Fuel Composition Effects On Combustor Performance

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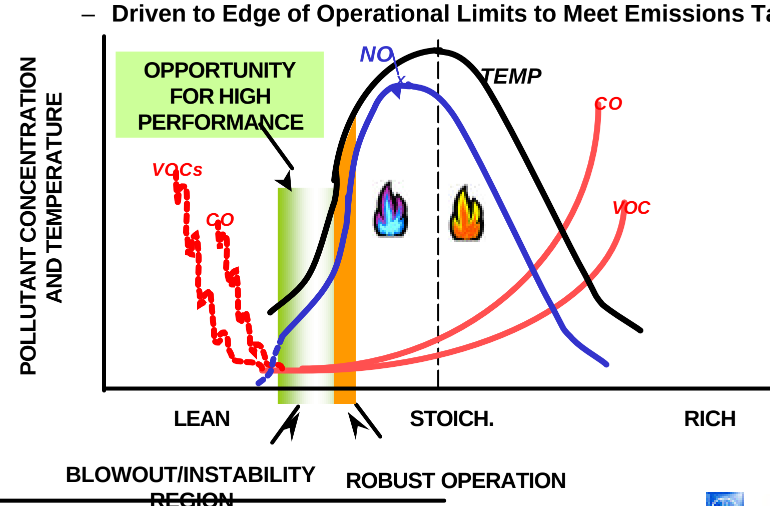
Motivation

- **Lean premixed combustion systems**
  - **Driven to Edge of Operational Limits to Meet Emissions Targets**



- **Question for Advanced DLN strategies:**
  - **What Is the Role of Variation in Natural Gas Composition in Performance?**
    - **Operability (ignition Delay, Flashback, Instabilities)**
    - **Emissions**

TYPICAL CONCENTRATIONS OF FUEL CONSTITUENTS FOR NATURAL GAS IN THE U.S.

CONSTITUENT	MEAN	MINIMUM	MAXIMUM
METHANE	93.9	74.5	98.1
ETHANE	3.2	0.5	13.3
PROPANE			
WITHOUT PEAK SHAVING	0.7	0	2.6
WITH PEAK SHAVING	0.1	0	23.7
HEXANES	0.1	0	0.4
INERTS*			
CO_2		0	3
H_2O		0.05 PPM	0.2 PPM

Liss, et al. (1992)

- **In California:**
  - **Consideration for Addition of Higher Hydrocarbons Associated With Well Heads in California Central Valley to Natural Gas Supply**
    - **Supply Risk Mitigation**
    - **Offset Increased Demand Envisioned for Natural Gas Vehicles**
  - **Question: What is Impact on Other Users of Natural Gas (e.g., Power Generation)?**
  - **"Methane Number" Used to Describe "Knock" Tendencies**
    - **100 equivalent to pure CH_4**
    - **0 equivalent to pure H_2**
    - **Consideration allows MN to 73**
      - **84% CH_4, 10% C_2H_6, 4%C_3H_8**

Objectives

- Evaluate The Effects Of Ethane, Propane, and Diluent Content of Natural Gas (and associated MN value) on the NOx and CO Emissions from a Commercial Microturbine Generator

- Evaluate the Extent to Which Correlations for Emissions vs Fuel Composition Developed on a Model Combustor Capture the Measured Effects

Approach

- Establish Gas Blending Capability for 60kW MTG
  - Mass Flow Controllers to set target MN
  - In-line GC to monitor actual composition

- Measure Performance (e.g., LBO, CO, NO_x)
  - SCAQMD Method 100 for Emissions (Source Test)

- Compare Results based on Model Combustor Study
  - Statistically Based Test Matrix Utilized to Relate Emissions with Fuel Composition and Distribution

