Ammonia Combustion with Near-Zero Pollutant Emissions

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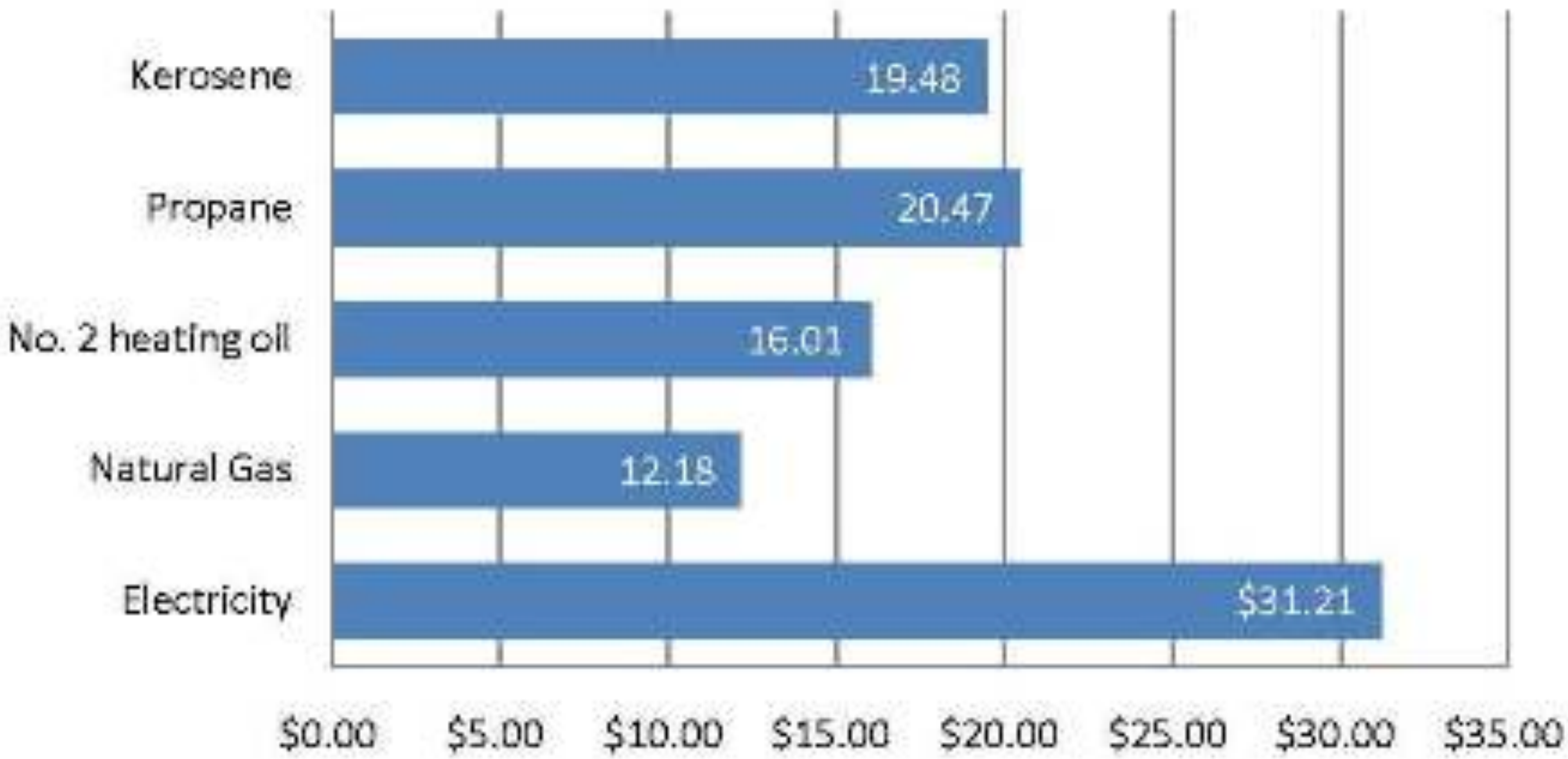
Presentation's Outline

- Motivation
- Background
- Experimental Setup
- Results
- Conclusions
- Future Work
- References

Motivation

- Why Ammonia?
- What's the driving force behind the current research?
  - Carbon emissions, displacing fossil fuels



Background

- Neal Sullivan et. al., 2002; Experimental and Numerical study of NO_x formation CH4/NH3 mixture in laminar non-premixed flame.
- C. Duynslaegher et. al., 2009; Investigated NO_x formation mechanisms in NH3 combustion.
- M. Zieba et. al., 2009; FLOX of NH3. Studied the NO_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.

