Combustion Efficiency and Exhaust Emissions of Ammonia Combustion in Diesel Engines

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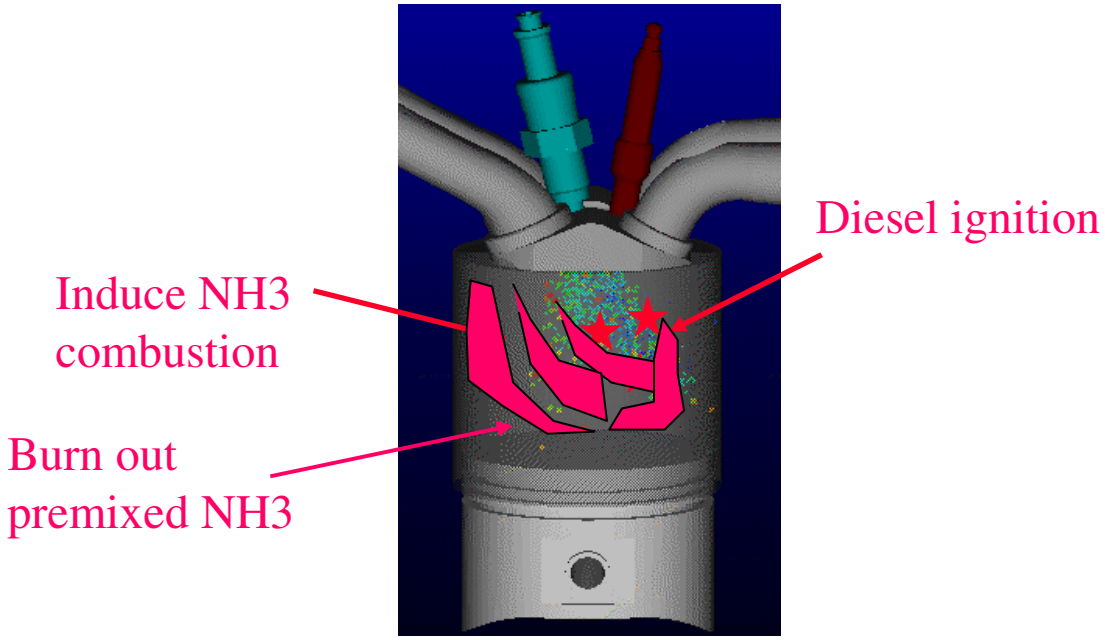
Background

- Motivation
  - Ammonia (NH_3) combustion does not generate CO_2
  - Hydrogen carrier, renewable, etc.
- Challenges
  - Ammonia is very difficult to ignite
    - Octane number ~ 130
    - Autoignition T ~ 651 ºC (gasoline: 440 ºC; diesel: 225 ºC)
  - Ammonia flame temperature is lower than diesel flame T
  - Erosive to some materials
  - Ammonia emissions can be harmful
  - Potential high NOx emissions due to fuel-bound nitrogen

