Small-scale testing solving global emissions problems: Insights into catalytic N_2O decomposition

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Priority Topic Area: **Environmental Protection and Improvement**

Research Background

As greenhouse gas (GHG) emissions continue to rise rapidly (**Figure 1**), addressing climate change remains an urgent global challenge. While CO_2 is the most abundant GHG, **methane** and **nitrous oxide** (N_2O) have far greater **global warming potentials** (**28** and **265 that of CO_2** respectively)[1]. N_2O emissions stem from nitrogen-based fertilisers in **agriculture**, as well as key **industrial processes** such as adipic and nitric acid production. Alongside supporting decarbonisation efforts, this study highlights how **small-scale reactor testing** can enhance technical understanding of N_2O abatement through heterogeneous catalysis processes.

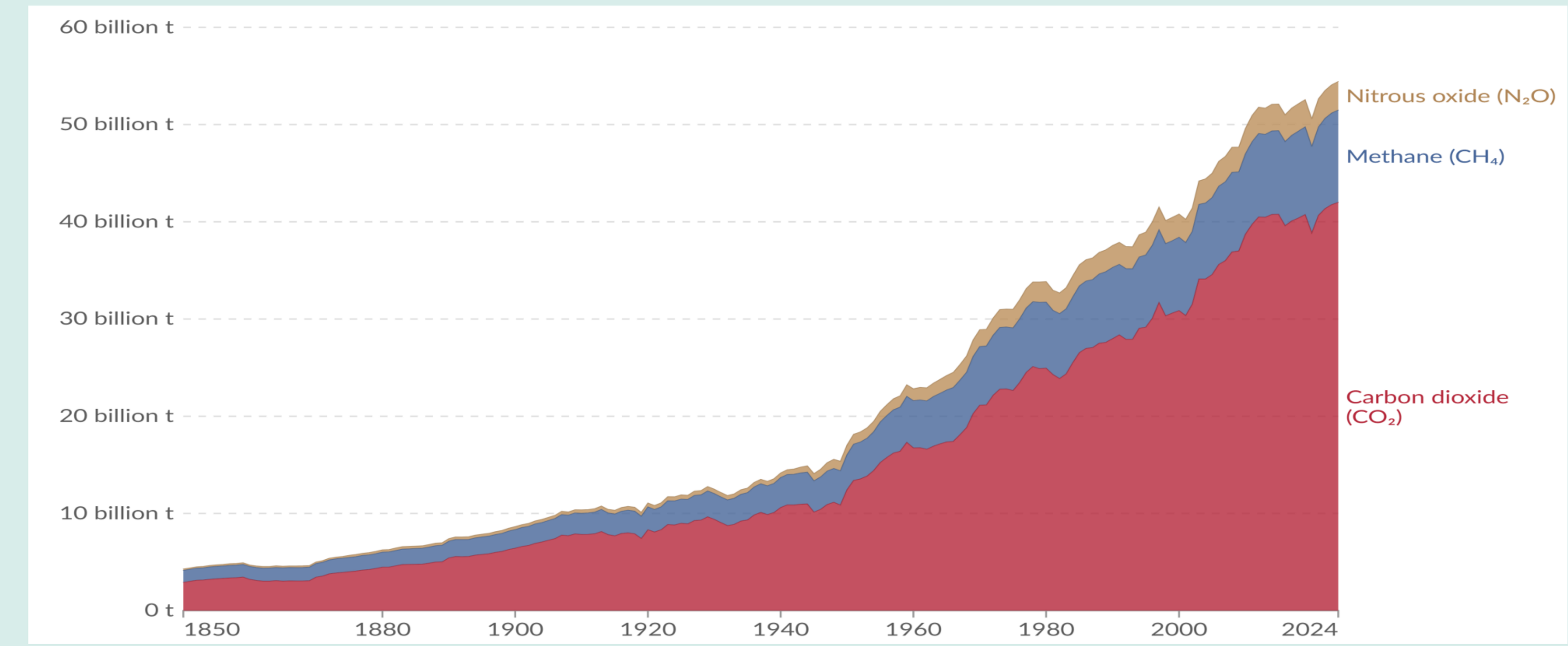

Figure 1: *A graph displaying a breakdown in the increase in GHG emissions from 1850-2024 (Ritchie, Roser and Rosado, 2024)*