Experiment: MTG System

- Capstone C-60 MTG

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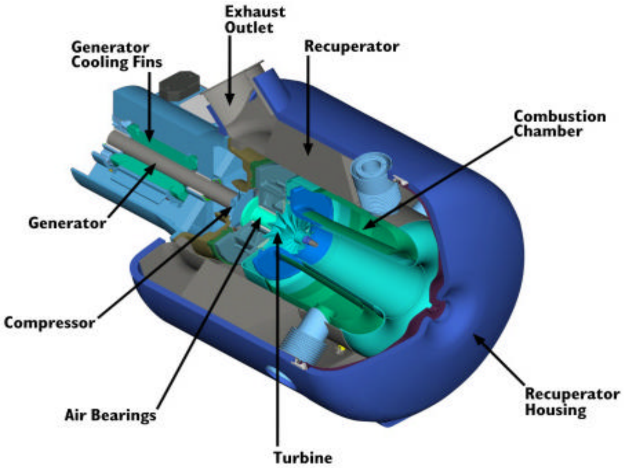
Experiment: MTG System

- MTG Combustion System
  - Control System Based on Turbine Exit Temperature, RPM



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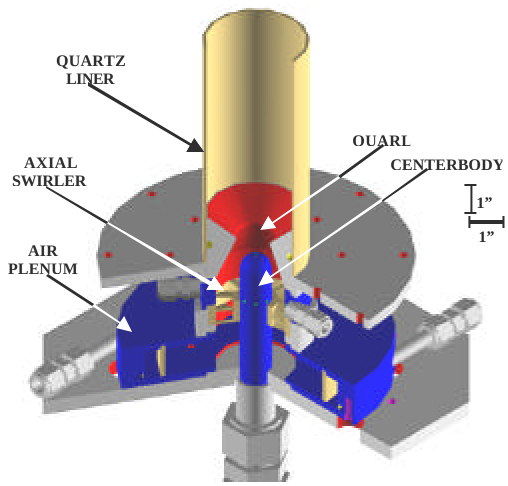
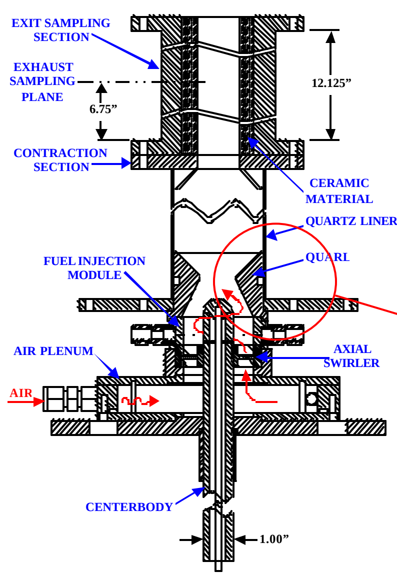
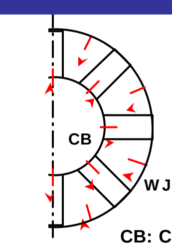
Experiment: Model Combustor



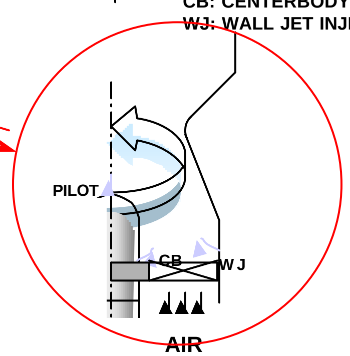
- Pressure: 1 atm
- Inlet Temperature: 660 K
- Traverse: 3-d
- Nominal Firing Rate: 35 kW