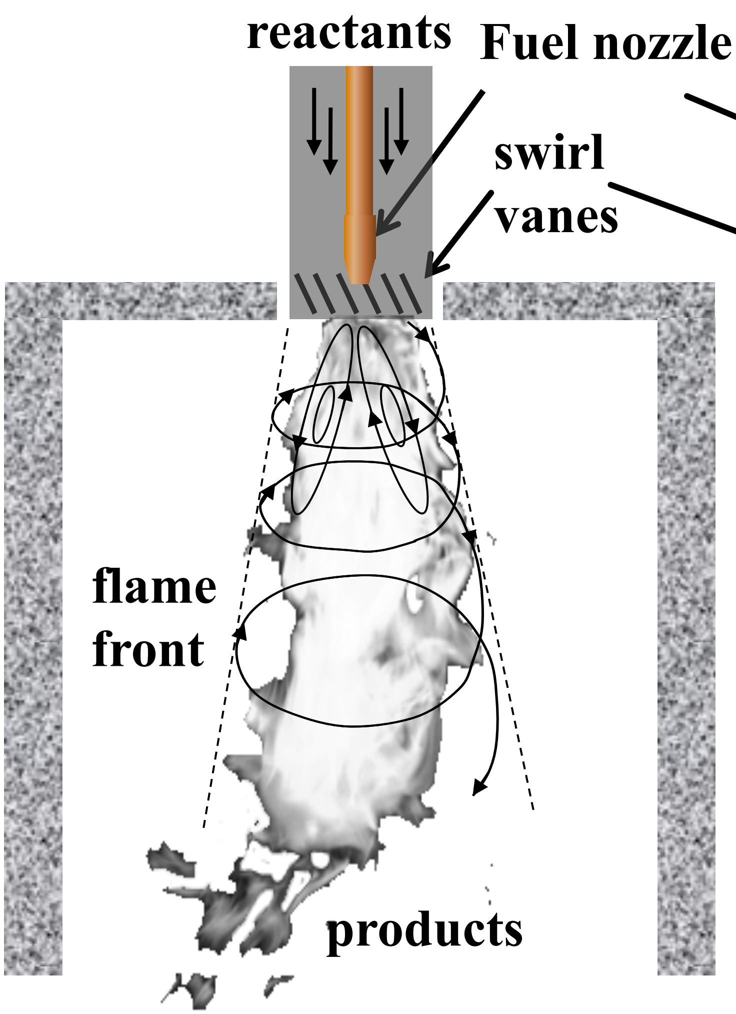
Experimental Set-Up

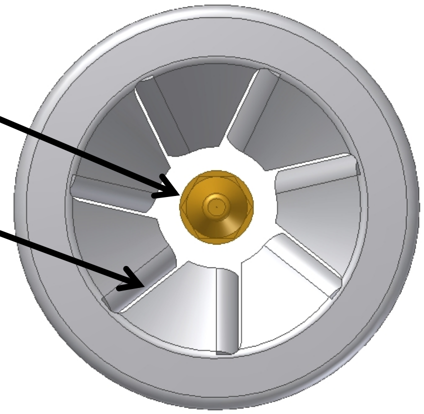
Simulated Oil Heating Furnace

- 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:** H_2/NH_3 & CH_4/NH_3

CH_4/NH_3/Air, 300C, Equiv Ratio ~0.95, HeatRate ~ 10KW & E%NH_3 = 15

- **Keywords:**
  1. Heat-Rate (KW)

     $$\dot{m}_{NH3}HHV + \dot{m}_{H2/CH4}HHV$$

     .
  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 → **better mixing**.
  2. Provide high residence time.

Experimental Procedure

Study of Natural Gas (CH_4) and Hydrogen (H_2) Replacement by NH3

Effect of;

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

on E%NH_3 and emissions

Emissions Analyzer:

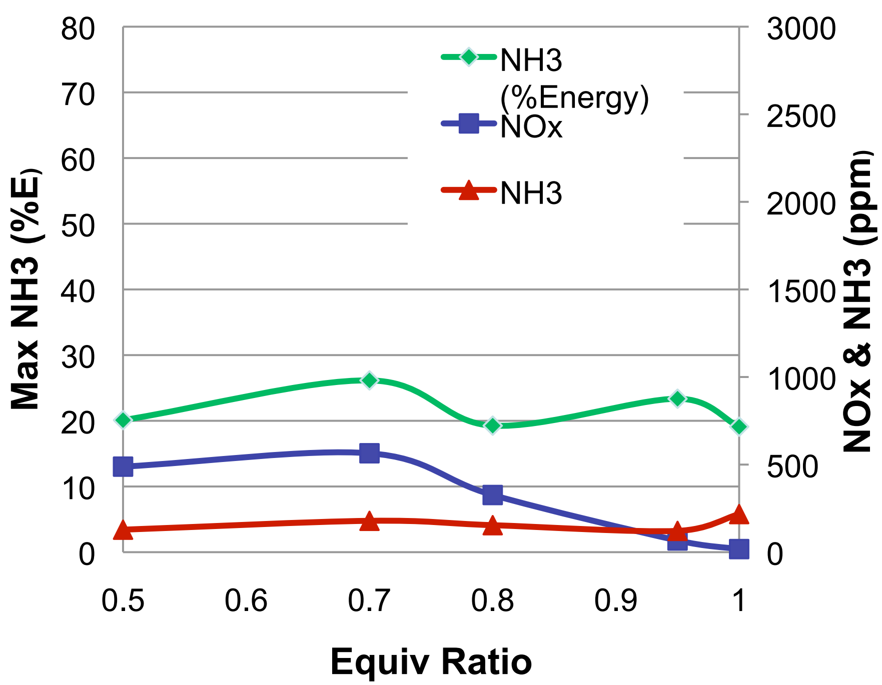
- NO - chem cell
- CO (low) - chem cell
- CO (high) - chem cell
- O2 - chem cell
- Unburned HC's – NDIR
- CO2 – NDIR
- Ammonia - NDIR

