed and the results of the incinerator optimization, including natural gas savings. It will also describe some of the hurdles that were faced and potential ways to overcome these barriers and accomplish the proposed optimizations.

At one refinery, the sulfur plant business team worked with the environmental group to reduce the firebox temperature from 1350^{o}F to 1000^{o}F, resulting in significant natural gas savings, reduced greenhouse gas (GHG) emissions, NOx emissions, and energy intensity index (EII). No equipment modifications were required.

In another refinery, using a similar approach, the temperature was reduced from 1200^{o}F to 1000^{o}F. In this refinery, the initial driver for the optimization was a leak of the superheating steam coils.

Two additional refineries also optimized their incinerators in the past few years, and are now operating around 1100^{o}F and 1300^{o}F, respectively. A refinery in the US was the first one in the circuit to conduct incinerator testing and to consistently operate at a lower temperature for many years.

More recently, one more incinerator optimization study was conducted at another refinery, and the results identified energy savings and CO_2 reductions by decreasing the operating temperature from 1400 to 1000°F while reducing excess O_2 from 5% to 3%.

Although some incinerators might have less room for optimization and certain jurisdictions have additional environmental requirements that limit potential optimizations, it is important for the process engineers to investigate what those limits are and, if necessary, to challenge the assumptions that the site might have based on past operations. Incinerator optimization is possible and sharing these experiences with others will hopefully encourage more sites to do this.

I. Introduction

Several years ago, the ExxonMobil sulfur network created best practices for refineries to optimize Sulfur Recovery Unit (SRU) incinerator operations, primarily by reducing incinerator operating temperatures for energy savings. More recently, additional opportunities have been identified, such as minimizing excess O_2 in the stack and reducing CO_2 emissions. The actual energy savings and CO_2 emissions reductions will be unique to each site, depending on equipment design, process conditions, unit configuration, and local regulations.

The primary process objective of a typical sulfur plant incinerator is to oxidize all sulfur-containing compounds (H_2S, COS, CS_2, and sulfur vapor) to SO_2 prior to release into the atmosphere. There are often additional regulatory requirements that may limit the extent of possible optimization; examples include CO, NO_X, VOC, hydrocarbons, and particulate matter concentrations out the stack. Therefore, the key constraint on how much an incinerator can be optimized will be contingent on local environmental requirements. Regarding minimization of excess oxygen in the stack, there can be additional limits established by fired equipment specialist, as it relates to furnace flooding prevention.

II. Incinerator Design Considerations

Time, temperature, and turbulence are the three key parameters to consider for incinerator design. Each of these parameters has an important effect on furnace operations. If any of these parameters is not optimal, the other two parameters must compensate to maintain adequate incinerator performance. During incinerator performance planning, all three parameters need to be considered:

1. Time – This specifically refers to the residence time in the incinerator combustion chamber and must include allowance for both mixing and reaction. Many incinerators are designed to achieve 99% destruction with a residence time of roughly one second, assuming nominal operating temperatures. Residence times of less than one second may require higher temperatures and/or more efficient mixing.

2. Temperature – This is the incinerator operating temperature and is the main parameter to minimize/optimize for energy savings. Based on Sulphur Expert's 2013 presentation[1], assuming 100-200 vppm H_2S in the tail gas to the incinerator, reasonable mixing and 3% excess oxygen, approximate temperatures between 725 – 760°F should be adequate for < 10 vppm H_2S in the stack. Higher temperatures will be required if H_2S content in the tail gas

is > 200 ppm or greater destruction efficiency is needed. It is difficult to combust high CO levels in the tail gas stream and this may require temperatures > 1200°F.

3. <u>Turbulence</u> – This element covers mixing both at the burner and inside the combustion chamber. The burner must be designed to mix air, fuel, and any waste streams present over a wide range of conditions. Additional waste streams may also mix with the "flame" in the combustion chamber itself. Turbulence is determined by the original design, but it can deteriorate as burner components degrade, or when operating conditions change considerably from the original basis.

III. Optimization strategy

Optimization strategy steps can be categorized as short term or long term. From the three key variables for incinerator design, the only parameter that can be optimized in the short term and while the unit is online is temperature. Changing residence time and turbulence would require a unit shutdown and most likely equipment modifications. Reduction of excess O_2 target is another lever to reduce fuel gas firing, and some sites that had already optimized temperature have now initiated efforts to reduce excess O_2.

