Sulfur Tail Gas Thermal Oxidizer Systems

By Peter Pickard

Introduction

SRU's (Sulfur Recovery Units) are critical pieces of equipment in refineries and gas plants. SRUs remove sulfur compounds from certain fuel gases produced during crude oil refining and from natural gas. SRUs produce elemental sulfur and various gas waste streams. These waste streams must be destroyed to prevent environmental and health risks. Thermal oxidizers, or "incinerators" as they are also known, have been used for many years to oxidize remaining H_2S, CO and other minor combustibles in these waste streams. This article discusses various particular design features of sulfur tail gas oxidizers.

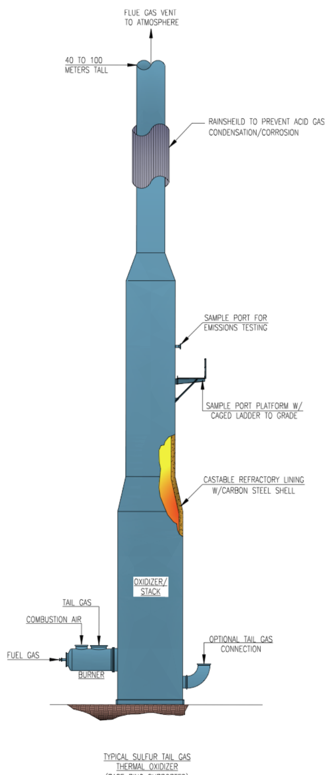

Figure 1. Typical sulfur tail gas thermal oxidizer (base ring supported)

Waste Characterization/Emissions

The primary waste stream from an SRU is the sulfur tail gas stream. There are other waste streams variously called "pit vent", "sweep air", etc. These other waste streams have very low mass flow compared to the tail gas stream and are not a major design consideration. These waste streams can be injected into the oxidizing chamber somewhere downstream of the burner.

H_2S, sulfur vapor, SO_2, COS and CS_2 in the waste is oxidized (or burned) in the thermal oxidizer to form SO_2 and a small amount of SO_3 in the flue gas. SOx in the flue gas is an environmental and a corrosion design concern. Unless the flue gas is treated with a downstream scrubber, which is very rare, all the SOx will exit the stack. Therefore, it is important to note that while a thermal oxidizer can control the amount of sulfur compounds mentioned above, it cannot control SOx emissions. The SOx emissions are completely determined by the sulfur content in the incoming waste.

The primary purpose of a sulfur tail gas oxidizer is to destroy H_2S because it is a highly toxic gas, even in low concentrations. The specified H_2S emission limit from an oxidizer typically varies from 5 to 10 ppmv.

In many cases, CO emissions limits are also specified. H_2S is much easier to burn than CO. H_2S autoignition temperature is 529 ºF (276 ºC). CO autoignition temperature is 1166 ºF (630 ºC). Emissions of CO are typically not guaranteed by an oxidizer manufacturer unless the operating temperature is above 1400 ºF (760 ºC). As with any combustion system, the higher the operating temperature, the lower the CO emissions. However, a higher operating temperature can result in higher NOx emissions.

Low NOx fired heater burner technology is frequently confused with the capability of a thermal oxidizer burner. Ultra-low NOx burner technology used for fired heaters can not be applied to burners for thermal oxidizers. The widely varying applications encountered in the supply of thermal oxidizers require a different design approach than that used for fired heater burners.

For example, the use of flue gas recirculation for NOx reduction is vastly different for fired heater burners than for thermal oxidizer burners. Flue gas recirculation associated with fired heater burners is internal to the heater. However, flue gas recirculation associated with a thermal oxidizer would have to be external to the combustion chamber. The reason for external recirculation is due to the fact that the thermal oxidizer combustion chamber is lined with refractory (without a heat sink) eliminating the availability of cooled flue gas for internal flue gas recirculation.

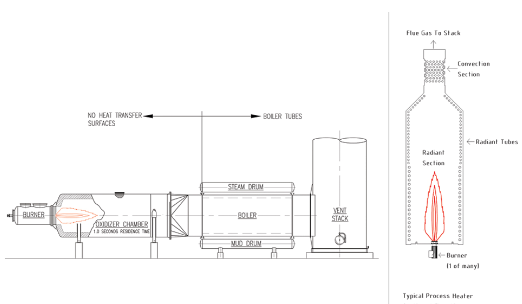

Figure 2. Comparison of fired heater burner and thermal oxidizer burner

Only in thermal oxidizer applications utilizing a waste heat boiler downstream can one employ flue gas recirculation for NOx reduction in a thermal oxidizer external to the burner and oxidizer chamber. This is commonly known as, "external flue gas recirculation". A slip stream of the flue gas downstream of the boiler can be recirculated back to the burner via a recycle fan. However, the ducting, electrical power usage, larger plot space required and more complicated burner make this approach quite expensive and therefore rare.

