Opportunity NO$_x$

Gas processing plants remove pollutants, such as volatile organic compounds (VOCs) and hydrogen sulfide, that are naturally present in effluent streams from gas processing operations, including amine treating, glycol dehydration and sulfur recovery. Thermal oxidation is often the most economical and effective method to eliminate these pollutants. However, public scrutiny of stack emissions continues to increase and facilities may now face strict environmental regulations limiting the NO$_x$ output of a plant. Depending upon the nature of the effluent streams, ultra low NO$_x$ burner technology may be used to meet these stringent emission requirements.

Kirk Wesselowski, Zeeco, USA, shows how to achieve ultra low NO$_x$ emissions in thermal oxidisers for gas processing.

Thermal oxidisers in gas processing

In natural gas processing, wellhead gas is usually passed through field separator units to remove hydrocarbon condensate and water. If hydrogen sulfide is present, it is often removed using a sweetening process, which involves absorption in an amine solution before the gas can be utilised. The overhead from the amine regenerator is frequently sent to a thermal oxidiser, (often called an incinerator) in which the H_2S and other combustibles are oxidised to form sulfur dioxide, carbon dioxide and water vapour, before they are vented to the atmosphere via an elevated stack. Glycol dehydrators, sulfur recovery units and other processes may also generate tail gases or vent gases that have unacceptable levels of H_2S and CO, as well as VOCs that require mitigation. Tank vents sometimes require treatment before the gases can be released to the atmosphere. A thermal oxidiser is often the simplest and most cost effective way to achieve
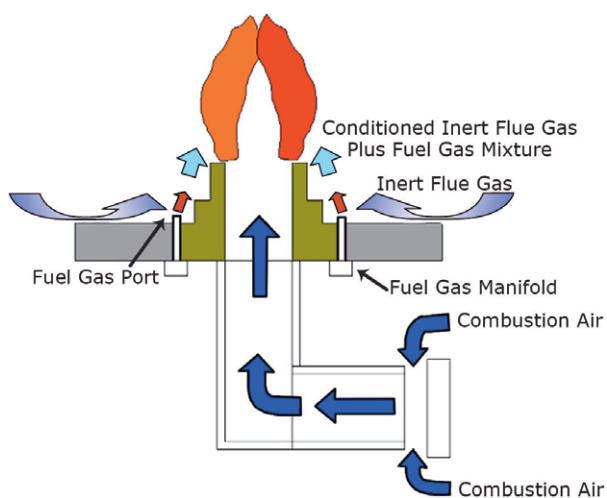
Figure 1. Free jet burner technology.
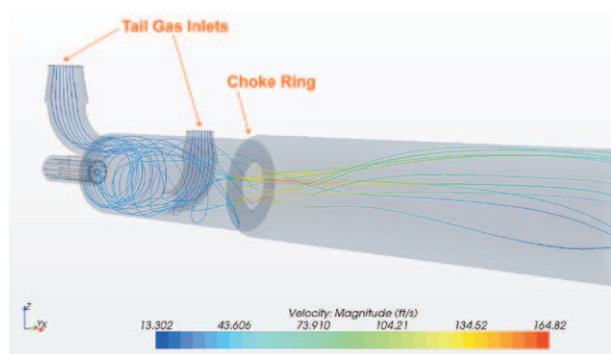
Figure 2. CPFD model of a thermal oxidiser.

Table 1. SRU tail gas thermal oxidiser test results

	SRU tail gas to thermal oxidiser	Flue gas from thermal oxidiser
Temperature, ˚C	132	871
Oxygen (wet), mol%	0.00	2.51
NH_3, ppmv (wet) at 3% O_2	470	< 0.1
NO_x, ppmv (wet) at 3% O_2	Not measured	18.5

effective destruction of H_2S and other combustibles in these waste gas streams.

In its most basic form, a thermal oxidiser typically consists of the following:

- Burner: generally fired using natural gas, which provides the necessary energy to initiate and sustain the combustion reaction.
- Source of combustion air: either from a centrifugal fan or a natural draft air inlet.
- Waste gas injection system: designed to deliver the waste gas to the combustion chamber to be completely and efficiently burned.
- Combustion chamber: provides effective mixing with adequate residence time for the combustion reaction to occur.
- Optional heat recovery equipment: dependent upon the need for energy within the plant.
- Vent stack: may be integral with the combustion chamber, to disperse the combustion products into the atmosphere.