1. Short Term

1.1. Understand permitted emissions requirement at each site.

This includes the emissions limits for sulfur-containing species (H_2S, SO_2, COS, CS_2) and whether there are additional emissions limits (CO, NO_x, VOCs, Hydrocarbons, etc.). Based on the way the existing permit is written and the willingness of the authorities to negotiate, the site can identify the potential modifications to permitted emissions limits, and there are occasions in which there is some flexibility written into the existing permit that the sites can leverage to optimize without permit modifications.

It is important to determine how the emissions limits are measured and tracked (e.g., CEMS analyzers vs calculated values). There could be indirect parameters that the site monitors to ensure compliance (minimum temperature, excess O_2, other parameters). It is prudent to involve the environmental group early in this process to avoid major recycle and try to leverage network experience from other sites.

1.2. Calculate theoretical savings.

The Sulphur Experts empirical correlation (Sulphur Recovery, Harold G. Paskall and John A. Sames, Seventeenth Edition, Table II, page 550) is an excellent starting point to estimate the minimum temperature that the incinerator can operate to stay below the limits on reduced sulfur species (H_2S, COS, CS_2). The temperature target is established by adding a reasonable cushion to the minimum temperature, and the potential fuel gas savings are calculated by difference of the current fuel gas usage minus the expected fuel gas consumption at the lower temperature, assuming a certain excess O_2 in the flue gas at the stack.

The target excess O_2 in the flue gas should also be optimized, as it will result in further reduction on fuel gas requirements. Most incinerators should be able to operate at an excess O_2 range between 2 to 5 mol%. Operating at higher excess O_2 requires feeding more air than necessary, and this extra flow (including the 79% inert nitrogen content) must be heated up to the incinerator target temperature, resulting in an unnecessary increase in fuel gas demand. There are also jurisdictions where additional incentives to reduce CO_2 are available, and those are calculated by comparing the current CO_2 emissions versus the optimized case CO_2 emissions, and these can be added to the fuel gas savings to estimate the overall credits.

1.3. Optimize operations of the SRU and TGCU

This is an important aspect that is sometimes overlooked, and it includes maximizing COS and CS_2 destruction by operating the first sulfur converter bottom bed temperature around 600-650^oF, as well as operating the tail gas reactor at the recommended temperature depending on the type of catalyst that is used (conventional vs. low temperature tail gas catalyst). In addition, the selective amine section of the TGCU should be operated such that H_2S removal is maximized. This is achieved by setting a steam/feed ratio at the regenerator reboiler, resulting in the lowest practical H_2S lean loading, while maintaining the selective amine circulation at optimal levels to avoid wasteful steam consumption (e.g., avoiding over-circulation).

1.4. Validate instrumentation for reliable readings.

Since the optimization steps are geared towards minimizing excess O_2 and temperature at the incinerator, it is essential that the O_2 analyzer and the temperature indicators are reliable. Moreover, the fuel gas and air flow meters (forced draft incinerators) need to be calibrated and ranged adequately for the target incinerator conditions. In some cases, it might be necessary to re-range or recalibrate instruments, or even to replace flow control valves that are more adequate to the optimized range of operations. For natural draft incinerators, there might be practical limitations on how much the excess O_2 can be reduced, as it will require field operators to do manual adjustments of the air registers; the air damper sometimes can be controlled remotely.

1.5. Calculate residence time.

Residence time for most incinerators is in the range of 0.6 to 1.0 seconds, and it can be estimated for a particular site by calculating the incinerator chamber volume and dividing it by the volumetric flow rate.

1.6. Conduct field observations.

This is an important step to maximize the overall optimization effort. It includes ensuring adequate placement of instrumentation, checking the appearance of the flame, confirming that the fuel gas quality (e.g., composition, BTU value, etc.) is not fluctuating significantly, and looking for air leaks. Some sites have unique configurations that might require additional verifications.

2. Long Term

2.1. Stack Testing

There are several companies that can carry out stack testing. The environmental department can provide guidance as to which vendors are certified for stack testing. Since stack testing happens very infrequently, the site needs to create a test plan and stack testing results should be documented for future reference. Below are some important considerations to keep in mind while creating the test plan:

- Notifications to all applicable environmental regulatory agencies prior to conducting the test; this will help to explain potential abnormal operations or exceedances during the test.