Results & Discussion

Equivalence Ratio

CH_4/NH_3/Air, 300C, Q_total ~ 560 slpm, Max E%NH_3, HR ~ 15KW

w/o FH



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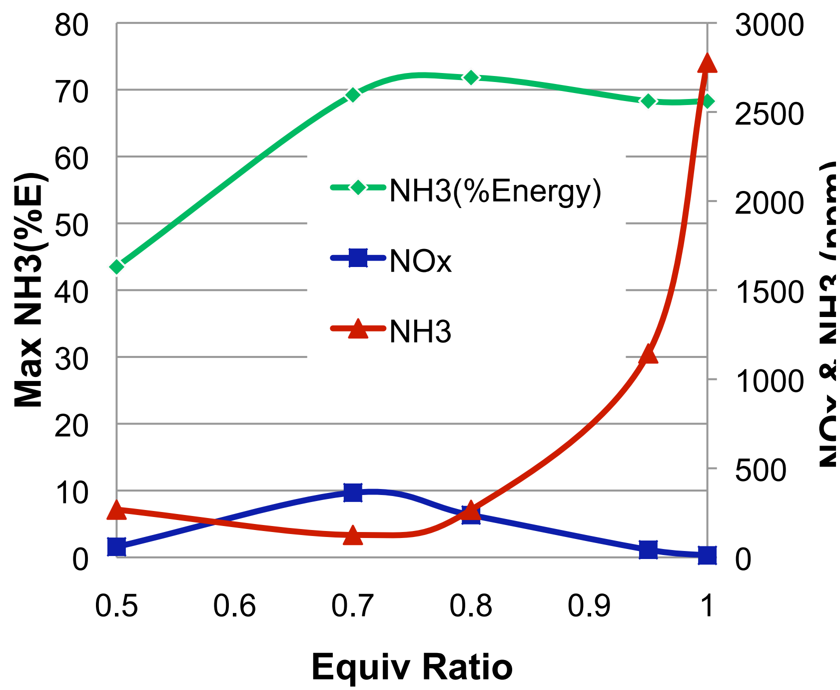

Results & Discussion

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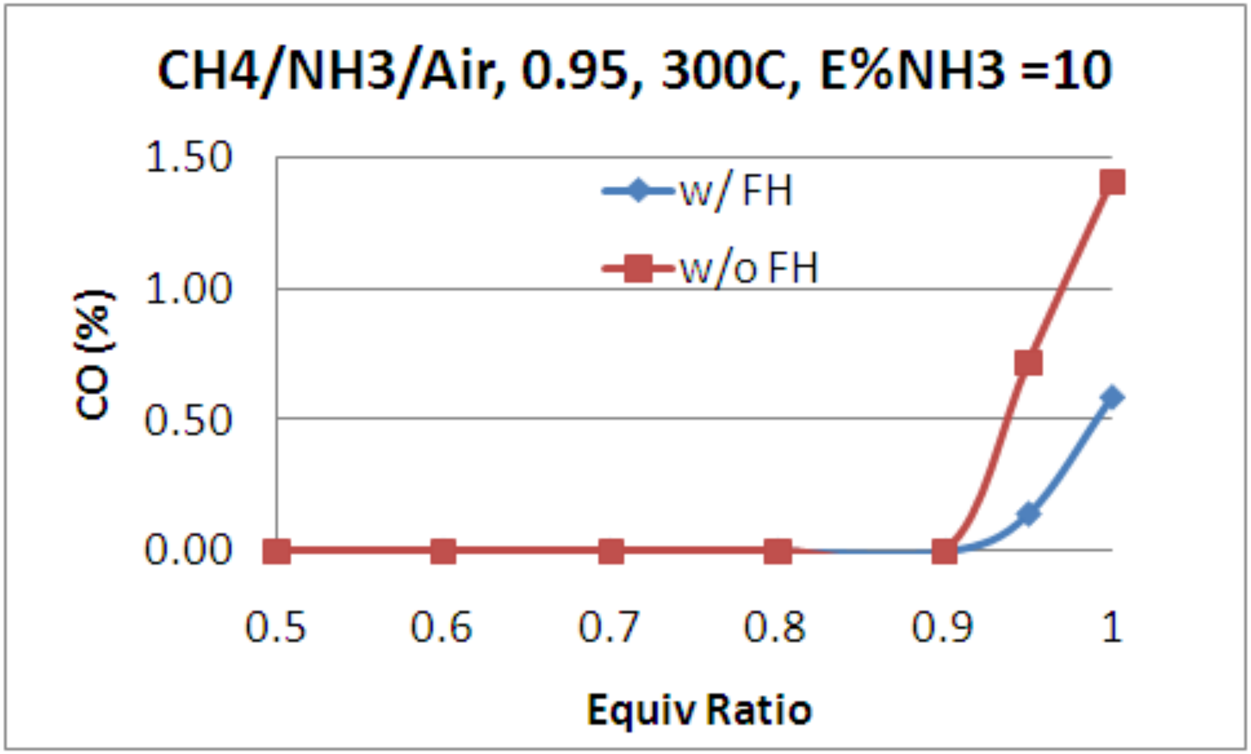

