Department of Materials Science and Engineering Seminar Series 2025

HIGH-TEMPERATURE CATALYTIC AMMONIA COMBUSTION

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Date and time: Tuesday, 3 February 2026, 3:00 PM

Venue: E4-04-07 E-Cube 3

Abstract

Ammonia (NH3), a carbon-free fuel derived from air, water, and renewable energy, is a promising energy carrier due to its high energy density (12.7 MJ/L) and scalable infrastructure. However, its combustion faces challenges, including a narrow flammability range, high ignition temperature, slow flame speed, and significant NOx emissions. Current mitigation strategies fall into two categories: (1) fuel modification (e.g., co-firing with hydrogen from NH3 cracking), which improves reactivity but increases NOx and requires complex heat-integrated systems; and (2) advanced combustion techniques (e.g., rich-lean staging and MILD combustion), which reduce NOx but remain technically challenging.

An alternative approach is catalytic ammonia combustion (CAC), which leverages surface-mediated reactions to enhance combustion efficiency while suppressing NOx emissions-benefiting from NH3's inherent role as a reductant in selective catalytic reduction processes. While early CAC research focused on pollution control or low-temperature applications (< 900°C), recent studies demonstrate its potential for energy generation, achieving low NOx at moderate temperatures (~600 °C) or under fuel-rich conditions. However, high-temperature CAC (HT-CAC, >1000 °C) faces limitations due to (i) stringent catalyst stability requirements and (ii) elevated NOx emissions.

In the first study, we synthesized atomically dispersed Pt species on 10% ZrO2-Al2O3 via a one-pot method. The catalyst ignites NH3 combustion at just 200 °C

and exhibits exceptional stability at 1100 °C, reducing NOx emissions to ~50 ppm without detectable NH3 slip. Through in-situ CO-DRIFTS, NaCN etching experiments, and XAS analysis, we identified Pt single atoms as the active species and elucidated the reaction mechanism via in situ NH3-DRIFTS.

In the second study, we addressed the phase instability of Al2O3 supports at ⩾ 1200 °C, where conventional dopants (Zr, Ba, Ce, Mg, Mn) fail to prevent transformation to α-Al2O3 (specific surface area < 5 m2/g). Comparative experiments revealed that 5 mol. % La doping (La5Al95Ox) effectively inhibits this transformation, maintaining ~ 40 m2/g surface area at 1200 °C, whereas ⩾ 10 mol. % La forms perovskite-phase LaAlO3-a denser structure with reduced surface areas. The resulting Pt/La5Al95Ox catalyst demonstrated robust thermal stability in HT-CAC at 1200 °C.

In the third study, we explored high-entropy fluorite oxide aerogels (HEFOA) synthesized via supercritical drying. HEFOA's enhanced chemical disorder confers higher surface area and thermal resistance than its low-entropy counterpart (LEFOA). A one-pot Pt incorporation yielded Pt@HEFOA, which showed good activity and stability during a 50-hour HT-CAC test at 1200 °C, paving the way for durable catalysts in extreme-temperature applications.

Collectively, this thesis demonstrates that combining noble-metal catalysts with refractory support is a viable strategy for HT-CAC, offering potential to decarbonize "hard-to-abate" sectors like industrial heating and advance sustainable NH3-based energy cycles.

Biography

Du Yankun is a PhD candidate in the Department of Materials Science and Engineering at the National University of Singapore, co-supervised by Assistant Professor Qian He and Professor Ning Yan. He holds bachelor's and master's degrees in engineering. His research focuses on high-temperature catalytic ammonia combustion and the synthesis of thermally stable oxide materials for energy and environmental applications.

Please join us!

HOST: Asst Prof Zhao Ming