- Monitoring SRU operations, flame stability, process air, tail gas flow rate and composition, vibrations, etc.
- Discussion of temporary deviations of documented unit limits or operating envelopes while performing the test to maximize value of the test.
- Obtaining test plan endorsement from operations and environmental department.
- Leveraging stack testing experiences from other sites.

Below are some of the questions that stack testing can help to elucidate:

- Can the incinerator operate at optimal conditions?
- Can it meet all emissions limits at the new conditions?
- Do the kinetic factors used in theoretical combustion calculations need to be adjusted?
- How much fuel is saved at the new conditions?

2.2. Computational Fluid Dynamics (CFD) Modeling

To determine if there is enough mixing/turbulence for combustion at the incinerator, computational fluid dynamics (CFD) can be a useful tool, as it can track the concentrations of key components, such as hydrocarbons, nitrogen, oxygen, hydrogen, water, hydrogen sulfide, and sulfur dioxide. Some companies have in-house CFD capabilities and there are also specialists in the industry. CFD modeling takes time, and it can be expensive, depending on the number of cases that need to be run. The results can be used to redesign the burner or the incinerator chamber internals for improved mixing.

IV. Examples

Refinery #1

A refinery in the US was the first one to systematically approach incinerator optimization, even before the creation of the network best practices. They improved air controls to help minimize excess O_2 at one of their Sulfur Recovery Unit incinerators. A comprehensive stack testing plan was formulated to obtain the necessary data to support a plan to lower the operating incinerator temperature from 1200^{o}F to 1000^{o}F, while still meeting emissions limits. The testing was successful, and the refinery has been consistently operating at 1000^{o}F for the past many years, with the associated energy savings. They have also managed to keep excess O_2 around 3%.

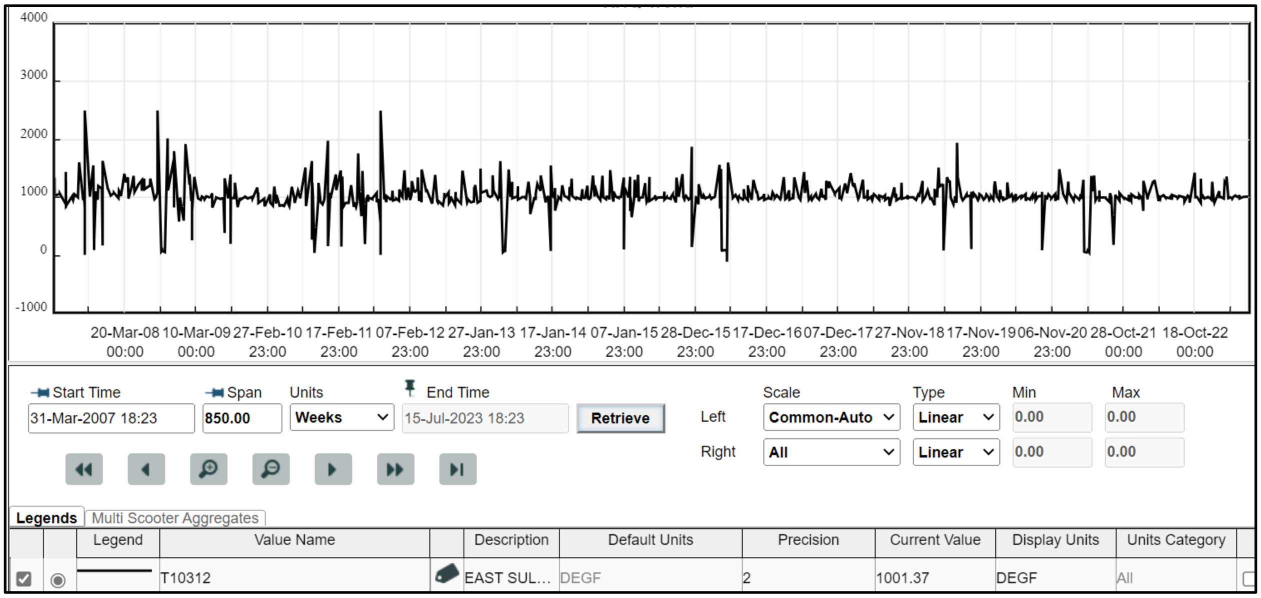

Figure 1. Incinerator firebox temperature trend for Refinery 1

Refinery #2

Another US refinery had operated their SRU thermal oxidizer (ThOx) above 1350°F for many years. The technical support team worked with the business team to conduct a firebox temperature reduction study in the 1050-1350°F range, consisting in a gradual reduction of the temperature with several hold points to allow the fired heater team to conduct flue gas sampling and measurement of O_2, CO, and NO_X concentrations using portable analyzers (Testo); at two of these hold points, H_2S concentration was measured by Draeger tubes. Testo and CEMS oxygen data trended very closely (see parity plot below).