The NOx emissions from a thermal oxidizer will depend on various factors such as the allowable CO emission limit, the CO content in the tail gas, the fuel gas composition, the waste gas composition and burner design. Typically, the NOx emissions will range from 0.06 to 0.1 pound of NOx per 1,000,000 Btu of heat released.

Although flue gas recirculation cannot be used to lower NOx emissions, Callidus has developed a "tool kit" of thermal oxidizer burner design techniques over the years. All these methods involve a way to lower the flame temperature and may include such things as staged fuel gas combustion, water injection and steam injection. These techniques have been used for many years by several companies. Callidus also has several other proprietary techniques to reduce NOx levels. These designs involve the various ways tail gas can be used to cool the flame. Care must be taken in how tail gas is used to cool the flame. If the flame is cooled too much, CO emissions may increase. Experience, coupled with computational fluid dynamic modeling can result in designs that can lower NOx by 10 to 20%

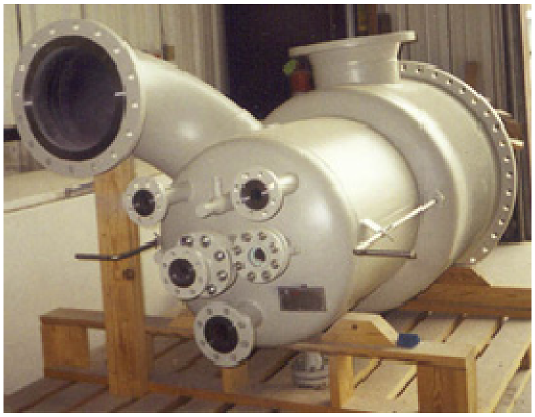

Figure 3. Typical tail gas incinerator burner

Corrosion
Due to the presence of SOx in the flue gas, care must be taken to prevent the steel shell of the oxidizer from getting below the dew point of the acid gas. Sulfuric acid can condense at very high temperature in flue gas. The acid gas dew point in the flue gas from a sulfur tail gas incinerator is typically between 300 and 350 ºF (177º C). Since thermal oxidizers furnaces are typically carbon steel with a castable or brick refractory lining, care must be taken to keep the steel temperature about 50 ºF (28 ºC) above the dew point in order to avoid corrosion from dew point condensation. If it is not possible to keep the above the dew point, a coal tar mastic lining or other high temperature acid resistant paint can be applied to the internal surface of the carbon steel shell before the refractory is installed. Although coatings are helpful, it only takes a small imperfection in the coating to allow acid to penetrate and cause corrosion. Therefore, maintaining the temperature of the steel above the dew point is the most reliable approach to prevent corrosion.

To maintain steel shell temperature above SOx dew point, a thermal shroud is generally installed around the shell of the oxidizer. This shroud is typically aluminum or galvanized carbon steel and stands off from the shell by 3 to 6 inches (75 to 150 mm). This shroud also called a "rain shield" maintains a warm layer of slow-moving air between the shroud and the shell that keeps the steel hot but not as hot as external insulation. External insulation would result in temperatures beyond the oxidizing temperature of carbon steel.

Physical Orientation
Oxidizers are usually vertical with horizontally fired burners. Due to the potential presence of liquid sulfur in the tail gas, the burner orientation is horizontal to allow the sulfur to drain into the bottom of the incinerator vessel. Vertical, up-fired burners are never recommended since the liquid sulfur could pool at the bottom of the chamber and fall into the combustion air plenum of the burner.

Due to the presence of SOx in the flue gas, the stack outlet on sulfur tail gas oxidizers is typically 150 feet (46 meters) or more above grade. The height of the stack is dictated by a dispersion analysis for ground level concentration of SOx. Environmental regulations dictate acceptable ground level concentrations. In order to perform an accurate dispersion model analysis, knowledge of the surrounding terrain and adjacent structures is necessary.

The stack and thermal oxidizer chamber are in many instances the same vessel. Stacks are typically self-supported by the base ring but in some cases are derrick supported. Some of the derrick supported designs will be less expensive but will require larger plot space and more time to assemble in the field.

For large capacity systems, the oxidizer chamber is horizontal. If a vertical design were used, it would result in fuel gas flame impingement on the refractory wall opposite the horizontally fired burner. This is especially true if the burner is natural draft since the flame will be longer than in a forced draft system.

Figure 4. Tail gas incinerator with a flare

Forced Draft vs. Natural Draft
Burners can be natural draft or forced draft depending on turndown requirements and whether or not waste heat recovery equipment is located downstream. It is generally not acceptable to supply a natural draft burner for a system with heat recovery. The pressure drop of the flue gas through a superheater or waste heat recovery boiler is usually too great for natural draft alone to overcome. The combustion air turndown available in a natural draft unit is lower than in a forced draft system. Combustion air turndown limits fuel gas burner turndown which limits tail gas turndown. Combustion air turndown in a natural draft unit is between 2:1 and 3:1 depending on the stack height.