Results & Discussion

Temperature Effect

H_2/NH_3/Air, 300C, Q_total ~ 300 slpm, Equiv Ratio ~ 0.95

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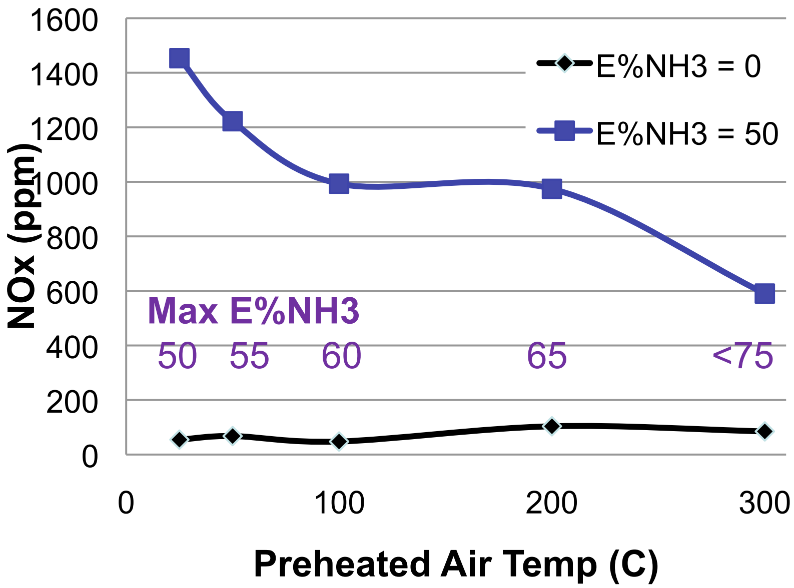


