THE CASE FOR cleaner combustion

Matthew Martin, ClearSign Technologies Corp., makes a case for why nitrogen oxides are a critical pollutant and outlines a strategy for emissions abatement.

Despite an overwhelming emphasis on carbon dioxide and greenhouse gas contributing to emissions, nitrogen oxides (NO_X) remain a critical pollutant. Unabated NO_X emissions pose significant health and environmental risks. The role of NO_X in producing smog exposes communities surrounding emissions sources to both health hazards and readily visible evidence of the impacts of industrialisation.

Selective catalytic reduction (SCR) units represent previous NO_X reduction technology, achieving NO_X emissions as low as 2.5 ppm. The relatively high total cost of installation, operating expense, and, more recently, the recognised potential for secondary PM2.5 formation (a particulate so small it becomes trapped in human lungs) due to ammonia slip or by-product reactions, has delayed or stopped the universal implementation of SCRs across most industries.

Fortunately, new technologies, such as the ClearSign Core™ M1 burner, generate NO_X emissions equivalent to, or lower than, SCRs paired with conventional burners. Operators can use such technology to their economic advantage by increasing production where NO_X emissions are a limiting factor, reducing total installed cost, and getting ahead of costly future changes.

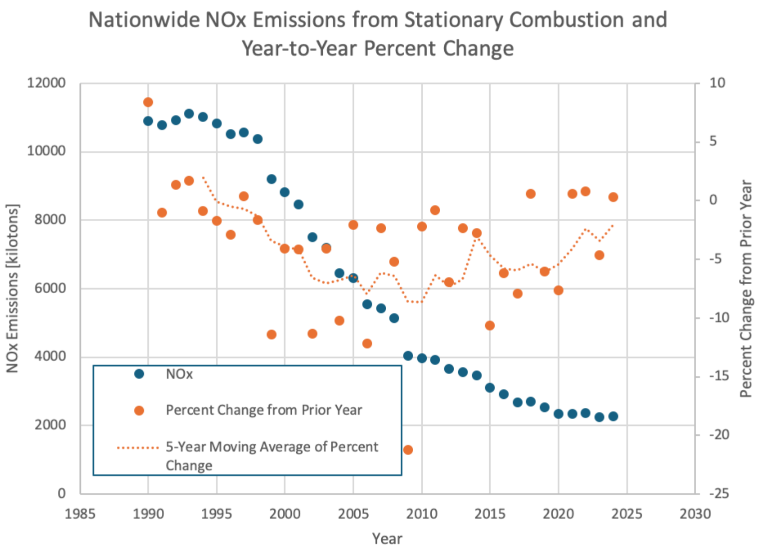

Figure 1. National NO_X emissions and year-to-year percent change for the US.

Table 1. Performance data from a fielded application

% of maximum duty	CO [ppm at 3%O_2]	NO_x [ppm at 3% O_2]	Operating excess oxygen [% dry]
60	145	6	3.10
70	5	5	3.10
80	0	4	3.00
90	0	3	3.10
100	0	3	3.10
80	0	2	3.00

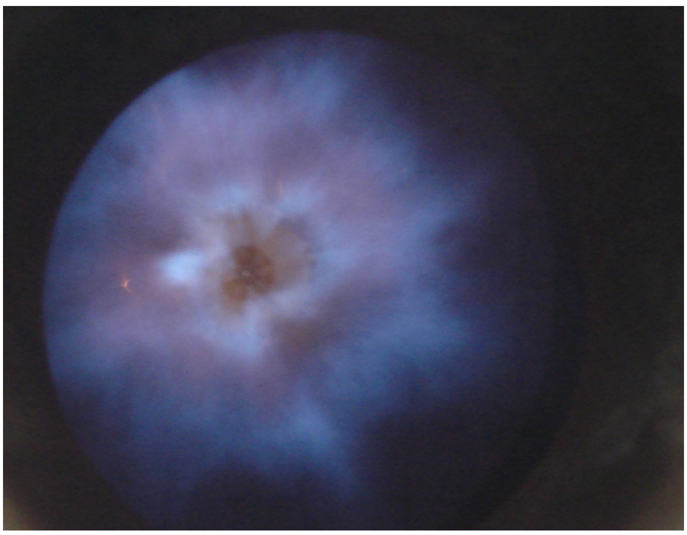

Figure 2. The M1 burner firing in a heater.

The persistent challenge of NO_X emissions

Combustion-related NO_X is primarily produced in the high-temperature flame zone emanating from burners when providing heat for industrial processes. Once these emissions exit the stack of the combustion device, they contribute to the formation of ground-level ozone and fine particulate matter, both of which have adverse health effects. Figure 1 shows NO_X emissions from and year-to-year change in NO_X for the US, with data taken from the Environmental Protection Agency (EPA).[1] The data is not normalised for changing fuel sources or economic output but nonetheless shows a slow-down in reduction based on a five-year rolling average. One very possible reason for this is that all the economically feasible NO_X reduction projects have been undertaken.

Regulatory landscape and financial implications

Regulatory bodies have established various compliance limits for NO_X emissions throughout the world. For example, in California, US, it is common to have an emissions limit of 2.5 ppm to avoid additional fees. Non-compliance can result in substantial financial penalties. In the most extreme cases, a cessation in plant operation may be required due to the cost of implementation.

