Evidence Note: NO_x Emissions in Flameless Oxidation of Hydrocarbons

Technology: flameless or distributed combustion (also known as MILD combustion = Moderate or Intense Low-Oxygen Dilution). By avoiding hot flame fronts, employing strong flue gas recirculation, and using diluted reaction mixtures, peak temperatures and radical concentrations are significantly reduced. This drastically limits thermal and prompt NO_x formation. As a result, laboratory and industrial applications have achieved NO_x emissions in the single-digit ppm range — in other words, 'virtually none'.

Key Figures & Mechanism

- In MILD combustion, reaction mixtures are highly diluted (through internal flue gas recirculation) and preheated, so the mixture is already above the auto-ignition temperature before a classical flame can form. (Source: Frontiers in Mechanical Engineering, 2020)
- Combustion occurs over a wider volume ('distributed reaction zone') instead of a narrow flame front — therefore, no extremely high local temperatures (> ~1800 K) and no short residence times in those zones → thermal NO_x (Zeldovich mechanism) is strongly reduced.
- Flue gas recirculation locally lowers the oxygen mass fraction, reduces radical concentrations (O, H, OH), and suppresses temperature peaks; thus both thermal and prompt NO_x formation routes are mitigated.
- If the fuel contains little or no chemically bound nitrogen, fuel-NO_x formation is negligible.

References

Iavarone, S. & Parente, A. (2020). 'NO_x Formation in MILD Combustion: Potential and Limitations of Existing Approaches in CFD', Frontiers in Mechanical Engineering, 6:13. DOI: 10.3389/fmech.2020.00013.
Link: https://www.frontiersin.org/journals/mechanical-engineering/articles/10.3389/fmech.2020.00013/full

Mini-Review: 'Heat Transfer Mechanisms in MILD Combustion Systems', Frontiers in Mechanical Engineering (2021).
Link: https://www.frontiersin.org/journals/mechanical-engineering/articles/10.3389/fmech.2021.505923/full

'Nitrogen oxides emissions from the MILD combustion …', Journal of the Air & Waste Management Association (2016).
Link: https://www.tandfonline.com/doi/full/10.1080/10962247.2016.1234420

Recommendations for Report Use

- Use Iavarone & Parente (2020) as the theoretical foundation for low NO_x formation.
- Refer to the JAWMA article (2016) for experimental emission data.

- Include FLOX® publications as practical examples/technology cases.
- Clarify that while ‘virtually no NO_x’ is stated, the data typically show single-digit ppm values (i.e., not literally 0 ppm).