Fig. 7

w/ FH

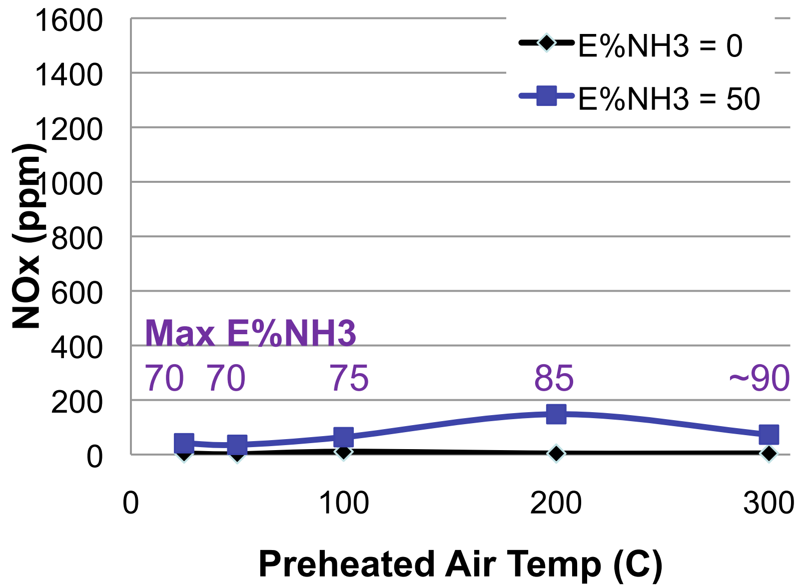
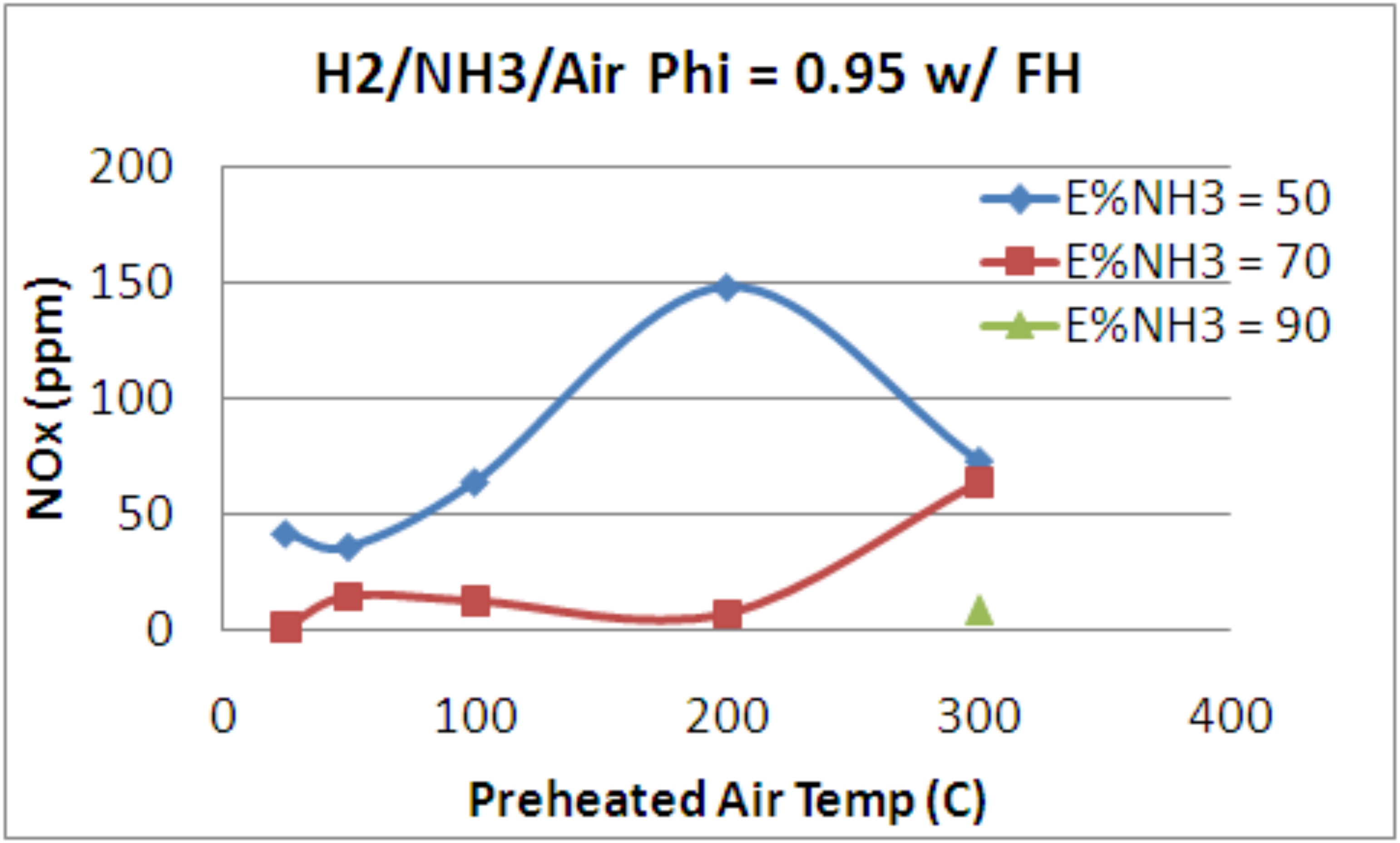
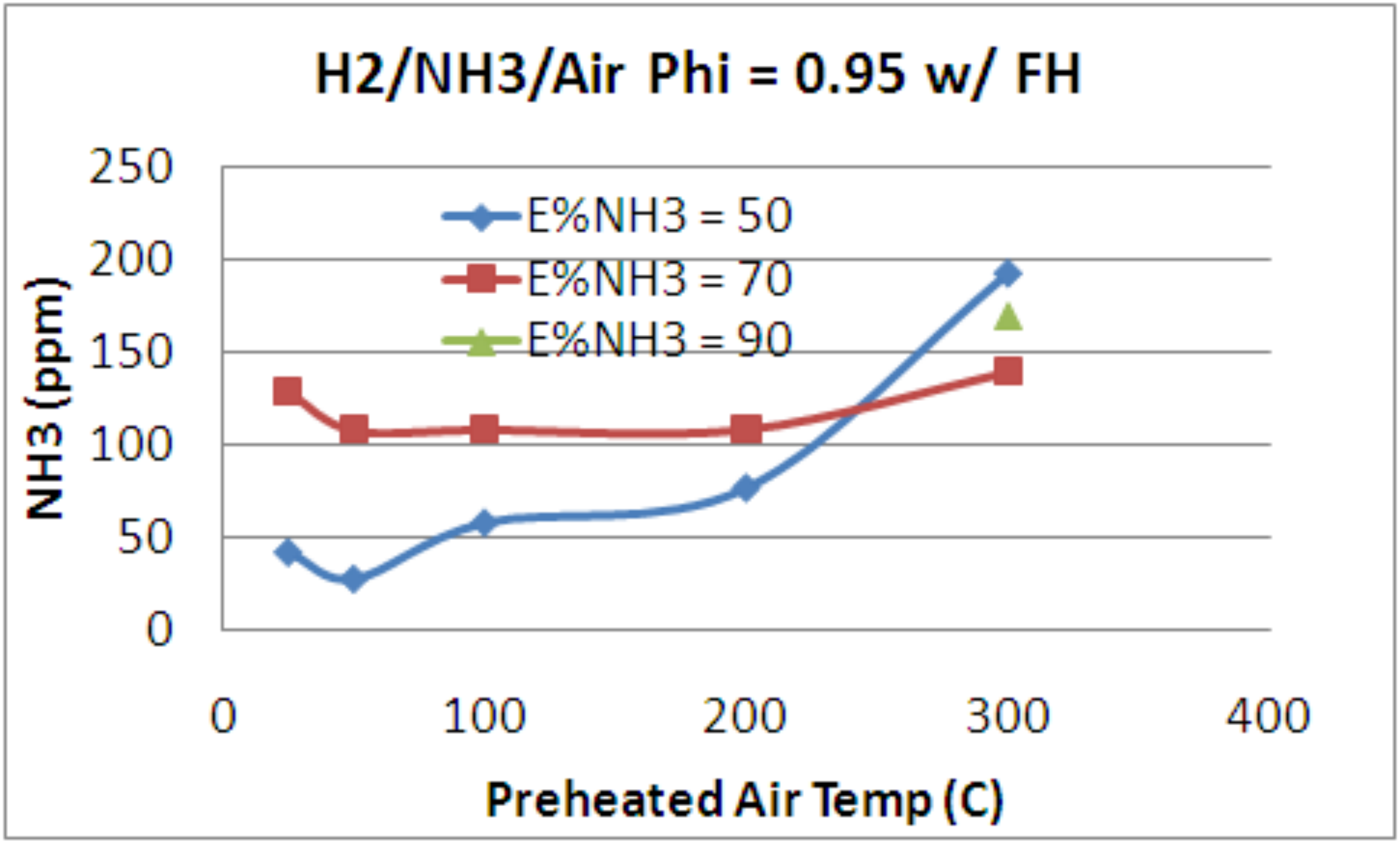