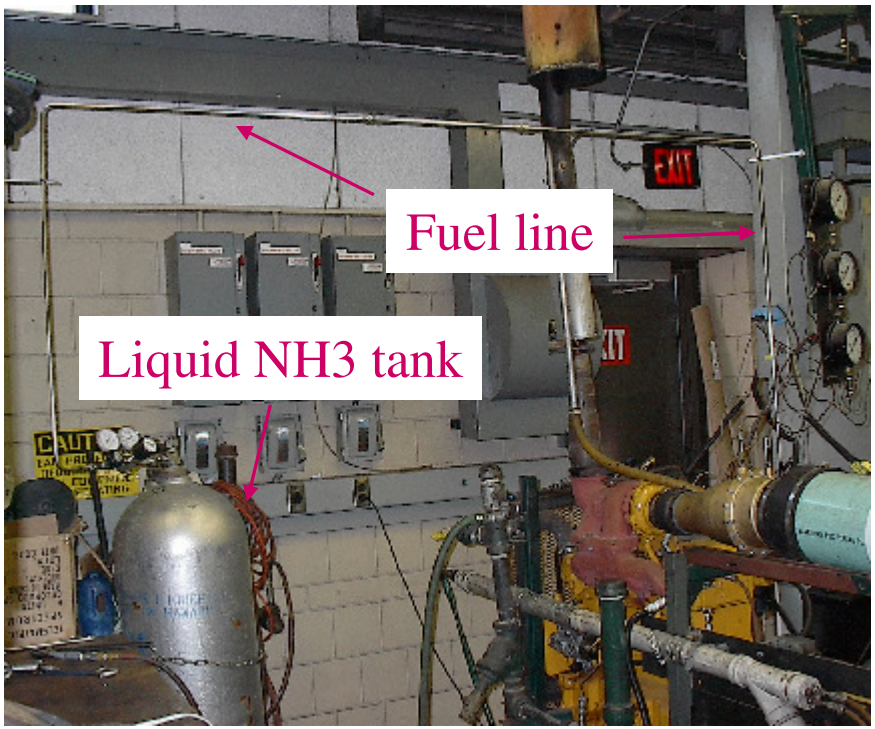
Approach

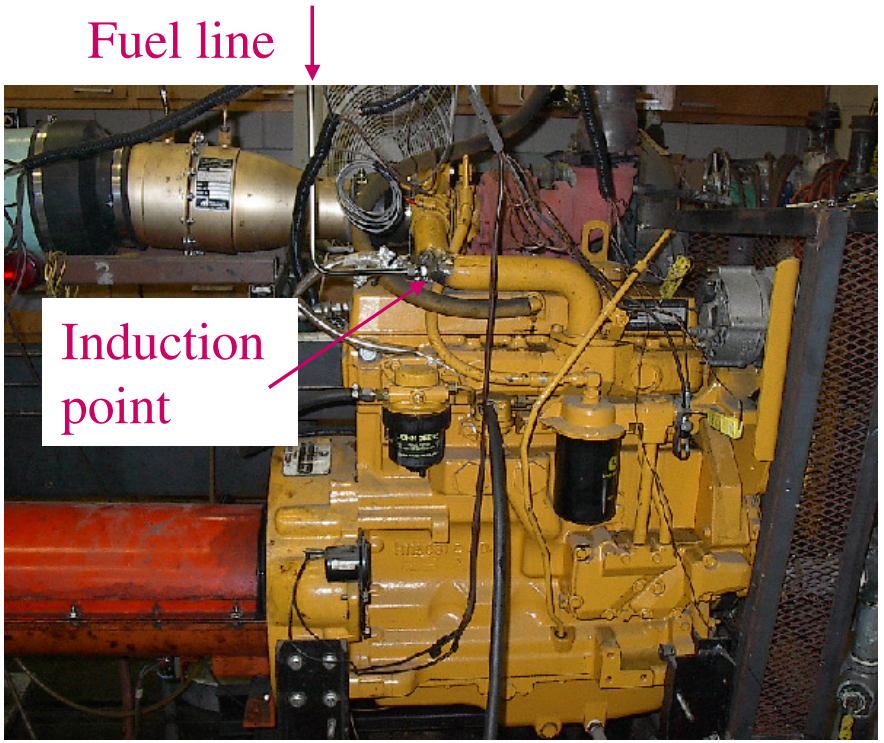
- Introduce ammonia to the intake manifold
- Create premixed ammonia/air mixture in the cylinder
- Inject diesel (or biodiesel) to initiate combustion
  - Without modifying the existing diesel injection system



Ammonia Fueling System

- Fuel system
  - Vapor ammonia introduced into the intake duct – after turbo, before manifold





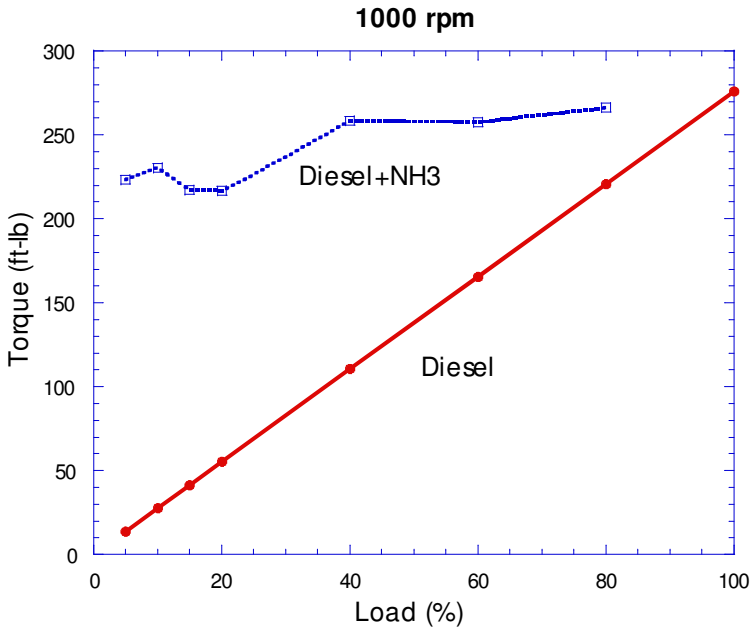
Review – Previous Results

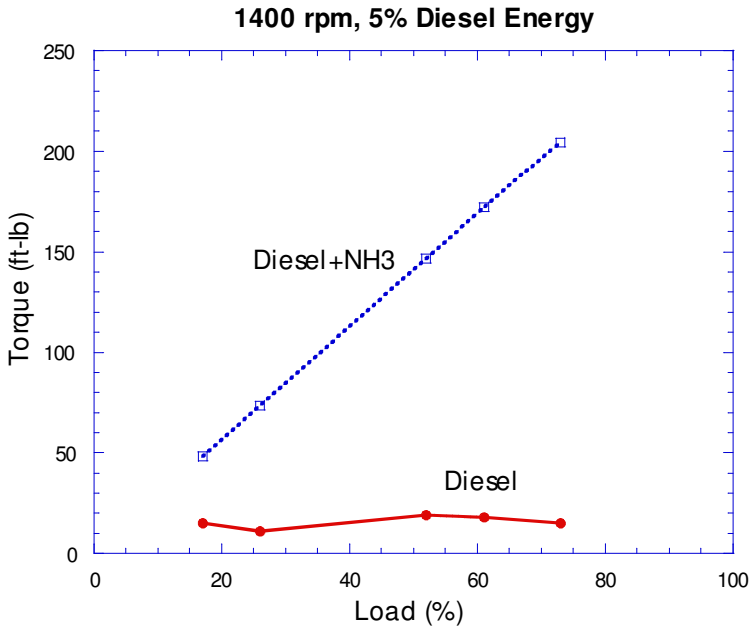
- Demonstrated ammonia combustion with D2 and B100

