Ultra-low NOx burners in methanol plants

Recently, the Kingdom of Saudi Arabia's (KSA) strict environmental regulations have required operators to replace older, previous generations of burners with the latest in ultra-low NOx technology. In this article **R.K. Isaacs** and **R. Roberts** of Zeeco, Inc. and **N. Palfreeman** of Zeeco Europe Ltd review the engineering details of the ultra-low NOx burners used in the retrofit application, provide specific retrofit installation details, lessons learned, and discuss verified successful field results.

Zeeco was contacted by a local methanol producer in the Middle East to assist with retrofitting the steam methane reformer's 234 downfired burners that were unable to meet the Royal Commission's NOx requirement (55 ng/J) at high plant rates.

After a comprehensive evaluation, the operator selected Zeeco's next generation ultra-low NOx free-jet burner to replace the existing burners. This ultra-low NOx burner technology produces a flame profile with very limited flame-to-flame interaction for burner installations, while also achieving shorter flame lengths within a small mechanical footprint. The free-jet burner design utilises the "free jet" mixing theory to maximise the amount of inert internal products of combustion mixed with the fuel gas to produce lower thermal NOx emissions. The GLSF free-jet burner from Zeeco uses internal flue gas recirculation (IFGR) to reduce the thermal NOx emissions from the combustion zone. The GLSF free-jet burner has several advantages over some other low NOx burners as follows:

- The typical free-jet burner is able to fit into the same cutout or mounting, as a similar-sized raw gas burner.
- The typical free-jet burner tile is approximately the same size and weight as a typical raw gas burner.
- The free-jet burner is simple to operate and easy to maintain.
- The free-jet burner has significantly lower NOx emissions than a raw gas burner.

Thermal NOx creation and reduction

In order to understand why an ultra-low NOx burner design was successful in this application, formation of thermal NOx emissions must first be examined. For gaseous fuels with no fuel-bound nitrogen (N_2), thermal NOx is the primary contributor to overall NOx production. Thermal NOx is produced when flame temperatures reach a high enough level to "break" the covalent N_2 bond apart, allowing the "free" nitrogen atoms to bond with oxygen to form NOx.

Typical combustion in a natural gas fired burner

The following stoichiometric equation represents the reaction of methane and air with excess air:

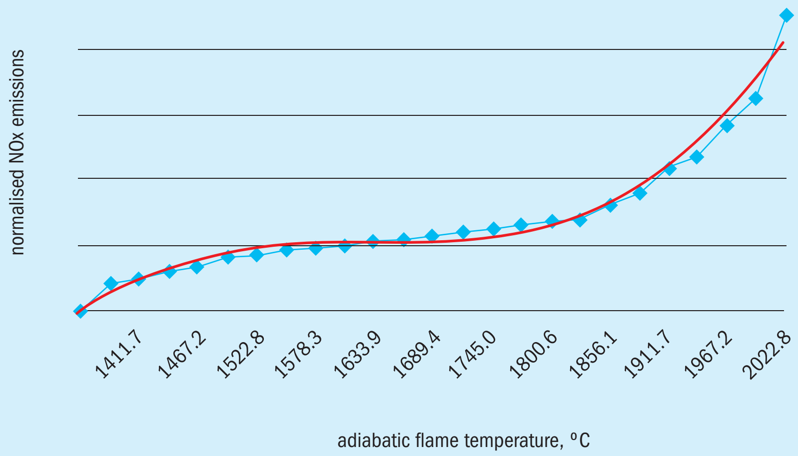
$$2CH_4 + 4\,(XA)\,O_2 + 15\,(XR)\,N_2 \rightarrow 2CO_2 + 4H_2O + (XA)\,15N_2 + (XR)\,O_2$$

where XA = excess air and XR = excess reactants

Natural air is comprised of 21% O_2 and 79% N_2. Combustion occurs when oxygen reacts and combines with fuel (typically hydrocarbon). Since the temperature of combustion is not normally high enough to break all of the nitrogen bonds, a majority of nitrogen in the air stream passes through the combustion process and remains diatomic nitrogen (N_2) in the inert combustion products. Very little N_2 is able to reach high enough temperatures in the high intensity regions of the flame to break apart and form "free" nitrogen. Once the covalent nitrogen bond is broken, the "free" nitrogen is available to bond with other atoms. Basic chemistry dictates that free nitrogen, or nitrogen radicals will react to other atoms or molecules that can accept them to create a more stable atom. Of the possible reactions with the products of combustion, free nitrogen will most likely bond with other free nitrogen to form N_2. If, however, a free nitrogen atom is not available, the free nitrogen will react with the oxygen atoms to form thermal NOx. As the flame temperature increases, the stability of the N_2 covalent bond decreases, allowing the formation of free nitrogen and subsequently increasing thermal NOx. Burner designers can reduce overall NOx emissions by decreasing the peak flame temperature, which can reduce the formation of free nitrogen available to form thermal NOx.