Fig. 8

Results & Discussion



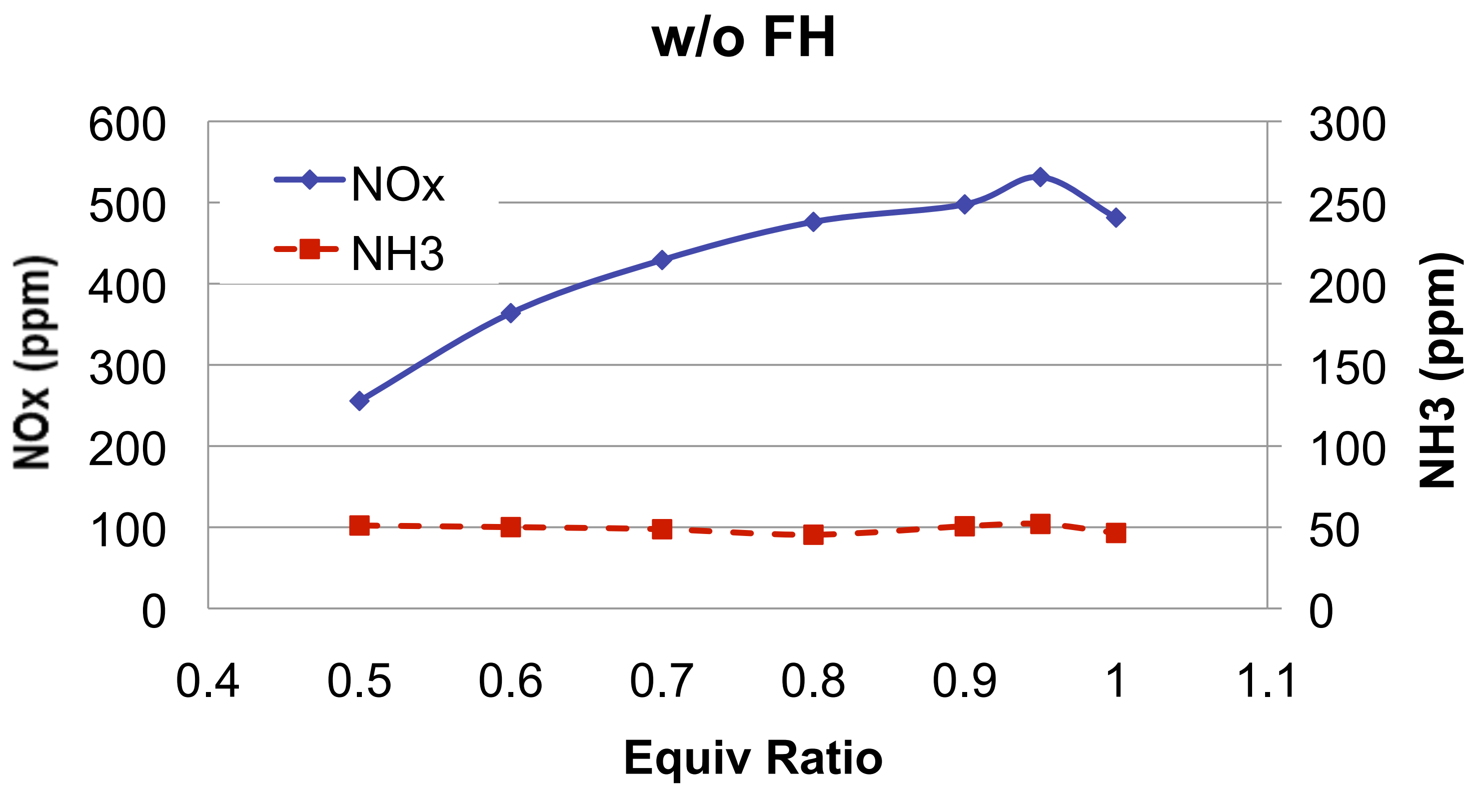
Results & Discussion



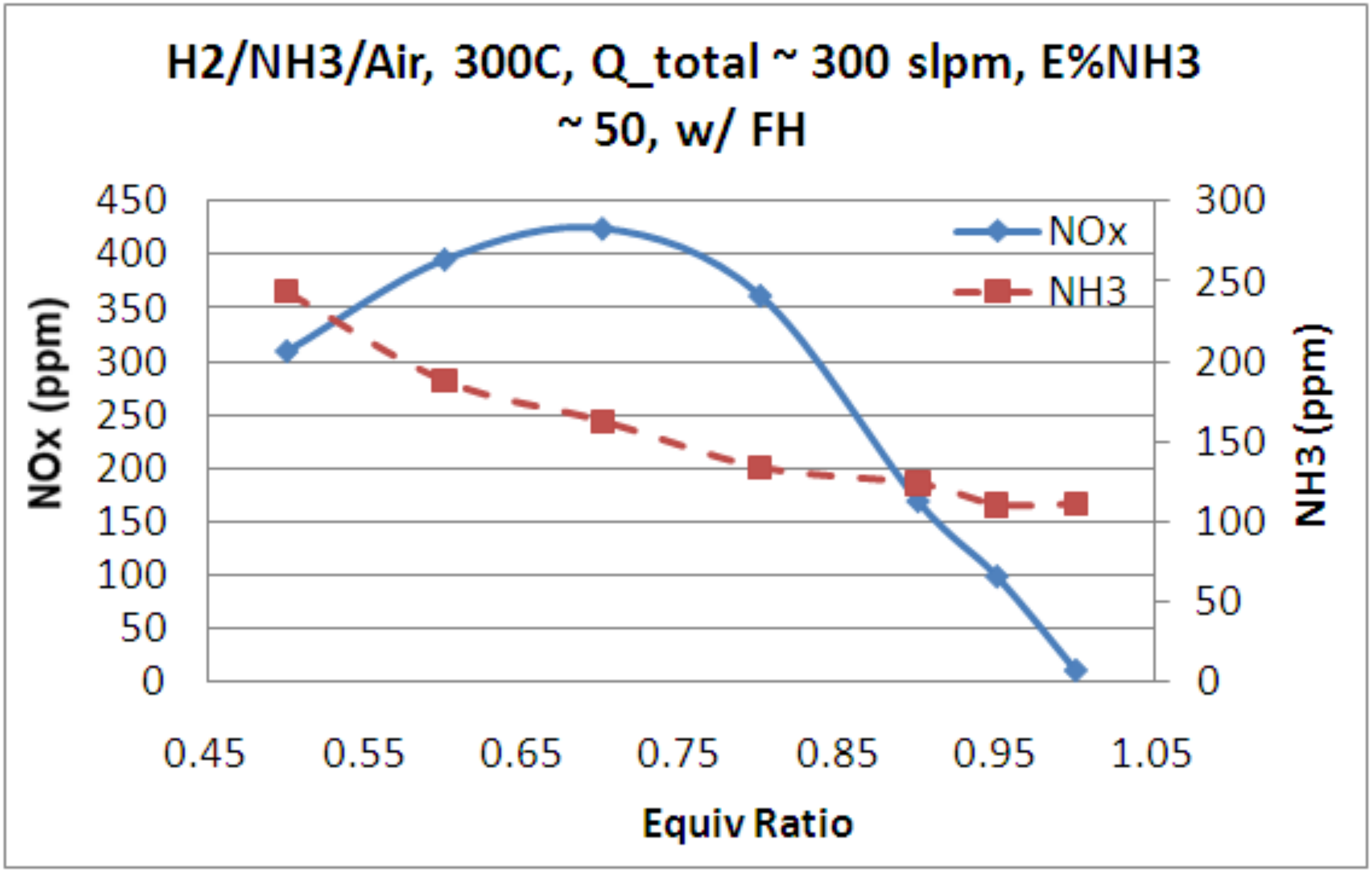
Results & Discussions

Equivalence Ratio

H_2/NH_3/Air, 300C, Q_total ~ 300 slpm, E%NH_3 ~ 50