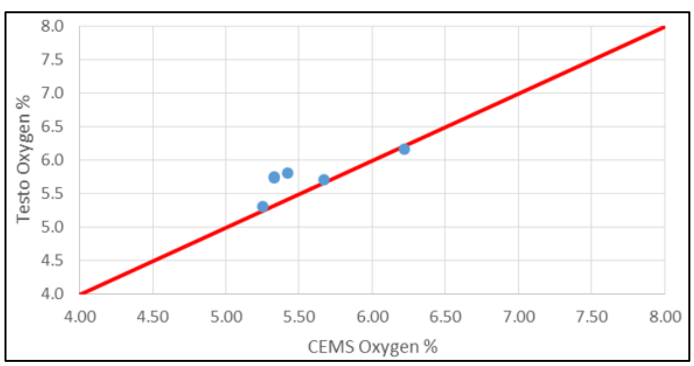

Figure 2. Portable analyzer (Testo) vs. CEMS O_2 of Refinery #2 ThOx

CO concentrations trended linearly with firebox temperature. The technical team then challenged the environmental group, and the discussions unveiled that the SRU ThOx emissions were covered by a site wide CO "flex permit" (tons CO/yr.). Further investigation revealed that the site had been operating, in average, at less than 25% of this limit for the past 10 years. Therefore, despite the decrease in CO conversion at lower ThOx temperatures, the CO emissions would not risk exceeding the CO flex permit and there was a reduction in CO_2 emissions.

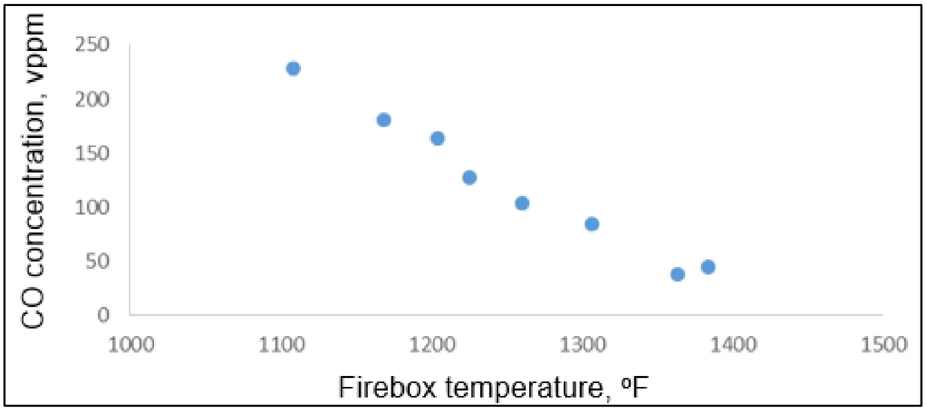

Figure 3. CO concentration as a function of firebox temperature of Refinery #2 ThOx

Utilizing this information and having a minimum required temperature on the thermal oxidizer at 950°F, set by the current refinery permit, the site was able to establish a target ThOx operating temperature of 1050°F. The natural gas to the ThOx was decreased by about 30%, resulting in significant operating expenses (OpEx) savings and a reduction of 0.6 EII (energy intensity index). There is also the added benefit of reduced NO_X emissions, as NO_X formation hardly occurs at these lower temperatures.