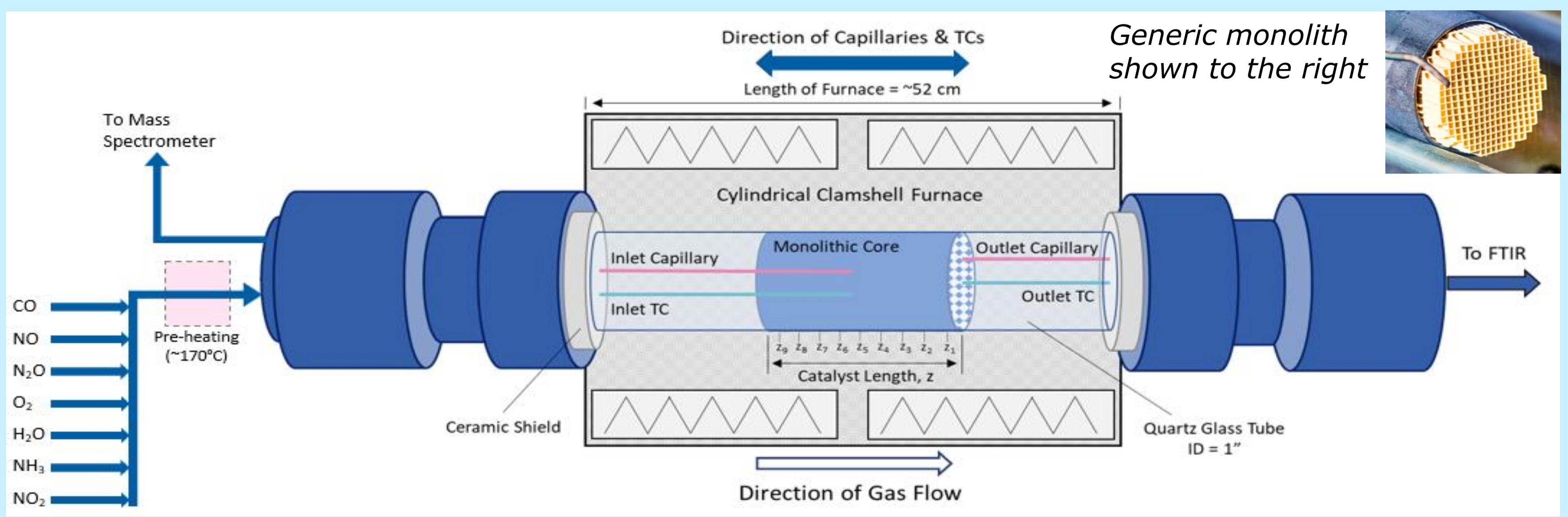

Figure 2: *A schematic displaying the SPACI-MS experimental rig [figure adapted from reference 2]*

Testing Methodology

- Extensive literature studies and JM's knowledge of **N_2O abatement** for automotive applications with **PGM catalysts** and **metallic zeolites** determined economic viability of an **iron-based zeolite** for N_2O abatement.
- After conducting a rigorous **Design of Experiment** (DoE), key process variables were rationalised, tested and optimised, whilst minimising the number of experiments.
- Experiments were carried out using **monolithic reactors**, which simulate gas exhaust conditions.
- Using **SPACI-MS** (**Spa**tially Resolved **C**apillary **I**nlet **M**ass **S**pectrometry, **Figure 2**) with an FTIR analyser, evolutions of reactions, and **concentration** and **temperature profiles** throughout catalysts were uncovered.

Experimental Findings

- **S**imulated **C**atalyst **A**ctivity **T**esting (**SCAT**) revealed effect of different process variables, including inlet temperature and gas concentrations
- Results showed the **advantageous effect** of **increasing NO** concentration on N_2O decomposition.
- **Figure 3** demonstrates how **SPACI-MS** supported this study, confirming the **beneficial effect of NO**, and showing the spatial resolution of N_2O conversion, which ranged from **~14%** to **>90%** by **5cm** along the core
- Corresponding temperature profiles showed exothermic increases from **42°C** to **198°C**, highlighting regions of **catalytic activity** and **thermal loads** on the catalyst.
- **Figure 5** contains a possible mechanism indicating how NO works to **reduce Fe-active sites** to **accelerate N_2O decomposition**.
- **Figure 4** used SCAT testing results to build a **predictive model** demonstrating the effect of varying inlet gases on N_2O conversion.
- Testing done within the context of **ammonia engines**, under **Innovate UK-funded project REGGAE**, validated previous trends observed.
- Early results suggest **NH_3** has **parabolic effect** on N_2O conversion, as seen in **Figure 4**.