Results & Discussion



Results & Discussion

Nozzle Effect

H_2/NH_3/Air, 300C, Q_total ~300 slpm, Equiv Ratio ~ 0.95

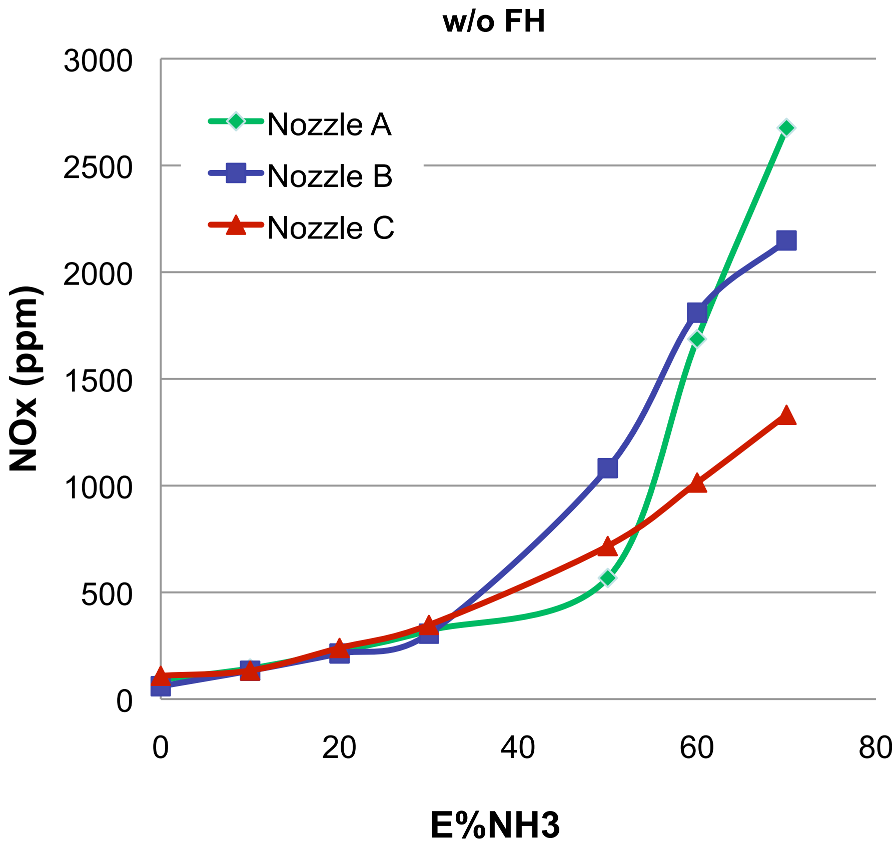


Fig. 18