The varied requirements of refining and petrochemical processes entail the use of numerous types and configurations of burners. The method utilised to lower NOx emissions can differ by application. Thermal NOx reduction is generally achieved by delaying the rate of combustion. Since the combustion process is a reaction between oxygen and fuel, the objective of delayed combustion is to reduce the rate at which the fuel and oxygen mix and burn. The faster the oxygen and the fuel gas mix, the faster the rate of combustion and the higher the peak flame temperature.

Fig 1: **Calculated peak flame temperature vs thermal NOx production**



Source: Zeeco

Figure 1 plots peak flame temperature against thermal NOx created.

NOx emissions increase as the adiabatic flame temperature increases. Slowing the combustion reaction reduces the flame temperature, which results in lower thermal NOx emissions. The challenge in achieving lower thermal NOx emissions is not the theory, it is in retrofitting the latest burner technologies into older existing furnaces without adding expensive external components or processes.

The industry's standard method to reduce thermal NOx is to mix the fuel gas together with the inert products of combustion to recondition the fuel before combustion occurs. Since the reconditioned fuel is mainly comprised of inert components, the resulting composition burns at a lower peak temperature. To best utilise the inert products of combustion (flue gas) within the furnace, the fuel gas is introduced along the outside perimeter of the burner tile in an area where flue gas is present while the furnace is in operation. As the fuel gas passes through the inert products of combustion, mixing occurs naturally. This mixing of inert products with fuel changes the composition of the fuel, and stabilisation occurs at the tile exit. Since the reconditioned fuel mixture is 15 to 50% inert in most cases, the resulting flame burns at a lower peak temperature and generates less thermal NOx.

The mixing of the fuel gas with flue gas prior to combustion is called internal flue gas recirculation (IFGR). When IFGR is too aggressive, it can result in an increased blower power usage, decreased burner turndown, and increased flame destabilisation. Through free-jet theory, maximising IFGR while maintaining flame stability and flame length can become a challenge.

Application and process description

The original raw gas burners operating in the methanol reformer were not able to meet the KSA's new emissions requirements. The NOx emission limit in the KSA at the time of the application was 43 ng/J (90 ppmv). The previous burners that were installed in the methanol reformer have NOx emissions consistently above 70 ng/J (US units) with occasionally excursions to 110 ng/J (US units). As a result of exceeding emissions requirements, the reformer's owner was required to retrofit with ultra low NOx burner technology. After a comprehensive evaluation, Zeeco was selected to provide 198 GLSF-10 downfired free-jet burners for the inner row, and 36 GLSF-7 downfired free-jet burners for the outer row, using the existing burner footprint. The 36 GLSF-7 burners for the outer rows were similar in size to the 198 GLSF-10 burners for the inner row, but the outer row burners have a smaller maximum heat release.

The compact size of the free-jet burner allows the distance between burners to be maximised when placed in conventional spacing. More space between burners decreases the likelihood of flame interaction and decreases NOx emissions. The absence of any flame holder in the burner throat and the fact that the burner does not "swirl" the air allows the momentum of the combustion air to remain in a vertical direction as it exits the tile. This results in a compact flame pattern and minimal flame interaction.

This application was conducted in two different phases.

Phase one

The first phase of the project called for Zeeco to fabricate two GLSF-10 downfired free-jet burners. One of these burners would be installed in Zeeco's test facility for test firing under simulated field conditions. The second GLSF-10 downfired free-jet burner would incorporate any combustion test changes and be shipped to the job site for trial fit into the steam reformer.

Zeeco conducted the GLSF-10 downfired burner testing at Zeeco's test facility in Broken Arrow, OK, USA. Zeeco successfully demonstrated that the burner would meet the emissions requirements for this project. Tables 1 and 2 provide the corrected NOx emissions measured during the burner combustion test at Zeeco for the natural gas test fuel and the high hydrogen test fuel.

The operator's engineers were on site for this combustion testing.

Trial fit up

The GLSF-10 downfired free-jet burners were designed to fit into the existing burner plenum that was currently installed on the methanol reformer. The existing raw

Table 1: **Natural gas test fuel – corrected NOx emissions**

NOx	Corrected O_2	Firebox temperature	Combustion air temperature
25.5 ng/J	1.5% O_2	1204°C	522°C
23.5 ng/J	3.0% O_2	1204°C	522°C

Table 2: **High hydrogen test fuel – corrected NOx emissions**

NOx	Corrected O_2	Firebox temperature	Combustion air temperature
24.3 ng/J	1.5% O_2	1204°C	522°C
22.5 ng/J	3.0% O_2	1204°C	522°C

