Ammonia Combustion with Near-Zero Pollutant Emissions

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• Motivation

• Background

• Experimental Setup

• Results

• Conclusions

• Future Work

• References
• Why Ammonia?
• What’s the driving force behind the current research?
  – Carbon emissions, displacing fossil fuels
• Neal Sullivan et. al., 2002; Experimental and Numerical study of NO\textsubscript{x} formation CH4/NH3 mixture in laminar non-premixed flame.

• C. Duynslaegher et. al., 2009; Investigated NO\textsubscript{x} formation mechanisms in NH3 combustion.

• M. Zieba et. al., 2009; FLOX of NH3. Studied the NO\textsubscript{x} chemistry.

• Zhenyu Tian et. al., 2009; Experimental and kinetic modeling study of premixed NH3/CH4/O2/Ar flames.

• T. Mendiara, P. Glarborg, 2009; Ammonia chemistry in oxy-fuel combustion of methane; Used CHEMKIN modeling.

Very Limited study has been reported on Ammonia Combustion for use in the practical scale combustors/furnaces.
Simulated Oil Heating Furnace

- Heating Capacity up to 40 kW
- Equipped with Thermocouple & Pressure Transducers.
- Custom Built Swirl-plate Stabilizer.
- Easily Movable fuel nozzle.
- Optical diagnostics accessible flame.
- Exhaust section: Chilled water-line & Sampling Locations with a optical accessible window.

- **Key features**: Flexible chamber with or without flame holder and self-sustained heat recovery system.
Experimental Set-Up

Nozzle Positions
1. Position A => 1.0” up
2. Position B => 0.5” up
3. Position C => Reference
Experimental Procedure

- **Fuel Mixtures:** \( \text{H}_2/\text{NH}_3 \) & \( \text{CH}_4/\text{NH}_3 \)

- **Keywords:**
  1. Heat-Rate (KW)
     \[ m_{\text{NH}_3} \text{HHV} + m_{\text{H}_2/\text{CH}_4} \text{HHV} \]
  2. E\%NH\(_3\) = fraction of total input energy contributed by ammonia.

- **Flame-Holder effects:**
  1. Creates reverse flow of the exhaust towards the upstream \( \rightarrow \) **better mixing.**
  2. Provide high residence time.

CH\(_4\)/NH\(_3\)/Air, 300C, Equiv Ratio \( \sim 0.95 \), HeatRate \( \sim 10 \text{KW} \) & E\%NH\(_3\) = 15
Experimental Procedure

Study of Natural Gas (CH₄) and Hydrogen (H₂) Replacement by NH₃

Effect of:
- Flame holder
- Preheated Air Temperature
- Equivalence Ratio
- Different Fuel Nozzle Positions

on E%NH₃ and emissions

Emissions Analyzer:
- NO - chem cell
- CO (low) - chem cell
- CO (high) - chem cell
- O₂ - chem cell
- Unburned HC's – NDIR
- CO₂ – NDIR
- Ammonia - NDIR
CH₄/NH₃/Air, 300°C, Q_total ~ 560 slpm, Max E%NH₃, HR ~ 15KW
Equivalence Ratio

$\text{CH}_4/\text{NH}_3/\text{Air}, \text{300C, Q}_\text{total} \sim 560 \text{ slpm, Max E}\%\text{NH}_3, \text{HR} \sim 15\text{KW}$
Results & Discussion

Temperature Effect

\[ \text{H}_2/\text{NH}_3/\text{Air}, 300\degree \text{C}, \ Q_{\text{total}} \sim 300 \text{ slpm, Equiv Ratio} \sim 0.95 \]

Fig. 7

**w/o FH**

![Graph showing NOx (ppm) vs. Preheated Air Temp (C) for different E%NH3 values without fuel injection.](image)

**Max E%NH3**

- 50
- 55
- 60
- 65
- <75

Fig. 8

**w/ FH**

![Graph showing NOx (ppm) vs. Preheated Air Temp (C) for different E%NH3 values with fuel injection.](image)

**Max E%NH3**

- 70
- 70
- 75
- 85
- ~90

**H$_2$/NH$_3$/Air, 300\degree \text{C}, Q_{\text{total}} \sim 300 \text{ slpm, Equiv Ratio} \sim 0.95**

Fig. 7

**H$_2$/NH$_3$/Air, 300\degree \text{C}, Q_{\text{total}} \sim 300 \text{ slpm, Equiv Ratio} \sim 0.95**

Fig. 8
Results & Discussion

H₂/NH₃/Air Phi = 0.95 w/ FH

- E%NH₃ = 50
- E%NH₃ = 70
- E%NH₃ = 90

NOₓ (ppm) vs. Preheated Air Temp (°C)
Results & Discussion

H₂/NH₃/Air Phi = 0.95 w/ FH

NH₃ (ppm)

Preheated Air Temp (°C)

E%NH₃ = 50
E%NH₃ = 70
E%NH₃ = 90
Results & Discussions

Equivalence Ratio

H₂/NH₃/Air, 300°C, Q_total ~ 300 slpm, E%NH₃ ~ 50

![Graph showing NOx and NH3 levels with equivalence ratio.](image)
Results & Discussion

H2/NH3/Air, 300C, Q_total ~ 300 slpm, E%NH3 ~ 50, w/ FH

- NOx
- NH3

Equiv Ratio vs NOx (ppm) and NH3 (ppm)
Nozzle Effect

H$_2$/NH$_3$/Air, 300C, Q$_{total}$ ~300 slpm, Equiv Ratio ~ 0.95

Fig. 18

Fig. 19
• For hydrocarbon replacement, difficult to achieve high replacement with near-zero NOx and ammonia. CO can be high near stoichiometric conditions

• Hydrogen addition of 10-30% shows good potential for near-zero emissions of NOx, ammonia, CO, CO₂, and unburned HC’s

• Strategies include flame holder, preheating, nozzle conditions, equivalence ratio
Other Ongoing and Future Work

- Currently evaluating chemical mechanism for NOx formation with CHEMKIN

- Flame speed analysis and emissions measurements to validate CHEMKIN model

- Investigating catalytic decomposition of NH3 using exhaust heat recovery to eliminate need to add hydrogen
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Questions !!!