The function of a thermal oxidiser is to provide an environment in which the combustion reaction of the waste gas can be sustained and completed. The combustion chamber temperature is controlled by modulating the firing rate of the burner in order to maintain a temperature that is high enough to ensure completion of the combustion reaction, but not high enough to damage the combustion chamber's refractory lining. A properly designed thermal oxidiser is sized to provide a residence time in the combustion chamber that usually exceeds one second from the waste gas injection point to the end of the chamber. This allows the thermal oxidiser to incinerate all waste gases before the treated flue gas is dispersed into the atmosphere.

Waste gas flaring can be considered an alternative to thermal oxidation. However, flaring these waste gases is often not a cost effective solution. If the gases do not contain enough hydrocarbons to sustain combustion without the addition of large quantities of supplemental enrichment fuel gas, then the process is ineffective and uneconomical. Enrichment fuel gas is required for a non-assisted flare for any waste gas with a lower heating value (LHV) of less than 7.45 MJ/Sm^3.[1] Since thermal oxidisers use a refractory lined combustion chamber to maintain a controlled environment, a low hydrocarbon waste gas can be burned using much less fuel than would be required to enrich the waste stream for flaring. Furthermore, the destruction efficiency for combustibles in thermal oxidisers can exceed 99.99%, while flares generally have lower destruction efficiencies. In addition, thermal oxidisers can incorporate downstream heat recovery systems such as a waste heat boiler or a thermal oil heater, but heat recovery is not possible with a flare system.

## Ultra low NO_x burner technology

With stricter emissions requirements becoming more prevalent across the globe, it is often no longer adequate to use a conventional gas burner within a thermal oxidiser system. An economical and energy efficient solution to reduce NO_x emissions from a thermal oxidiser is via the use of advanced ultra low NO_x combustion technology.

For gaseous fuels without fuel bound nitrogen, the primary contributor to overall NO_x production is thermal NO_x. A simplified reaction mechanism for thermal NO_x formation is the chain reaction:[2]

$$O + N_2 \leftrightarrows NO + N$$

$$N + O_2 \leftrightarrows NO + O$$
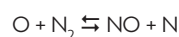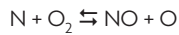
With the additional reaction:

$$N + OH \leftrightarrows NO + H$$
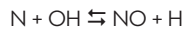
Eventually, much of the nitrogen monoxide (NO) formed by the chain reaction above is oxidised to nitrogen dioxide (NO_2) in the atmosphere. The first reaction in the chain above possesses high activation energy and is strongly temperature dependent. Therefore, thermal NO_x generation increases significantly at higher flame temperatures. Experienced combustion engineers

Figure 3. A thermal oxidiser installed at a gas processing plant. Installations such as this one using free jet ultra low NO_x burners may achieve NO_x levels below 20 ppmv at 3 vol% oxygen.

Table 2. Acid gas thermal oxidiser test results

	Amine acid gas to thermal oxidiser	Flue gas from thermal oxidiser
Temperature, °C	Not measured	802
Flow rate, Nm³/hr	612 Nm³/hr	3762 Nm³/hr
Oxygen (dry), mol%	Not measured	4.17
Non-methane hydrocarbon, ppmv (dry) at 3% O_2	5320	< 11.2
Benzene, ppmv (dry) at 3% O_2	176	> 0.7
CO, ppmv (dry) at 3% O_2	Not measured	< 21.0
NO_x, ppmv (dry) at 3% O_2	Not measured	4.9

can reduce overall NO_x emissions by decreasing the rate of the combustion reaction, thereby reducing the peak flame temperature.

One method that has proved very successful for achieving ultra low NO_x emissions is to use a burner that induces flue gas into the burner fuel gas stream before the flame stabilisation point, consequently decreasing the combustion reaction rate. An example of field proven ultra low NO_x technology is the ZEECO® Free Jet ultra low NO_x burner. Zeeco's patented approach places the fuel gas tips outside of the burner tile (Figure 1). With this configuration, the jet of fuel gas induces a local internal flue gas recirculation, entraining flue gas into the fuel gas. Since the flue gas in this region of the thermal oxidiser is normally only 2 − 4% oxygen, it has been made largely inert, and diluting the fuel gas in this manner delays the combustion reaction. Combustion air is introduced inside the burner tile and reacts with the fuel gas at the top of the tile, forming the flame stabilisation point. However, since the fuel gas has already been diluted with entrained flue gas, the overall reaction rate is slowed and the overall peak flame temperature is reduced. This results in significantly lowered thermal NO_x production compared to a conventional burner.

Burner stability from start up and throughout the range of operation is achieved by a specialised design, including a series of ledges on the tile. To facilitate stable combustion, the combustion process must be initiated in a low pressure area created by a refractory ledge. When combustion occurs, the refractory ledge retains heat, resulting in enhanced flame stability in the ultra low NO_x burner. Stability is equal to that of a conventional burner design, and turndowns in excess of 5:1 can be easily achieved.