1. Constant ammonia flow rate → constant torque increase

2. Varied diesel and ammonia flow rates to maintain constant torque

3. Used 5% diesel, varied ammonia flow rate for variable torque



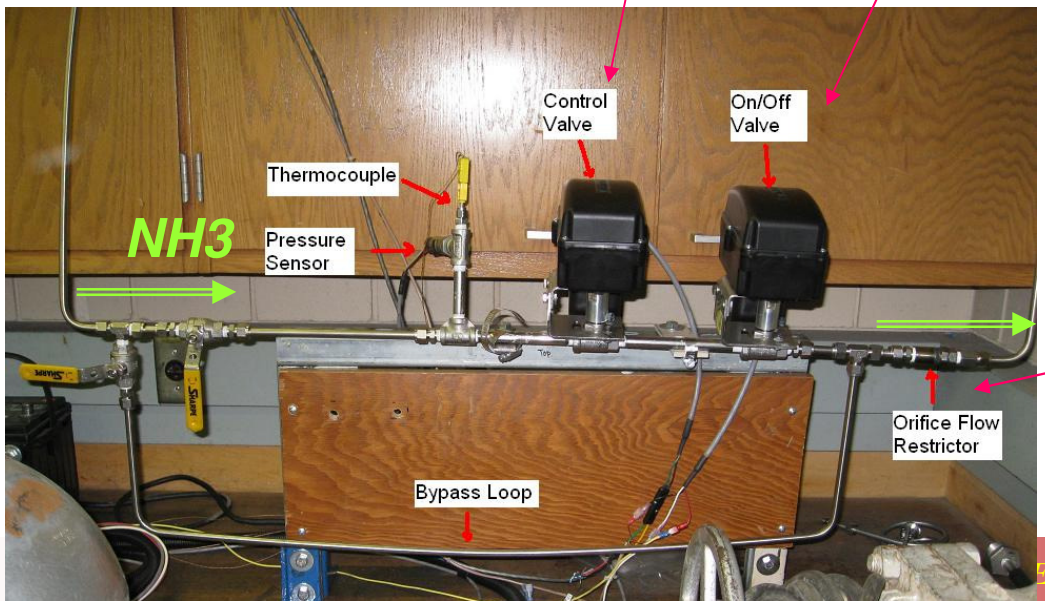


Present Results

- Ammonia flow rate control
- Gaseous and particulate emissions measurements
- Exhaust ammonia measurements
- Ammonia combustion efficiency
- Engine thermal efficiency analysis

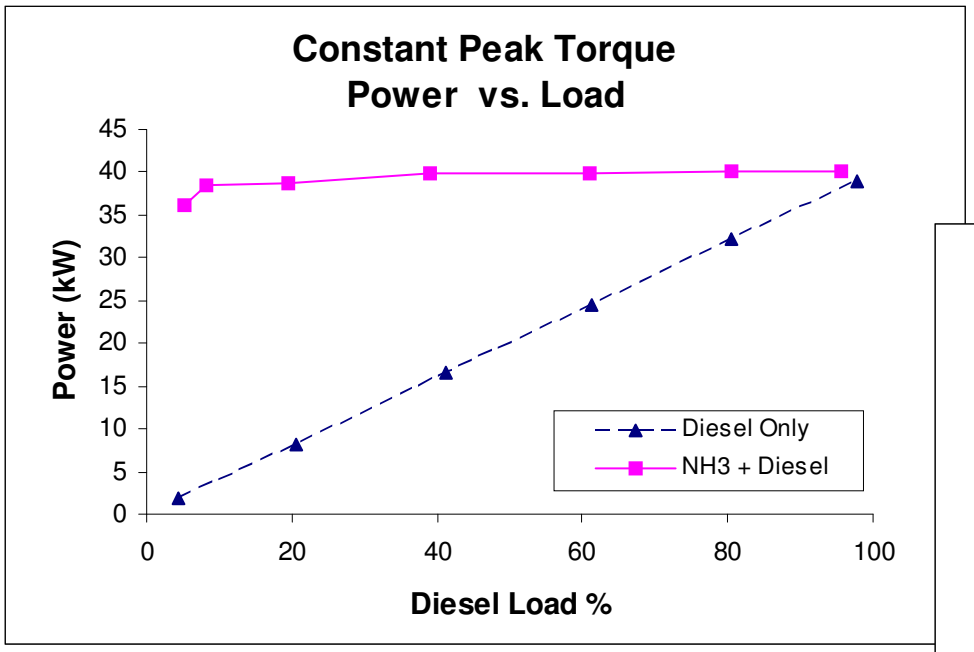
Ammonia Flow Rate Control

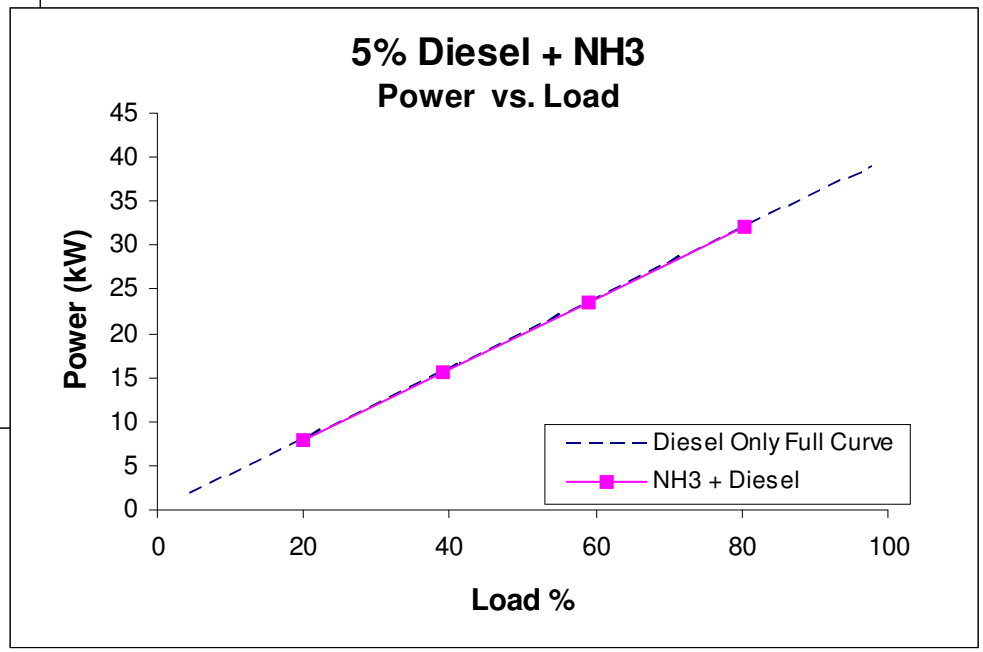
- Issues:
  - Materials – require stainless steel, carbon steel
  - High pressure, high flow rate (as compared to other lab uses)
    - 0.5 lb/min for 1000 rpm, full load, 95% energy replacement
  - Ag industrial application – regulating liquid ammonia at higher flow rates
- Developed control mechanism