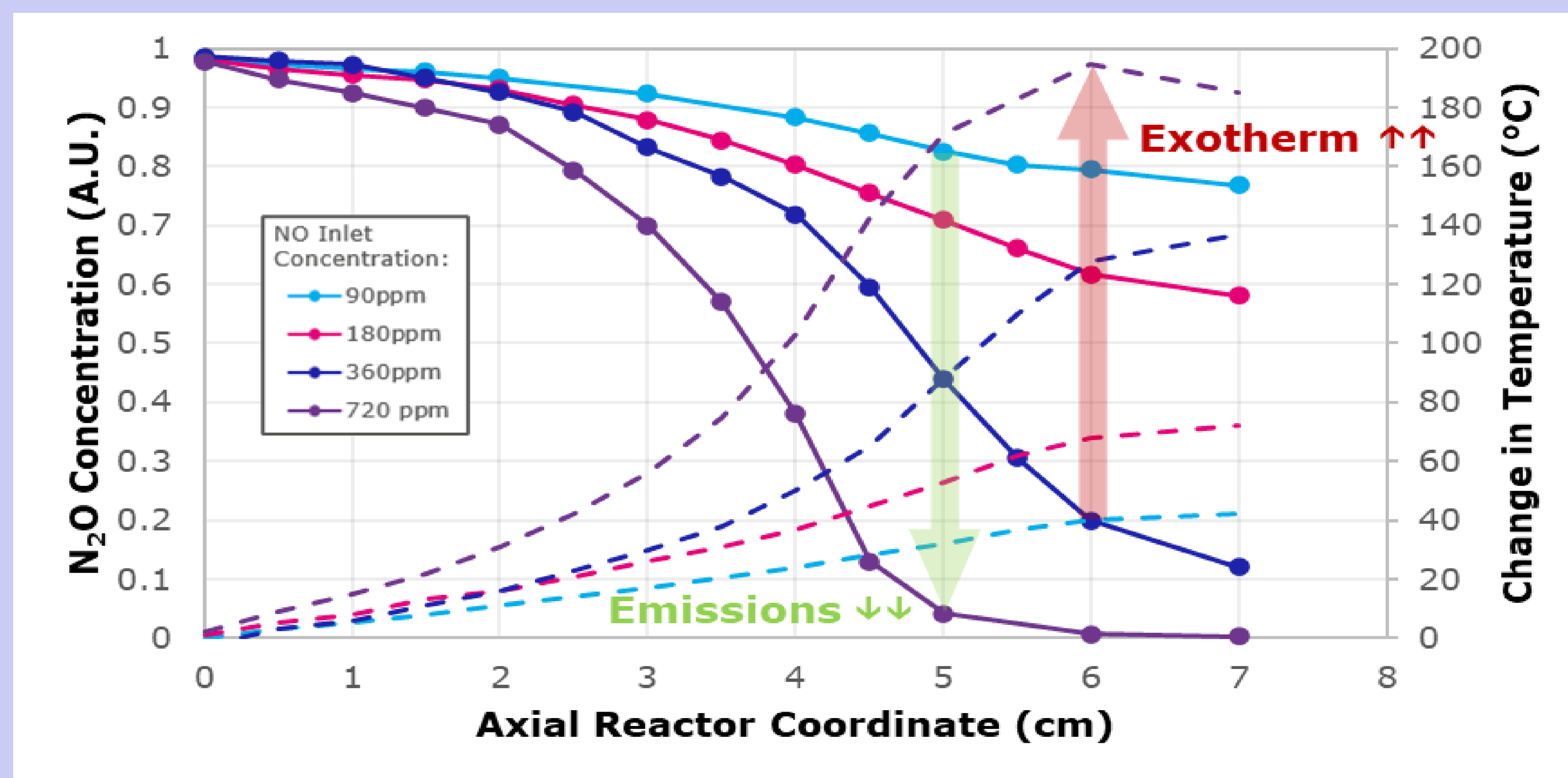

Figure 3: *A graph displaying the change in N_2O concentration along the axial length of the catalyst, according to varying NO inlet concentrations. The corresponding temperature profiles are indicated with dashed lines*