Fig 2: **GLSF downfired burners firing with mixed fuel gas**

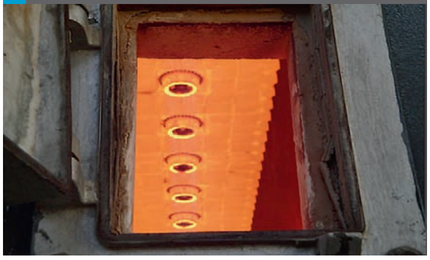
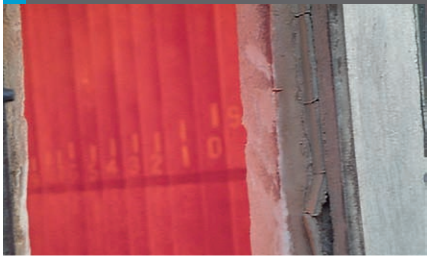
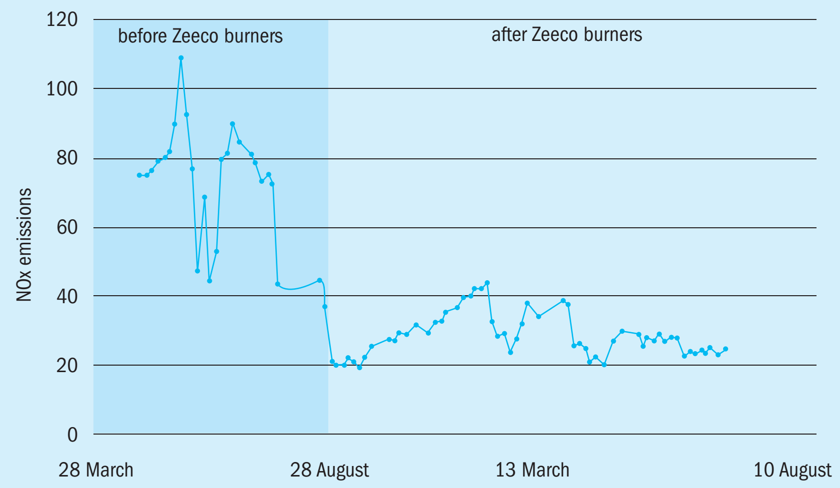


Fig 3: **Process tubes in the methanol reformer**



PHOTOS: ZEECO

Fig 4: **NOx emissions from methanol reformer**



Source: Zeeco

gas burners were removed, but the existing combustion air plenums and combustion air duct work were reused in order to minimise the reformer modifications during a short (3 week) turnaround. The operator was concerned that replacing the existing combustion air plenums and combustion air ductwork would take much longer than the time allotted for the turnaround. As a result, Zeeco had to verify that the free-jet burner would operate satisfactorily in a combustion air plenum designed by another burner manufacturer.

Zeeco provided the GSLF-10 downfired free-jet burner in two separate pieces: the burner tile with mounting plate and the burner front plate with assorted hardware. During the trial fit of the burner into the methanol reformer, there were several fit up issues with the GLSF-10 burner. It is important to note that all of these issues were due to discrepancies in the dimensional accuracy of the existing burner plenums. The original burner plenums were actually shorter in depth than what was shown on the existing burner general arrangement drawings. As a result, the GLSF-10 downfired free-jet burner would not easily fit into the plenum without some mechanical redesign.

Mechanical burner changes

In order to aid in proper fit up, it was decided between Zeeco and the operator to make mechanical modifications to the burner. It is important to note that none of the mechanical changes affected the gas tip to tile geometry that was used for the combustion test. As a result, there was no need to conduct additional combustion testing of the burner.

The GLSF-10 downfired free-jet burner was supplied in three separate parts as follows: the burner tile and gas manifold assembly, the burner front plate assembly with JM-1S auxiliary pilots, and external piping assemblies. The original register in the GSLF-10 burner was removed, since the existing plenum would provide satisfactory air distribution to the burner throat. In addition, the existing burner plenum was provided with an air register to control the air flow to the individual burner.

Phase two

After Zeeco and the operator were able to address the lessons learned from the trial fit up, the fabrication of the 198 GLSF-10 downfired free-jet burner and the 36 GLSF-7 downfired free-jet burners commenced. These burners were to be installed in the methanol reformer during a planned plant shutdown. The reformer was only scheduled to be shut down for a few weeks, so the installation of all 234 GLSF downfired burners was to be carried out within a three-week period.

Start-up and operation

The reformer was brought back into service with all 198 GLSF-10 and 36 GLSF-7 downfired free-jet burners in operation. After an initial operating period with the burner firing a natural gas fuel, the plant started to produce the mixed fuel gas with high hydrogen content (approximately 20% methane and 75% hydrogen). When the GLSF downfired free-jet burners were switched over to fire the mixed fuel gas, the flame quality was very good.

Figure 2 shows a picture of the burners in the methanol reformer on the mixed fuel gas (approximately 20% methane and 75% hydrogen).

The flame from the mixed fuel gas produces a proper, transparent flame pattern with even heat transfer to the process tubes. The flames were straight with no evidence of flame impingement on the process tubes. Based on the feedback received from site, the operator found the flame pattern on the mixed fuel gas to be acceptable.

Figure 3 shows the even colour of the process tubes in the methanol reformer. Even heat transfer to the process tubes is shown with even coloring and no hot spots. Uneven coloring and hot spots may represent flame impingement. The even heating allows the owner to meet the necessary process flow rate requirements for the methanol reformer.

Conclusion

The GLSF-7 and GLSF-10 downfired free-jet burners installed in the methanol reformer resulted in a decrease in NOx emissions. Figure 4 represents NOx emissions before and after the Zeeco GLSF downfired free-jet burner installation. After the new burners were installed, the NOx emissions from the methanol reformer were consistently below 43 ng/J, meeting the KSA's emissions requirements. ■