Engine Test Results

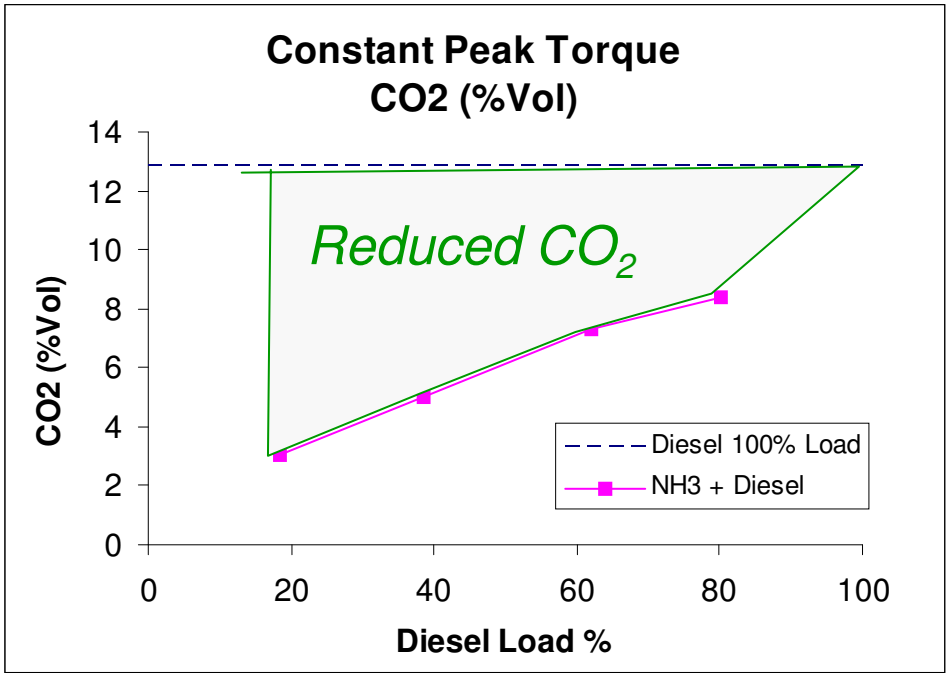
- Obtained stable engine power output

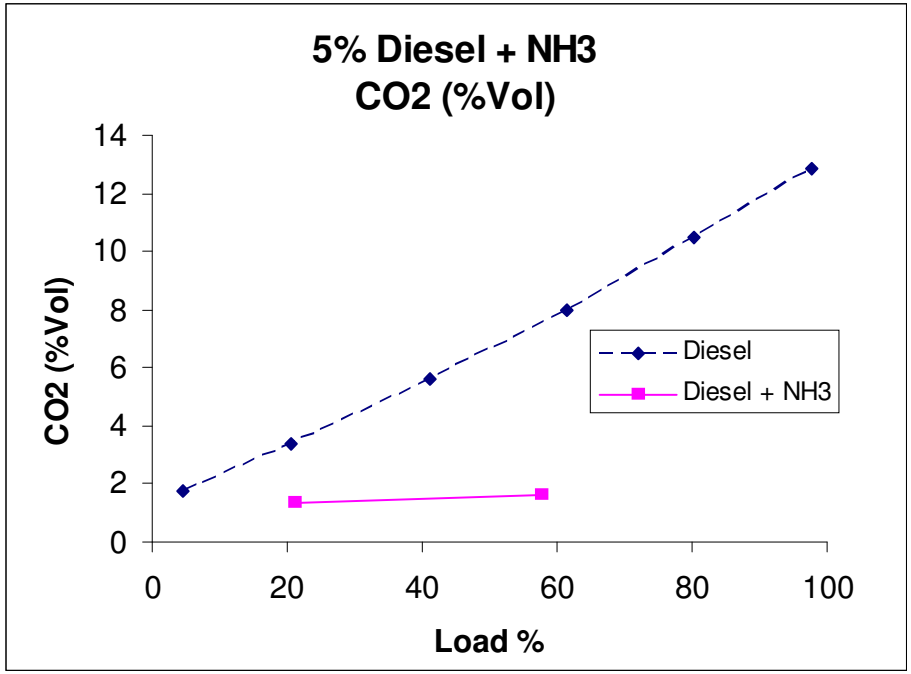




CO_2 Emissions

- Always much lower than diesel values