Based on the most recent and applicable data from a report prepared for the South Coast Air Quality Management district in 2020, the relative cost of NO_X controls has increased significantly over time. The total installed cost (TIC) of an SCR retrofit for a fired heater has increased by a factor of 1.39, and for a boiler by 1.43 times. This was calculated by comparing costs prepared for the same units in 2014 and again in 2020.[2] This cost escalation is noteworthy because the Producer Price Index (PPI) over the same period for power boilers and heat exchangers increased by a factor of 1.20 while the PPI for heating equipment (non-electric) increased by a factor of 1.14.[3] This implies that the total cost of installation is increasing at a faster rate than that of the capital equipment. Using Equation 1:

$$PV_f = P_0 \times \left(\frac{1+PPI}{1+r}\right)^t$$

Where:

- PV_f = the future value.
- P0 = the present cost (e.g. normalised to 1 for simplicity).

- PPI = 0.065 (e.g. 0.39/6 years from the Norton data).
- t = the number of time periods (e.g. 6 [2020-2014]).
- r = the discount rate (e.g. 0.025 based on 2014 10-year Treasury Yield).

Equation 1 yields a future normalised value of 1.26 based on a current cost of 1.00 vs an invested value of 1.16 over the same period. In other words, it is a better investment to install NO_X controls now rather than in the future if the total install costs continue to escalate at a similar rate. Higher discount rates will give less favourable results; however, the TIC escalation for retrofit SCRs is approaching parity with the lower end of typical hurdle rates even without any additional benefit.

The value of installing NO_X controls sooner rather than later is amplified if emissions are limiting plant capacity. In this case the payback can be manifold, and the emphasis instead on how inexpensively and quickly the controls can be installed.

Technological innovations

Emerging technologies can offer a promising alternative to post combustion treatment with an SCR. The ClearSign Core M1 burner is an example of such innovation. The burner has achieved 2 ppm in a practical installation without the need for external flue gas or steam. It can be installed horizontally or vertically and uses industry standard fuel and air pressures. Table 1 shows performance data from a fielded application. For the last data point, at 80% of maximum duty, a special NO_X reducing feature of the burner was placed in service to reduce the NO_X from 4 ppm to 2 ppm at the equivalent firing rate. Elements of the design of the burner can be adjusted to achieve lower NO_X at lower firing rates.

The burner achieves these low emissions by precise mixing of the fuel, air, and flue gas prior to combustion. This mixture yields flame temperatures that are below that of conventional or even ultra-low NO_X burners. Because the highest temperature region of the flame is where most NO_X formation occurs, the reactions that would produce high NO_X are inhibited. There is a balance between NO_X production – which is suppressed at low combustion temperature – and CO production – which is enhanced. The M1 burner strikes this balance, exhibiting low CO emissions above 70% duty and no CO emissions above 80% duty. The temperature of the operating environment also plays a role in both NO_X and CO emissions, as is the case with any burner. A higher temperature operating environment will result in much lower CO emissions and moderately higher NO_X emissions.

In addition to the operating points shown in Table 1, the burner produces less NO_X (even dilution corrected) at higher excess oxygen levels. At both 3.8% and 4.1%, excess oxygen data shows that the burner produced 2 ppm of NO_X (dilution corrected to 3% excess oxygen), even without the special NO_X reducing feature being placed in service.

The burner is shown firing in a heater in Figure 2. The burner does not use a refractory tile and so it potentially provides a much lower load on the heater installation point when compared to other burners. It can be ramped from start up conditions to full firing rate in a few minutes, providing rapid restart for intermittent service requirements.

The M1 burner presents a cost-effective alternative to traditional SCR systems. ClearSign data from an actual installation indicates that the TIC for a burner solution is approximately six times lower than that of an SCR, although this may vary depending on specific applications. Furthermore, for industries that accept high excess air operation to reduce NO_X, the M1 burner delivers lower NO_X with higher efficiency, leading to fuel savings of approximately 2.75% per year from excess air reduction.

Immediate impact

For operators of fired equipment in non-attainment zones in the US there can be an immediate financial and operational impact for installation of these ‘near-zero’ NO_X burners. The relative impact varies by region, industry, and local regulations, but there are some readily identifiable opportunities.

In Texas, US, emissions reduction credits are available that generally garner US$100 000/t of NO_X reduced.[4] For operators with a fleet of relatively high NO_X burners in an industry such as midstream oil and gas production, the NO_X credits may completely cover not only the capital cost, but also the TIC of the new burner. Perhaps more importantly, these NO_X credits could be used to field between 2 and 10 times as many heaters at the same total NO_X emissions cap.

In California, US, the burner can be readily used in once-through-steam-generators (OTSG) and certain firetube boilers. For firetube boilers, the burners can provide an alternative to implementing an SCR, relief from emissions fees, and increased fuel efficiency. The payback for installation of the burners may not meet with a near-term desirable investment return but will offset significant SCR costs and alleviate permit issues.

Conclusion

The persistent challenge to reduce NO_X emissions requires technological innovation to move more equipment into cost-effective compliance. As industries seek to balance economic growth with environmental responsibility, investments in advanced combustion technologies, like the ClearSign Core M1 burner, offer a viable path forward. Using innovative burners, the industry can mitigate the health impacts of NO_X, address environmental concerns, and move toward a cleaner, more sustainable future within reasonable and justifiable operational and capital costs.

References

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