HI (High Intensity) Burners
High intensity burners require high combustion air pressure drop, typically around 1.5 psig (10.3 kPa). The design causes the combustion air to swirl increasing turbulence downstream. This type of burner, although rarely used by tail gas incineration, is frequently used in applications in which it is important to have a short flame and excellent mixing such as in sulfur reaction furnaces and reheat burners.

At least 50% of the sulfur tail gas incinerators that Callidus has provided over the last 20 years are natural draft. Both medium intensity burners (moderately high pressure drop) and natural draft burners (very low pressure drop) have been used in tail gas service over the years with much success.

While a typical forced draft system with a waste heat boiler might require a combustion air fan discharge pressure of 8" w.c. (2 kPa), the same system with an HI burner would require 60" w.c (15 kPa). 7.5 times the electrical power is needed to utilize a 400 HP (300 KW) motor instead of a 50 HP (38 KW) motor. Although most oxidizer manufacturers have the capability of providing both types of burners, the companies that promote HI burners for tail gas service only manufacture HI burners. In today's search for cost effective, low energy solutions, the HI burner might not be the most economical solution.

Stack Sample Ports
Environmental regulations require sample ports be located after one second residence volume of the flue gas. This is measured from the centerline of the burner or the center line of the last waste gas nozzle to the center line of the sample port nozzle. Ideally, the sample ports should also be located in a straight run of stack, eight diameters downstream of last disturbance and at least 2 diameters from the exit or downstream disturbance. The "disturbance" is typically a transition in diameter of the stack. If this ideal arrangement is possible, then only two sample ports, located at 90 degrees around the circumference of the stack are required. In cases in which it is not possible to have eight diameters upsteam and two downstream, or in cases in which it is not economically feasible, it is acceptable to provide four sample ports oriented at 90 degrees around the circumference of the stack. Of course, in this case a 360 degree sample port access platform is required. If the ideal eight and two diameters cannot be provided, more samples are usually required during the stack test.

Refractory
The refractory lining can be low iron castable or brick. Brick refractory will provide longer life than castable. Fiber type refractory (ceramic fiber, board or modules) is not recommended. Acid gas will quickly destroy fiber type materials. In addition, fiber type refractory is too effective an insulator and will result in steel shell temperatures that are below the dew point, even with a rainshield.

Heat Recovery
Oxidizer chambers with heat recovery boilers are nearly always horizontal.

Combustion air pre-heaters and waste gas pre-heaters are not recommended in a sulfur tail gas oxidizer system. When combustion air or waste gas is heated with the flue gas from the incinerator, the surfaces of the heat exchanger can become too cold on the flue gas side and can lead to acid gas condensation corrosion. Care must also be taken in the design of a waste heat recovery boiler to avoid corrosion. The flue gas exit temperature should not be so low that the flue gas could begin to condense on the stack surface downstream. Typically, the boiler exit flue gas temperature is maintained at 400 to 500 degrees F, depending on the boiler feed water temperature and the steam temperature needed to avoid corrosion.

The stack downstream of a waste heat boiler is generally unlined carbon steel with external insulation. The external insulation insures that the flue gas remains hot enough to not condense out any SOx or H_2O as it rises through the stack. Near the exit the flue gas will unavoidably be close to the dew point or below. To avoid corrosion at the exit, the top 3 to 10 feet of the stack is specified as stainless steel.

Although occasionally considered, a flue gas bypass around the boiler is not recommended. The required bypass valve would be very large, expensive, prone to leak and could become a serious a maintenance problem.

Fabrication and Design Codes
Sulfur tail gas incinerators are typically designed to AISC or ASME code. The

operating pressure ranges from 1 or 2 inches water column vacuum to 8 to 10 inches water column positive pressure (in the case of a system with a waste heat boiler). ASME code design is not necessary at these pressures. However, some customers prefer ASME code for a sturdier design and higher quality fabrication. A cost effective compromise is to design per AISC but specify ASME fabrication.

Some SRU licensors anticipate deflagration potential in the oxidizer. In such cases, the oxidizer chamber is frequently designed for 50 psig per ASME Code.

Combustion Air Flow Measurement
The best methods of measuring air flow due to its typically low pressure and high flow are: pitot tube array, thermal dispersion or annubar. A pitot tube array can be the most cost effective since it requires very few up- and down-stream diameters for a good measurement. If the air flow is very large, the number of duct diameters required by other devices can result in very large plot space requirement. Orifice plates are definitely not practical due to the high pressure drop required. A venturi meter can be used, but they are expensive, require more pressure drop (4” w.c. vs less than 1” w.c.) and take up more space compared to the recommended methods.

Conclusion
Tail Gas Incineration has been used as an effective means for disposal of waste gases produced in Sulfur Recovery Units. Information provided in this article will be of interest and benefit to both the user of this equipment and those supplying it. The article should provide users with knowledge of design considerations important to the design of these systems. It should, also, allow suppliers to avoid designs or design consideration parameters that might adversely affect the reliability of these units.

Figure 5. Tail gas incinerator with heat recovery boiler

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