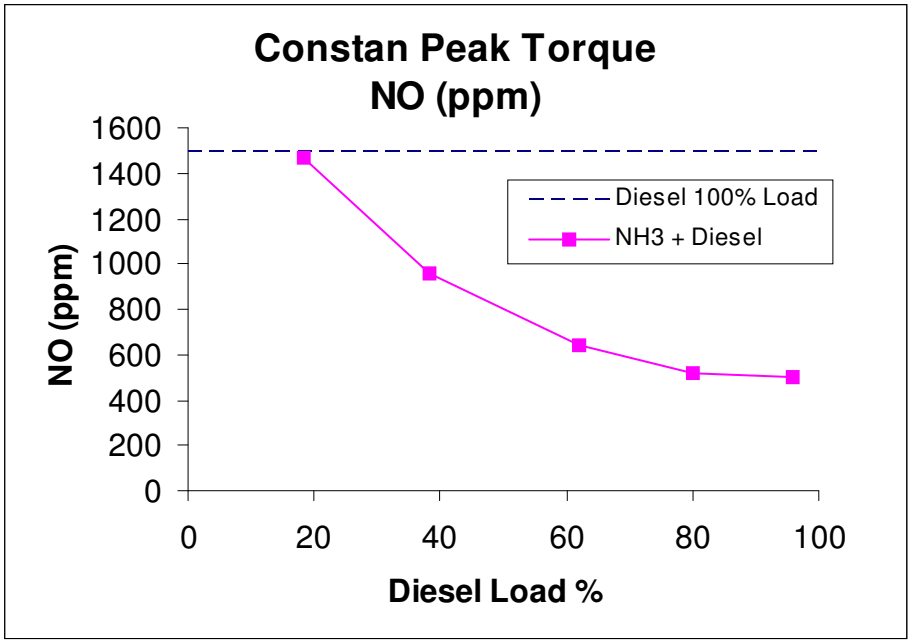


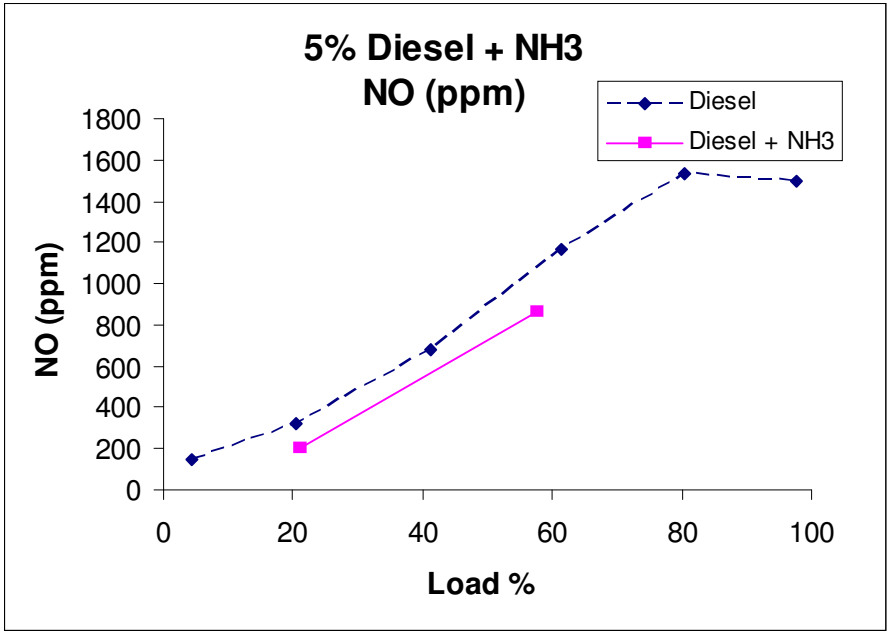


NO Emissions

- Ammonia can poison NO converter
  - Replace material from COM-03 to COM-GC3
  - This “glassy carbon” is resistant to such poisoning