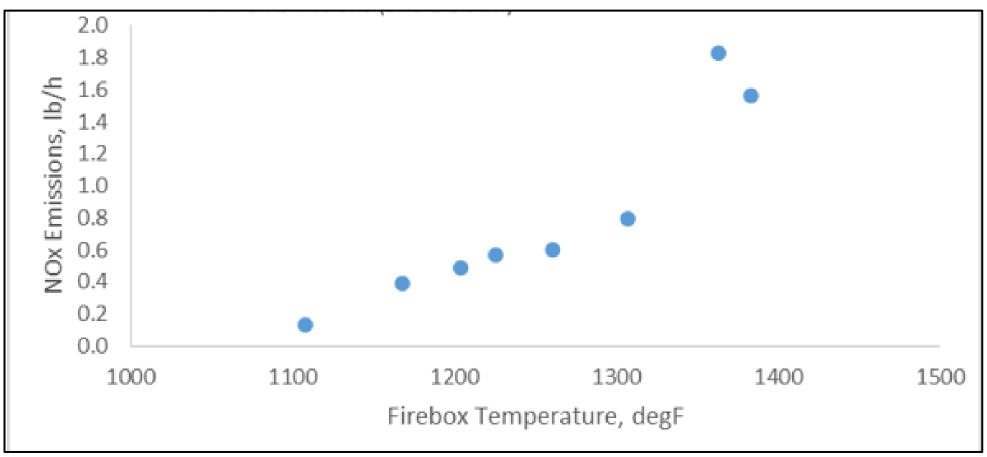

Figure 4. NOx emissions as a function of firebox temperature of Refinery #2 ThOx

Recent efforts are underway to reduce the excess O_2 from 6% to 2%. There are plans to conduct a step test to reduce excess O_2 by reducing the air louver percent output.

Refinery #3

Another US refinery has two incinerators (thermal oxidizers or ThOx, for short) equipped with a waste heat boiler and coils to superheat 600# steam generated by the heat of the incinerator. Each sulfur plant has a steam-driven air-blower which uses superheated 600# steam. One of the coils experienced a leak, and steam entered the stack and gave the appearance of a plume. This situation forced a bypass of the coils, thus stopping the generation of superheated 600# steam. Figure 5 shows that the ThOx process flow sequence went from the firebox, through the superheater coils, the waste heat boiler, and the stack.

As the coils were bypassed, the waste heat boiler would be exposed to higher temperatures, and the mechanical engineer expressed concerns about operating above 1050°F during the months leading to the turnaround.

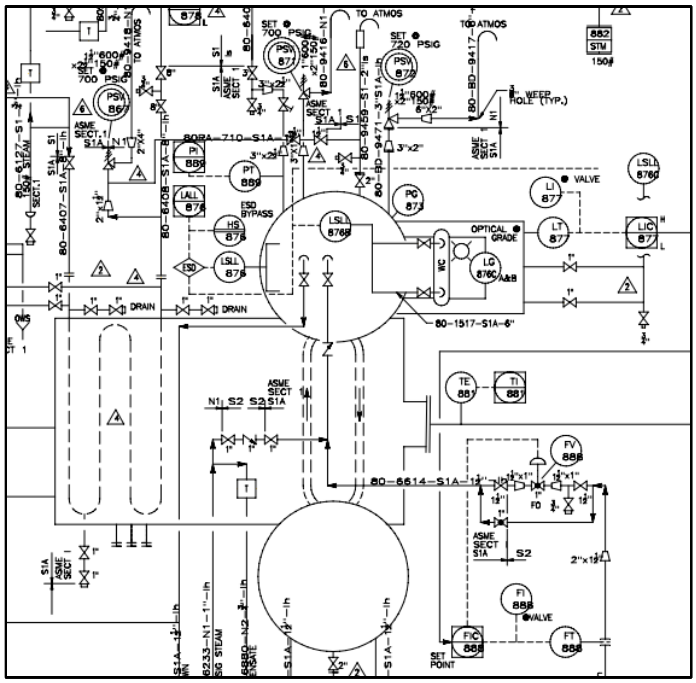

Figure 5. Refinery #3 ThOx Superheater Coils and Waste Heat Boiler Schematic

The technical team worked on getting a new set of superheater coils with improved metallurgy, establishing minimum flow requirements on the coils, and installing skin temperatures on the coils for better monitoring during the next scheduled unit outage. Meanwhile, there was a parallel effort to temporarily lower the ThOx firebox temperature below 1050°F, to prevent potential damage to the waste heat boiler. This concern became the main driver to pursue incinerator optimization at the site.

Two different vendors were brought to the refinery to conduct stack testing. The first round of testing covered the 1100 to 1300°F range. The lower operating envelope limit was set at 1000°F. The CO emissions were acceptable in the range of the testing along with a reduction in CO_2 emissions.

