



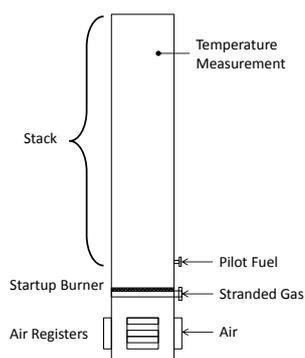
Providing a hot surface some distance away from the introduction of fuel and air in enclosed flares can allow for sufficient mixing prior to ignition. **Joe Colannino, ClearSign Combustion, USA**, explains how.

# OPTIMISING ENCLOSED FLARES

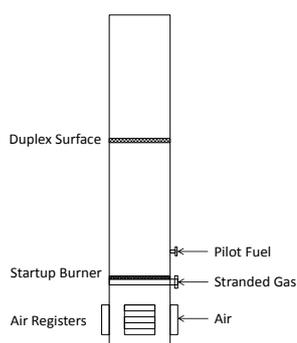
**E**nclosed flares are used in so-called 'stranded gas' operations. Stranded gas is gas that normally has value but is inconvenient or uneconomical to transport and requires safe disposal. If the gas is flammable, flaring is the usual option. If the gas volumes are small or the location is remote and the environmental impact is low, the products may be combusted in an open flare. However, when the gas volumes are larger or the environmental impact is higher, the gas is often burnt in an enclosed flare, which allows for more control over emissions performance. Enclosed flaring is the usual option for disposing of flammable gas that is generated from landfill or as a byproduct of oil extraction. Figure 1 depicts the essential elements of an enclosed flare.

A flammable gas is admitted to the flare through a fuel header and a source of ignition, such as a pilot, is used to ignite the gas. The enclosure above the burners is known as the 'stack'. Its purpose is to isolate the combustion process from the surrounding area and force hot products to exit through the top of the stack, away from personnel and equipment. Such stacks are often 40 – 60 ft tall. Adjustable air registers are opened to allow the necessary ambient air, for the combustion reaction.

The required airflow does not require a fan as the heat from the combustion reaction will provide sufficient draft to induce airflow through the air registers. The air registers comprise adjustable louver assemblies, which are opened or closed to regulate



**Figure 1.** An enclosed flare typically comprises adjustable air registers, a burner and an enclosure.  $\text{NO}_x$  from such units is typically about 50 ppm.



**Figure 2.** An enclosed flare modified with a DUPLEX™ surface. When combustion is hosted on the technology's surface as shown, rather than in the free space of the stack,  $\text{NO}_x$  typically drops to less than 5 ppm.

the airflow. The louvers may be manually set or automatically adjusted – most often by measuring the downstream stack temperature and comparing it to a desired set point. If the exiting flue gas is too hot, the louvers are opened to allow more cool air to be drafted into the unit. If the exiting flue gas is too cool, the louvers are closed to restrict airflow and increase the internal temperature. This process ensures sufficient temperature and residence time to sufficiently destroy the influent gas.

## Factors affecting emissions

Several techniques ensure sufficient destruction: if the flared gas is of a familiar type, a time-temperature requirement may be specified by convention. For example, for hydrocarbons, 2 sec. at 1400°F or greater is thought to sufficiently destroy the influent fuel. In other cases, no time-temperature requirement is specified, but rather limits are stated in terms of destructive removal efficiency (DRE) or volatile organic compounds (VOCs), which are then confirmed by a third-party testing company. Such limits vary widely from place to place, according to local custom and need. DRE is often required to be 99.9% or more, and VOC limits are often given in parts per million (ppm) or a mass per heat release rate basis (e.g. lbs per million Btu). When such limits are required, open flaring is disallowed because emissions from open flaring are very difficult to verify. Additionally,

performance and emissions of open flares can be adversely affected by atmospheric conditions, such as wind and rain.

Enclosed flares are generally more resistant to such affects because the enclosure better isolates the combustion process from the weather and better confines the exhaust plume, reducing the penetration of rain into the enclosure. Enclosed flares are also thought to better control emissions of unburned hydrocarbons and carbon monoxide (CO).

However, enclosed flares can potentially elevate nitrogen oxide ( $\text{NO}_x$ ) emissions. When a flame is enclosed, it is less able to radiate its heat to the atmosphere. The hot insulated walls of the enclosed flare reflect and re-radiate heat back to the flame, thus increasing the flame temperature. Such high temperatures fuse some of the nitrogen and oxygen found in the combustion air to nitric oxide (NO) or nitrogen dioxide ( $\text{NO}_2$ ), collectively referred to as  $\text{NO}_x$ .

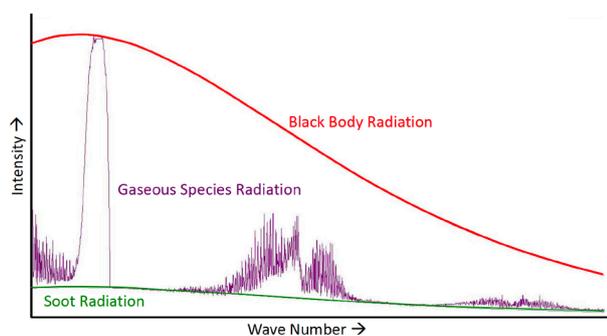
$\text{NO}_x$  is a positive function of time at temperature and is therefore increased as the flame temperature rises. It is generally produced within micro-flame structures, which are formed as a fuel jet interacts with a relatively slower moving airstream.  $\text{NO}_x$  is kinetically controlled, meaning that it requires sufficient time to form. Flames in enclosed flares are tens of feet in length, which gives ample opportunity for  $\text{NO}_x$  formation. However, flame length is affected most profoundly by the time required to mix the fuel with the air. If ignition could be delayed until after the mixing is more or less complete, the flame would burn more quickly, giving little time for  $\text{NO}_x$  to be formed.