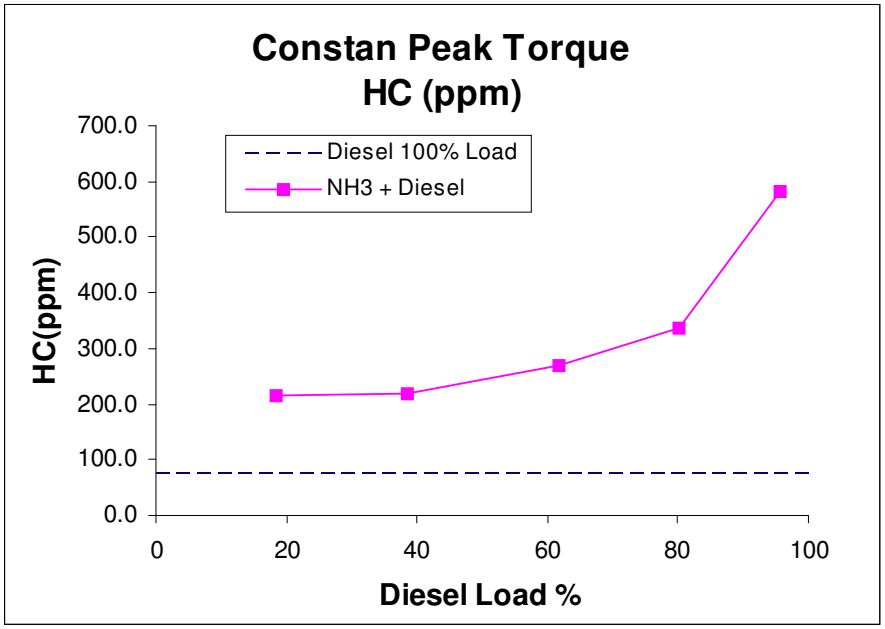
- Thermal NO & fuel-bound NO

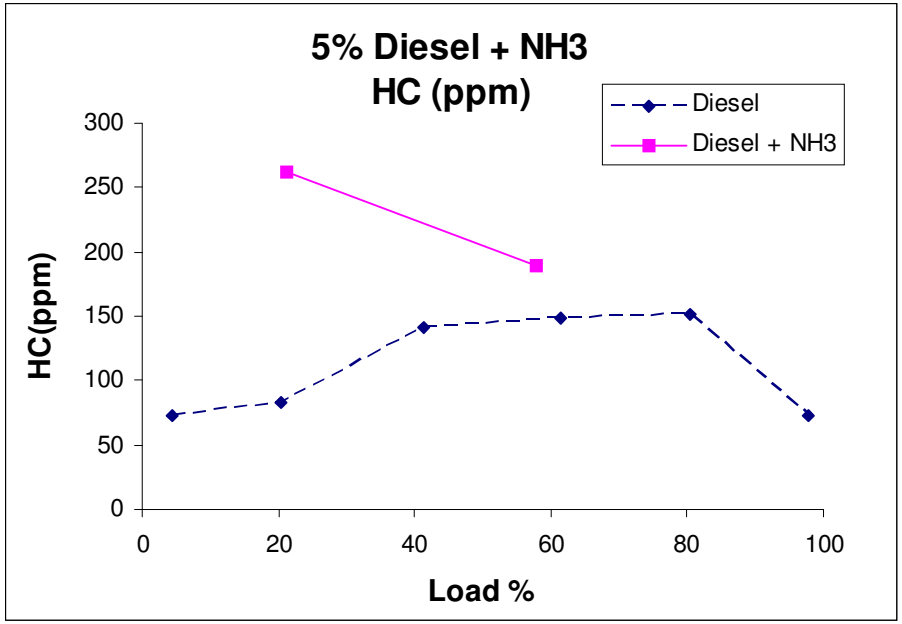




Hydrocarbon Emissions

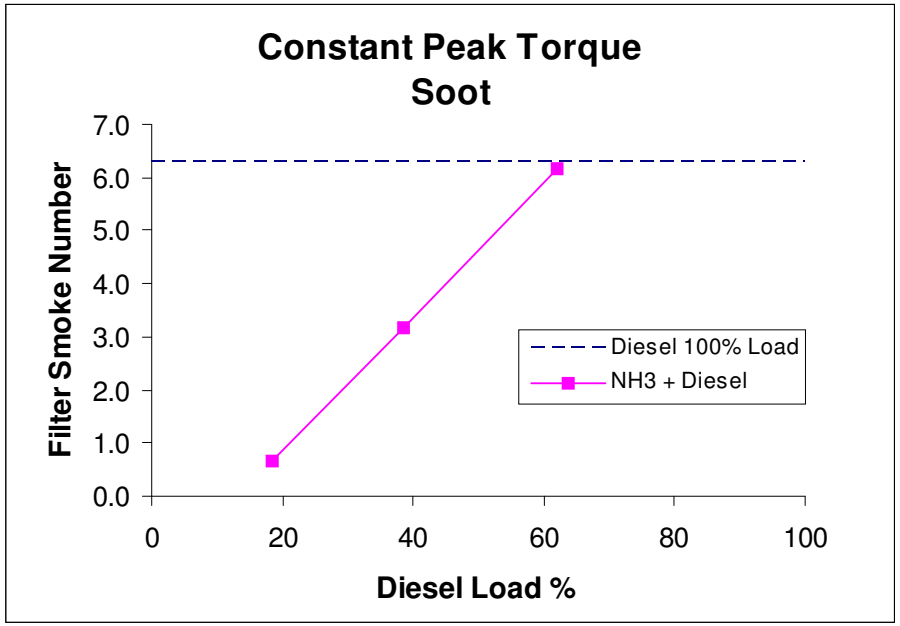
- Hydrocarbons are higher
  - Due possibly to incomplete combustion of diesel fuel caused by lower flame temperature of ammonia