The additional round of stack testing was done in the 1000-1100°F range to enable consistent operations at the 1050°F target temperature that the fixed equipment engineer had recommended for waste heat boiler reliability. This was successful and the site was able to operate at the 1050°F target until the planned turnaround. Once the new superheater coils were installed and the unit was started back up, the technical team was able to convince the business team to continue operating at 1050°F for energy savings. The site also established an excess O_2 target at 2-3%, after validating with fired equipment specialists, for additional energy savings. These incinerators were forced draft, with dedicated air blowers for each SRU train.

Refinery #4

A refinery in Europe has operated their incinerator at a temperature of 770-800°C and 5% excess O_2. An opportunity to reduce the severity was identified by the technical support team. Operating the incinerator at lower temperatures will reduce fuel gas consumption and GHG (greenhouse gas) emissions. The estimated yearly benefit for this site is substantial. Most of these savings originate from the reduction in fuel gas consumption. An evaluation was conducted to examine the technical feasibility of operating at lower temperature while maintaining H_2S and CO emission limits. The conclusion of this evaluation was that it was possible to reduce the temperature to 570°C and the excess oxygen to 3% with no negative impact to the overall emissions. This study also estimated the sulfuric acid dew point, sulfurous acid dew point, and water dew point for the new conditions to ensure that they would not be a concern for corrosion at the stack.

Refinery #5

A refinery in Canada conducted an emission testing program at their SRU incinerator. The minister of environment (MOE) required a relative accuracy test (RATA) to approve operation at lower temperatures. They conducted tests for a range of operating temperatures of 1250-1600°F. They measured reduced sulfur compounds, flow, SO_2, and moisture. This refinery did not have a tail gas treating unit, and their normal incinerator operating temperature was 1600°F. The testing included data points separated by about 50°F, giving the unit enough time to stabilize before proceeding to the next step. As one would expect, there was no significant difference in the amount of total reduced sulfur and SO_2 in this temperature range. There was a considerable incentive to reduce operating temperature. Since that test, they have been operating around 1300°F, and it might be possible to further optimize, as the current operating temperature is still higher than the other refineries that have gone through incinerator optimization efforts. The excess O_2 was also optimized with reduced CO_2 emissions; this incinerator is forced draft.