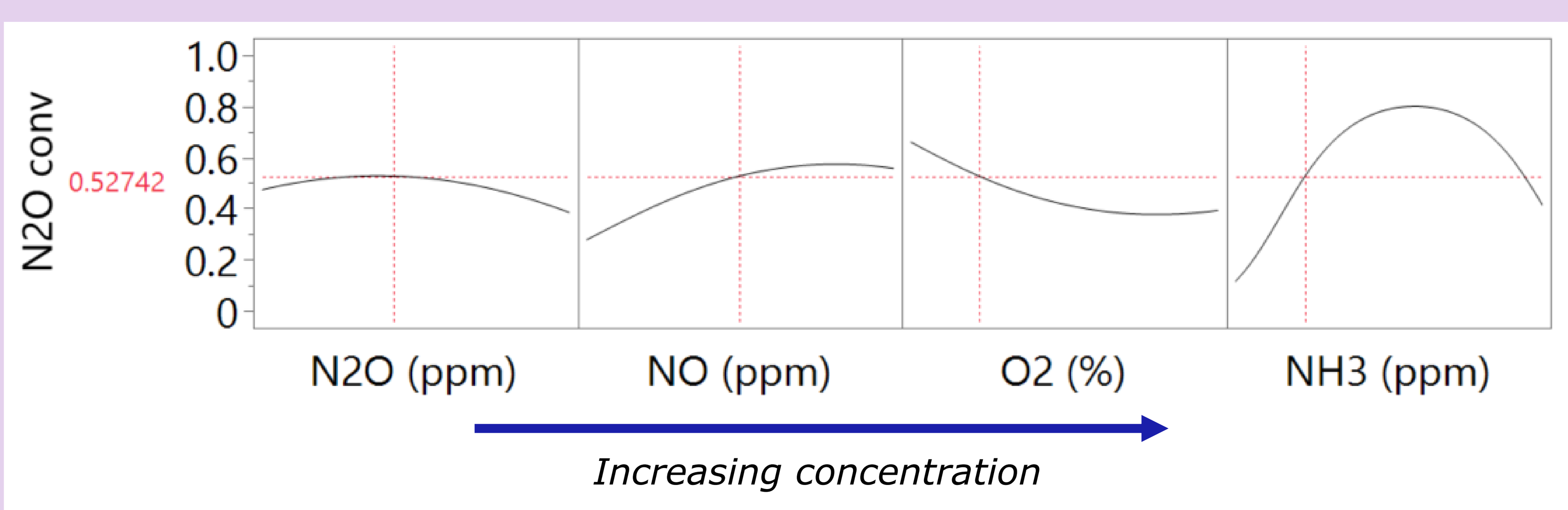

Figure 4: *The interactive DoE profiler which shows the main trends observed: N_2O concentration has no significant effect bar a slight negative trend; NO has a promoting effect and O_2 is demoting. There appears to be an optimum concentration of ammonia.*

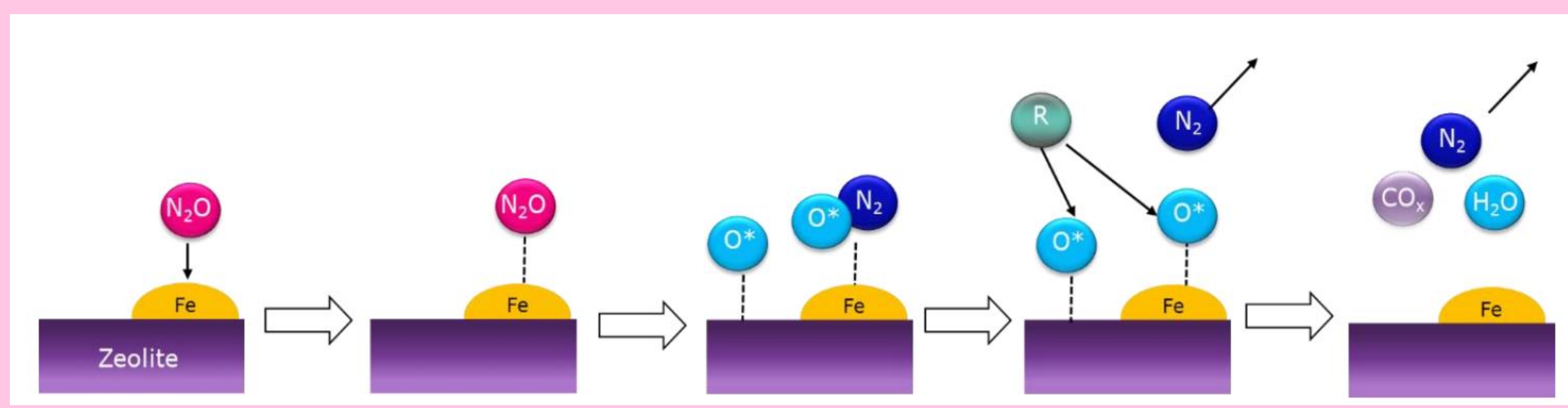

Figure 5: *Schematic showing the mechanism for N_2O decomposition whereby R is the reductant (either NO, NH_3, H_2 or a hydrocarbon) and that various products can be formed [figure adapted from reference 3].*

The Importance of Understanding N_2O Decomposition

N_2O has a global warming potential 265[1] times that of CO_2 and is currently the most harmful gas to the ozone layer[4]. It is therefore paramount to abate as much N_2O as possible to contribute towards meeting globally agreed upon climate change targets. Research like this shows how current catalytic technology can help companies improve on sustainability targets as well as phasing in newer, greener fuels.

Next Steps & Future Development

Testing like this shows promising potential for extension from traditional autocatalysis applications to future ones, like data centres, wastewater treatment, or alternative internal combustion engine fuels for marine applications. There is further room for novel formulations and catalysts to be tested to accommodate more stringent emissions requirements.

Acknowledgements

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References

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