## Distal surface architecture

One way of delaying ignition is to provide a hot surface some distance away from the introduction of fuel and air. This allows for sufficient mixing prior to ignition. ClearSign Combustion's DUPLEX™ technology provides a downstream porous-ceramic matrix for this purpose. To achieve ultra-low  $\text{NO}_x$  emissions, the enclosed flare is first operated in the conventional way. This preheats the distal surface. Once the surface is above the autoignition temperature of the fuel, the flame is transferred from the burner to the downstream surface (Figure 2). The resulting  $\text{NO}_x$  is generally less than 5 ppm and independent of the initial  $\text{NO}_x$  from the existing burner. Notably, in boilers and process heaters,  $\text{NO}_x$  is typically corrected to dry conditions of 3% oxygen. In enclosed flares and gas turbines,  $\text{NO}_x$  is typically corrected to dry conditions of 15% oxygen, and such was the case here. Other differences are also notable, for example, flame length shrinks dramatically, from feet to inches, and combustion noise is greatly attenuated.

## Why such low $\text{NO}_x$ ?

It is reasonable to ask why  $\text{NO}_x$  should drop precipitously by merely adding a downstream combustion surface, and there are several potential reasons. First, micro-flame structures are formed during the mixing process. By delaying ignition until after the mixing is substantially complete, there are fewer concentration gradients available to generate  $\text{NO}_x$ . Second, flame length is governed substantially by mixing, rather than by chemistry. In other words, it takes much longer to mix fuel and air than it takes to burn the mixture. Since ignition occurs after the mixing, flame length becomes very short. Inasmuch as  $\text{NO}_x$  is a kinetically governed process, it has little time to form. And, by decoupling mixing from combustion, the



**Figure 3.** Blackbody vs spectral radiation for a gaseous fuel. A blackbody radiates with greater intensity than gaseous species radiation.<sup>1</sup>

thermal energy that amplifies the pressure fluctuations is displaced, hence the reduction in combustion roar. Additionally, a porous ceramic matrix has an effective emissivity close to unity – the highest possible, whereas a flame radiates one or two orders of magnitude less efficiently.

The reason for such high emissivity is due to reflection and re-radiation in small cavities. This process inflates the emissivity to be effectively the same as a black body – the ideal radiator. The process of reflection and re-radiation is the same principle that makes the mouth of a cave look black when viewed from the outside. The contrast is that whilst a porous ceramic radiates according to a continuous blackbody distribution, flue gas radiates spectrally according to the particular vibrational modes of carbon dioxide (CO<sub>2</sub>) and water vapour in the flue gas. This is a less efficient process (Figure 3). A third possible reason is that flue gas entrainment prior to combustion can act to depress the necessary species concentrations for NO<sub>x</sub> formation.

### Case study: enclosed flare

An oil producer based in California, US, requested combustion system modifications to retrofit an enclosed flare for low NO<sub>x</sub> operation using ClearSign's DUPLEX technology. Operating parameters for the enclosed flare were as follows:

- Firing rate: 20 – 22 million Btu/hr.
- O<sub>2</sub>: 12 – 15%.
- Stack temperature: 1700°F – 1850°F.
- Fuel heating value: 1150 – 1650 Btu/ft<sup>3</sup>.

The guarantees were as follows:

- NO<sub>x</sub>: 0.023 lb/million Btu (approximately 18 ppm of NO<sub>x</sub>).
- DRE: 99.9%.

- PM10: 0.004 lb/million Btu.
- VOC: 0.008 lb/million Btu.

The technology was able to meet all guarantees as follows:

- VOCs: <0.004 lb/million Btu.
- CO: <5 ppm.
- NO<sub>x</sub>: <5 ppm.

In order to make the insertion of the technology as easy as possible, ClearSign designed a 24 in. wafer containing the complete assembly, comprising the technology's surface and a support structure. The support structure was fully analysed via finite element analysis (FEA) and proved fit for service. The wafer was then placed between the two flanged halves of the flare stack and bolted in place. With the aid of a crane, the on-site insertion of the DUPLEX assembly was completed in a fraction of a day.

Regarding the burner, the existing manifold system was reused and fuel risers were added to facilitate the operation. A flow straightener was added to correct previous airflow issues and conform it to the desired flow profile. A flame scanner continuously proves combustion on the technology's surface. After an initial warm-up period, combustion is transferred to the surface whereby NO<sub>x</sub> and other emissions drop precipitously.

### Conclusion

ClearSign's technology has proven to be an effective method of combusting fuels and generating sub-5 ppm NO<sub>x</sub> and CO. The technology is particularly advantageous when other NO<sub>x</sub> reduction methods, such as flue gas recirculation (FGR) or ultra-low NO<sub>x</sub> burners, are impractical. The technology does not require FGR or any change to excess air operation. It may be used with a simple modification to the existing burner, such as the installation of an additional set of nozzles designed specifically to allow the flame to transfer to the distal surface.

DUPLEX technology can reduce flame length. Moreover, the technology's surface has been shown to improve radiant efficiency. It is also compatible with high excess air devices such as enclosed flares having typical excess oxygen fractions of 10 – 15%, as well as more traditional fired equipment, such as boilers and process heaters, that typically operate in the 2 – 5% excess oxygen range. 

### Reference

1. Figure adapted from Technical University of Denmark CHEC Research Centre, Department of Chemical & Biochemical Engineering, <http://www.kt.dtu.dk/forskning/chec/faciliteter/experimental-facilities-within-chec/temperature-and-measurement-of-thermal-radiation>, (last accessed 24 May 2017).