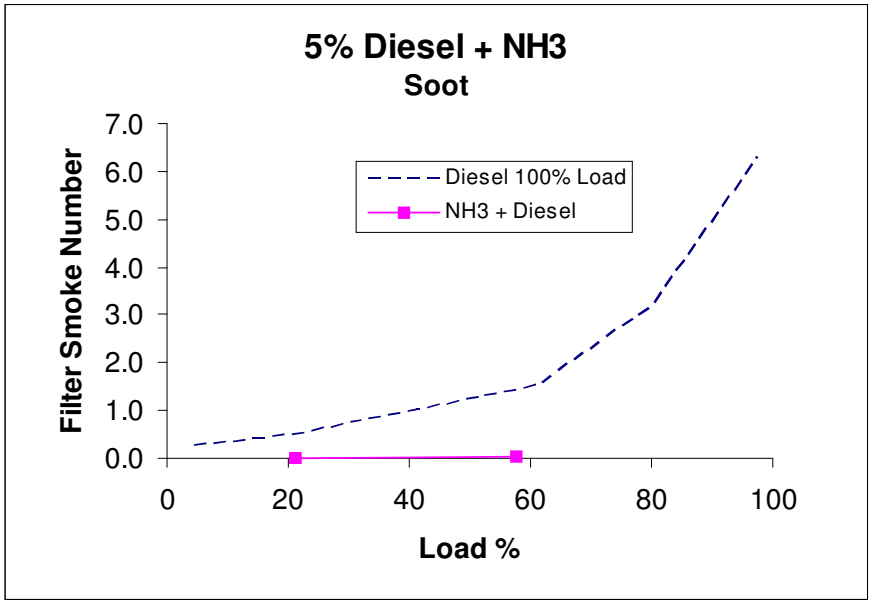




Soot Emissions

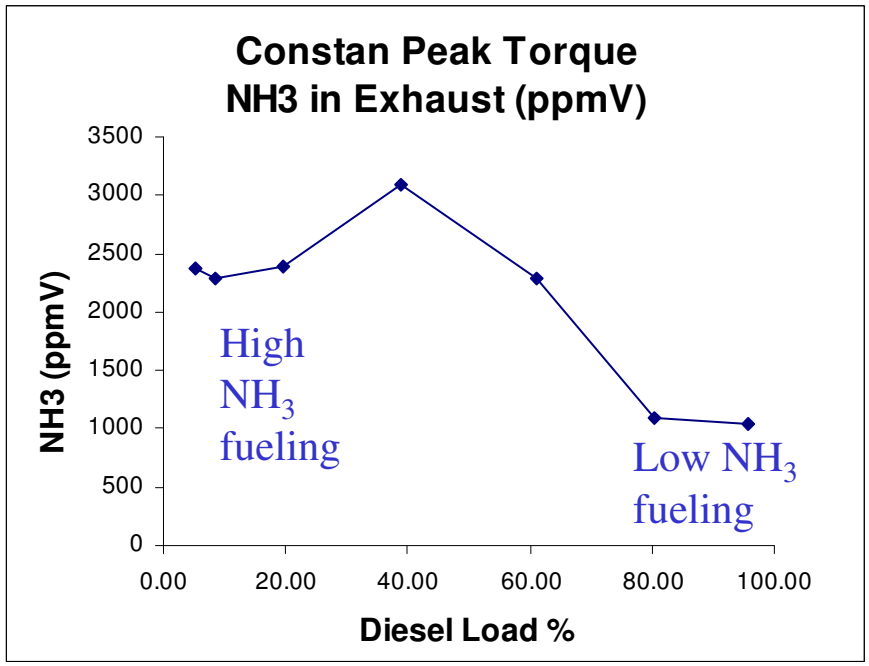
- Soot emissions vary depending on fueling rates

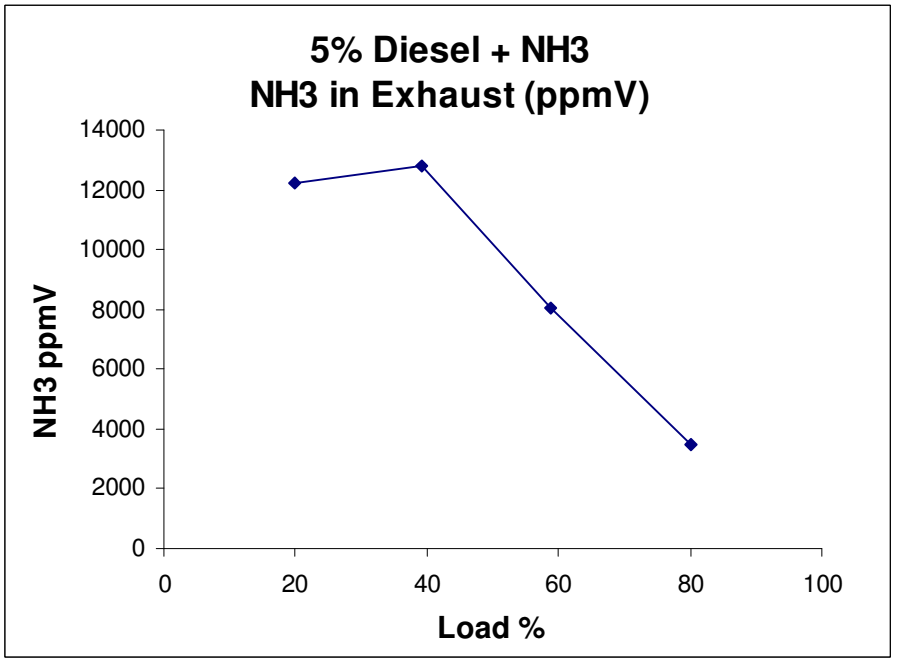




NH_3 Exhaust Concentrations

- Concentrations vary depending on NH_3 fueling rate
- Further study is required to reduce NH_3 emissions.