Successful installations

One example of a successful ultra low NO_x burner installation is located in a sulfur recovery unit (SRU) tail gas thermal oxidiser operating at a Canadian refinery. The tail gas waste stream contained a significant concentration of ammonia (NH_3) that averaged in excess of 400 ppmv. If burned in a high temperature, high oxygen environment, the amount of bound nitrogen could be converted to NO_x at a rate of 30% or greater. However, by using a specialised waste gas injection method with a controlled amount of excess air, along with an ultra low NO_x burner design, the test results in Table 1 show that the combined thermal NO_x plus fuel bound NO_x is 18.5 ppmv at 3% oxygen.

Another installation is located at an amine acid gas thermal oxidiser at a California, USA gas processing facility. This example features an ultra low NO_x burner design in an economical, vertical cylindrical thermal oxidiser with an integral stack. Table 2

Figure 4. An SRU tail gas thermal oxidiser installed at an LNG processing facility.

shows that the NO_x production from this thermal oxidiser was less than 5 ppmv at 3% oxygen: an extraordinarily low level compared to previous generations of amine acid gas thermal oxidisers.
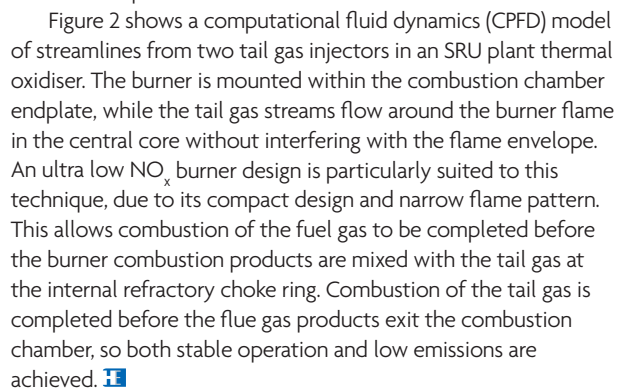
Challenges

Ultra low NO_x burners similar to those shown in Figure 1 were first implemented in process heaters and have been successfully used in heater applications for more than a decade. However, several factors must be considered when applying the ultra low NO_x burner design to a thermal oxidiser.

Certain waste gases may include components, such as ammonia or amines, which contain chemically bound nitrogen. When bound nitrogen is burned in an excess air environment, a substantial fraction of the nitrogen is converted to NO_x through a complex chain reaction. Since this reaction does not contain the high activation energy of the thermal NO_x reaction, it can occur at lower temperatures. In these circumstances, the ultra low NO_x burner is not as effective as a solution to mitigate the conversion of bound nitrogen to NO_x. As an alternative, wastes or fuels with significant bound nitrogen are usually incinerated using a multi stage process, where an initial substoichiometric combustion zone is followed by an oxidation zone.

Another important design aspect of a thermal oxidiser is the method used to introduce the waste stream(s) and combustion air, as well as the mixing of waste gases with the burner combustion products. Proper selection of a waste stream introduction method depends primarily upon the LHV of the waste stream and its associated combustion air demand. For example, waste gases that have a relatively low LHV of 800 kJ/

Nm^3 are generally injected into the thermal oxidiser separately from the fuel gas burner. These waste gases will have a lower combustion air demand, but the waste stream must be heated to a sufficient temperature for proper combustion through supplemental firing of the fuel gas burner. If the waste gas flow is mixed aggressively with the burner flame envelope, it can quench the burner flame to an unacceptably low temperature, resulting in poor burner stability, low combustion temperatures, incomplete combustion, high CO production and potential refractory damage. This phenomenon must be avoided by carefully injecting the waste streams separately from the burner flame envelope.

Figure 2 shows a computational fluid dynamics (CPFD) model of streamlines from two tail gas injectors in an SRU plant thermal oxidiser. The burner is mounted within the combustion chamber endplate, while the tail gas streams flow around the burner flame in the central core without interfering with the flame envelope. An ultra low NO_x burner design is particularly suited to this technique, due to its compact design and narrow flame pattern. This allows combustion of the fuel gas to be completed before the burner combustion products are mixed with the tail gas at the internal refractory choke ring. Combustion of the tail gas is completed before the flue gas products exit the combustion chamber, so both stable operation and low emissions are achieved. 🅷🅴

References

1. *Code of Federal Regulations, Title 40, Section 60.18.*
2. *TURNS, Stephen R.* An Introduction to Combustion, Concepts and Applications, *2nd ed., McGraw Hill, Boston (2000), pp. 168 – 169.*