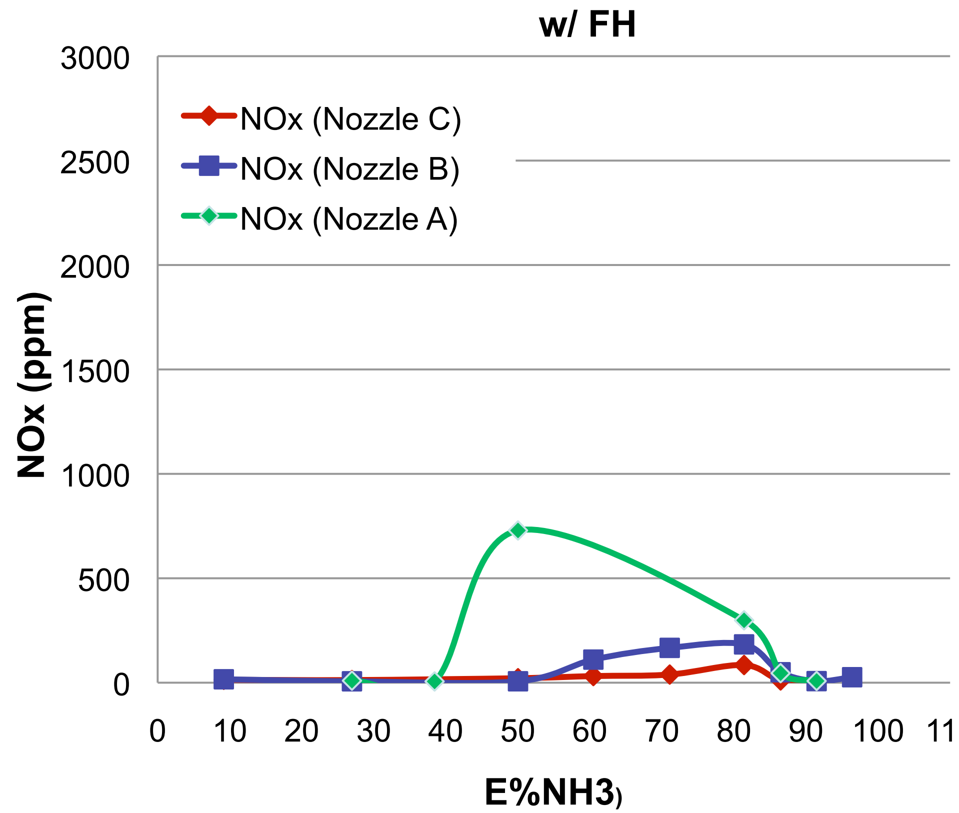


Fig. 19

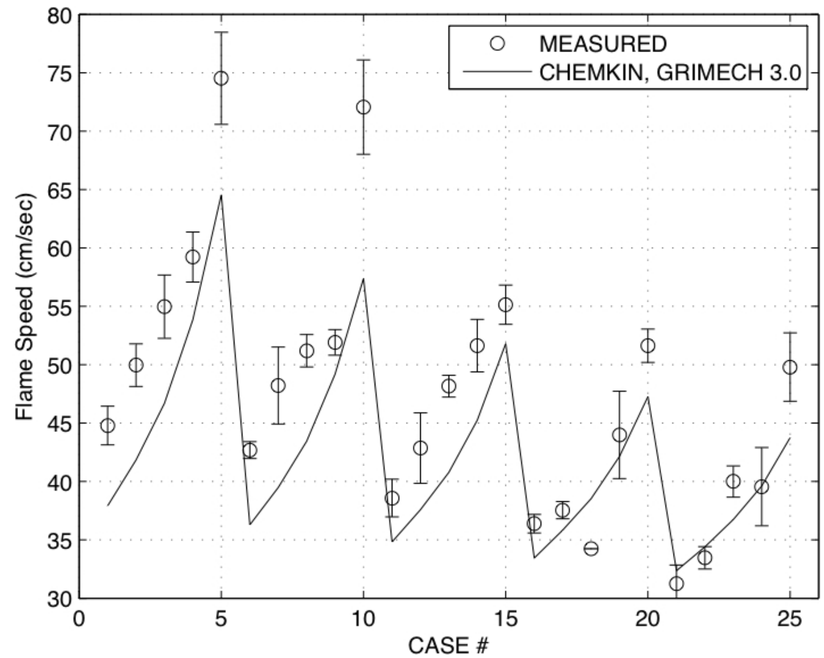
Conclusions

- 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, CO_2, 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 !!!