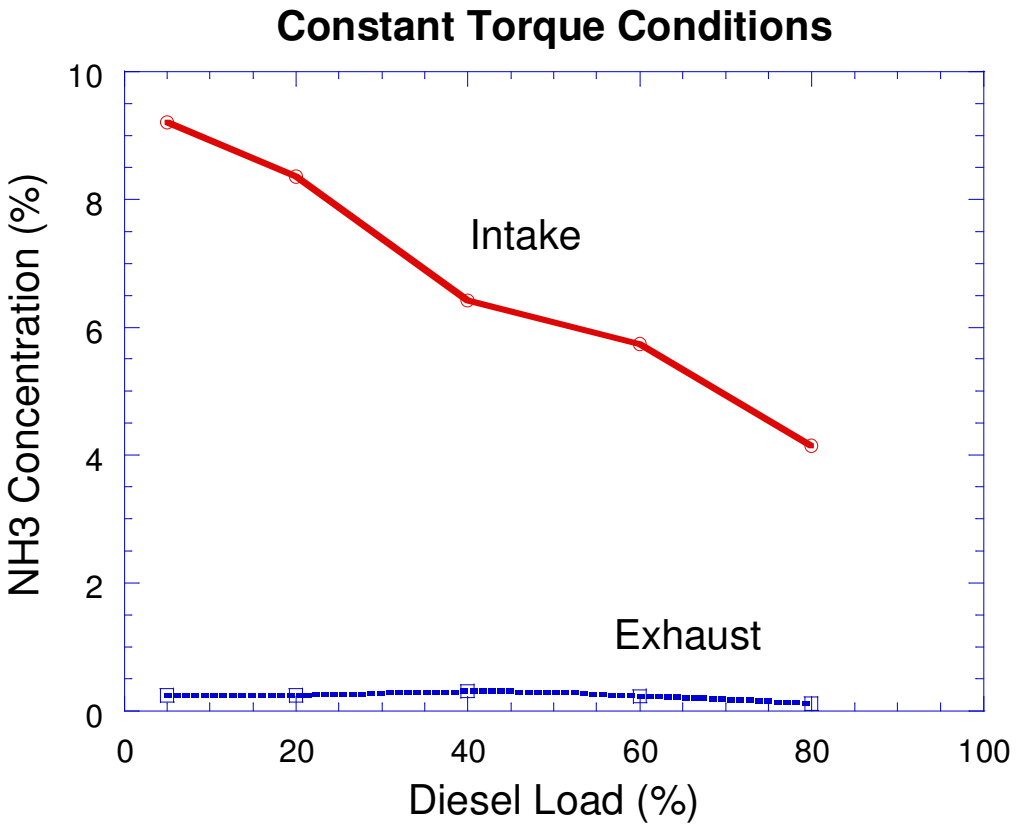




This strategy might not be feasible – not sufficient diesel energy to initiate combustion.

NH_3 Intake/Exhaust Concentration

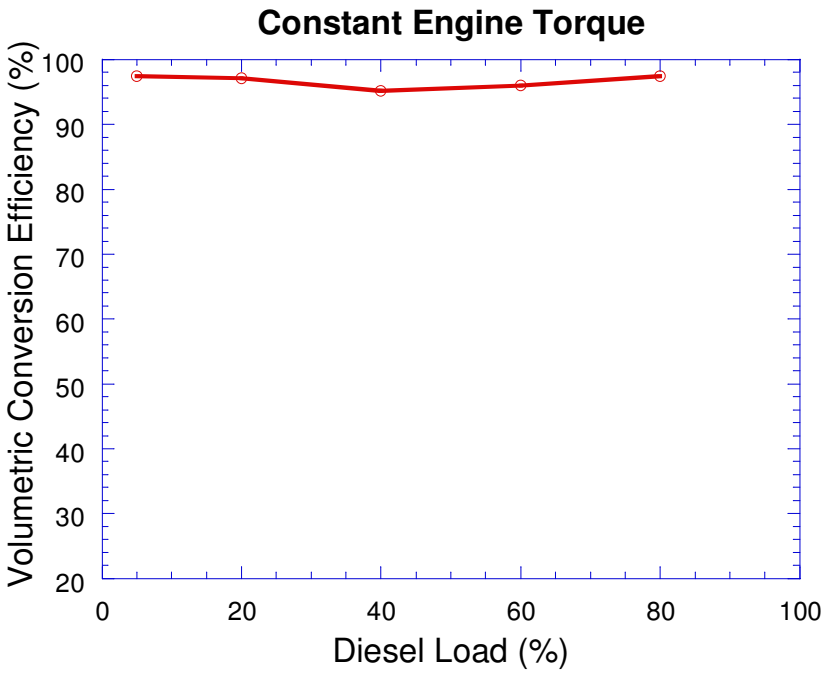
- Constant torque conditions



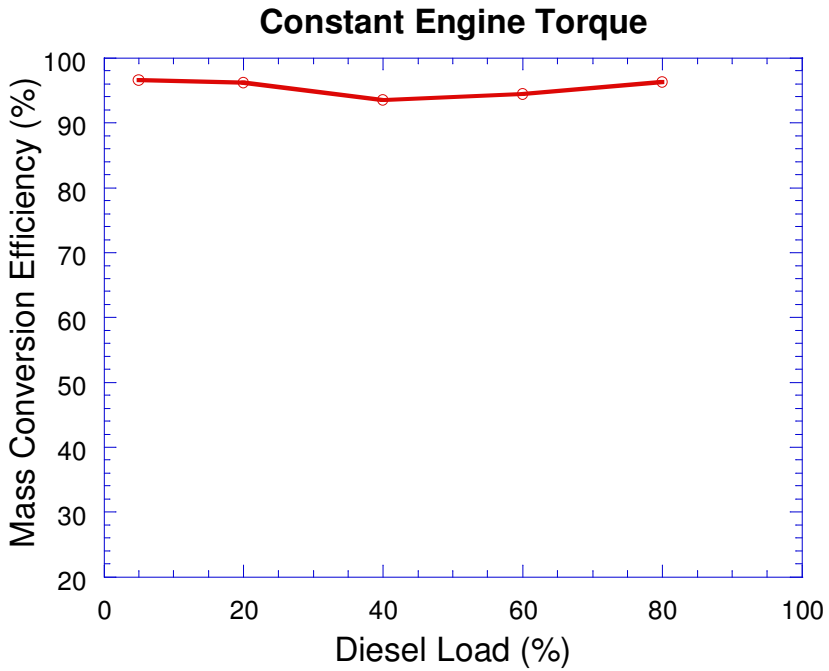
NH_3 Combustion Efficiency

- Constant engine torque conditions

Volume conversion efficiency



Mass conversion efficiency



Summary

- Reasonable fuel economy between 40~60% diesel fueling
- Ammonia combustion efficiency ~ 95%
- Ammonia emissions: 1000 ~ 3000 ppm under the specific conditions tested
- Future work –
  - Improve combustion efficiency of ammonia
  - Ammonia flow rate control depending on engine loads
  - Optimize diesel/ammonia dual-fuel system
  - Ammonia removal in exhaust