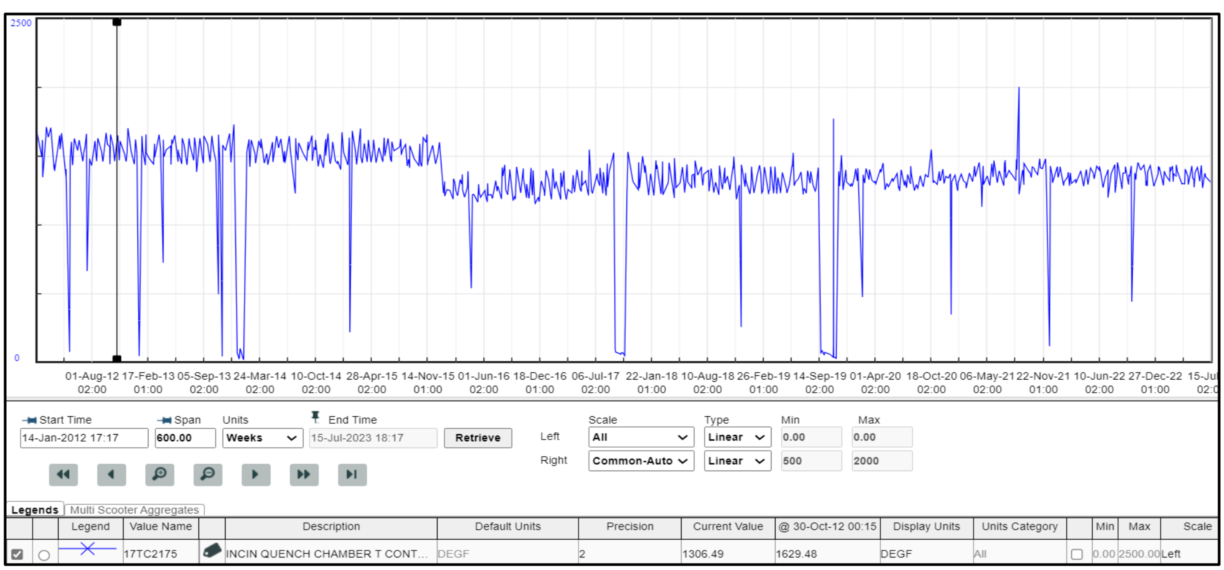

Figure 6. Refinery #5 Incinerator Temperature trend for the past 10 years

Other opportunities

Refinery #6

The final example required equipment modifications and did not involve a reduction in operating temperature, but it is still an interesting case study on how computational fluid dynamics (CFD) can be used to identify equipment modifications that can improve incinerator performance. The refinery used CFD modeling to identify incinerator internals modifications to improve mixing in a 240 LT/day sulfur recovery unit, thus avoiding a costly capital project that would have required relocation of the tail gas outlet nozzle to improve residence time.

The residence time before the modifications was < 0.6 sec., and there were incinerator outlet radial temperature variations of > 100°C, resulting in H_2S breakthrough ranging from 80 to 100 vppm at the stack. The figures below show the before and after CFD temperature profiles, which clearly show the significant improvement in temperature profile uniformity. The CFD predictions were validated by actual data after the modifications were implemented.

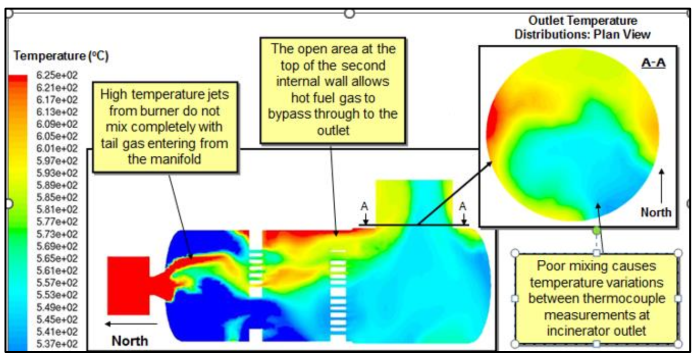

Figure 7. CFD modeling of Refinery #6 SRU incinerator – Before internal modifications.

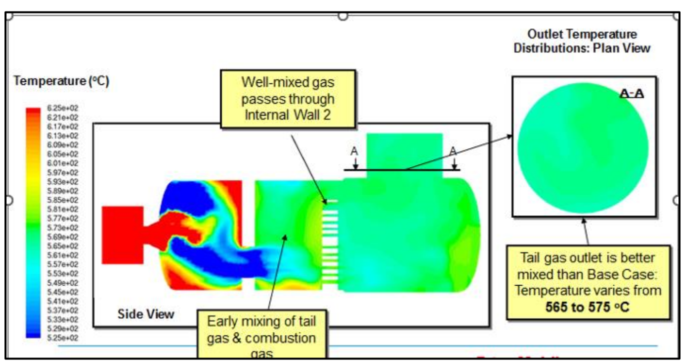

Figure 8. CFD modeling of Refinery #6 SRU incinerator – After internal modifications.

V. Conclusion

This paper has explained the business case for pursuing SRU incinerator optimization, and it has offered an overview of incinerator design considerations, and the methodologies that ExxonMobil has used to systematically carry out achievable incinerator optimization efforts at different refineries around the world. Several case studies have been presented, including examples of the site-specific motivations to do the optimization, estimated natural gas savings achieved, and some of the other benefits that can be considered, such as reduction in energy intensity index (EII), and CO_2 emissions reductions.

These examples were intended to provide a flavor of the considerations, decisions, and potential roadblocks that others might find when trying to optimize their incinerators. Most of the examples shown in this paper were traditional incinerators processing tail gas from a Claus SRU, followed by amine based TGCUs, but there was an example of a Claus SRU directly feeding an incinerator.

The main intent of this paper is to provide motivation for the industry to further pursue incinerator optimizations. The natural gas savings can be substantial; there will be a reduction in CO_2 and NOx emissions by operating at lower temperatures, and the refinery energy intensity index (EII) will also decrease. In many cases, no equipment modifications are required.

VI. References

1. Sulphur Plant Incineration, 2013, presented by Gerald Bohme (Sulphur Experts) on 21-Aug-2013 during ExxonMobil sulfur/amine network meeting in Las Vegas, NV.
2. Sulphur Recovery, Harold G. Paskall and John A. Sames, Seventeenth Edition, Table II, page 550.