Experiment: Model Combustor



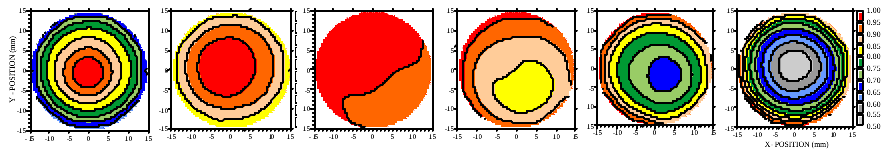


CB: CENTERBODY INJECTOR
WJ: WALL JET INJECTOR

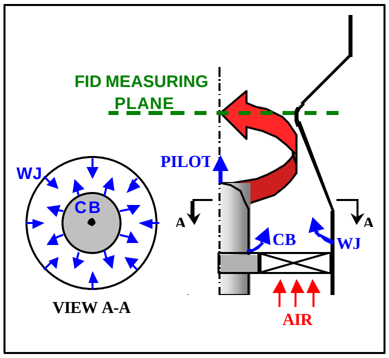


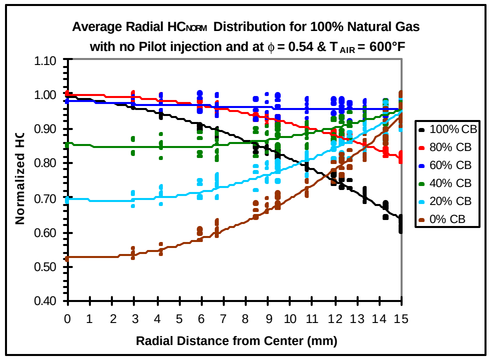
Experiment: Model Combustor

Fuel Distribution Control



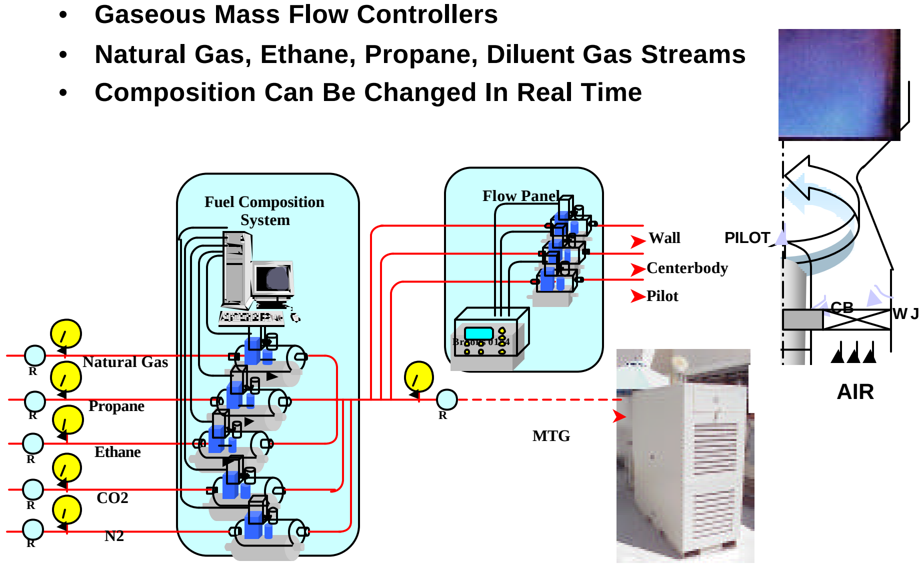
100% CB | 80% | 60% | 40% | 20% | 0%





Experiment: Fuel Composition Control

- Gaseous Mass Flow Controllers
- Natural Gas, Ethane, Propane, Diluent Gas Streams
- Composition Can Be Changed In Real Time



Results: MTG Studies

- **MTG MN Values and Associated Fuel Composition (Vol % typ.)**

	Natural Gas	MN 80	MN 73	MN 73 + inerts
C1	96.36±0.42	88.18±0.06	84.48±0.84	79.79±1.17
C2	1.40±0.36	6.84±0.12	9.78±0.49	9.17±0.14
C3	0.28±0.11	3.18±0.12	4.02±0.30	3.74±0.03
CO2	1.34±0.15	1.26±0.22	1.23±0.15	5.35±0.97
N2	0.47±0.02	0.39±0.09	0.34±0.04	1.81±0.34
HHV*	1014 ± 8	1102 ± 4	1138 ± 6	1083 ± 16

*BTU/scf

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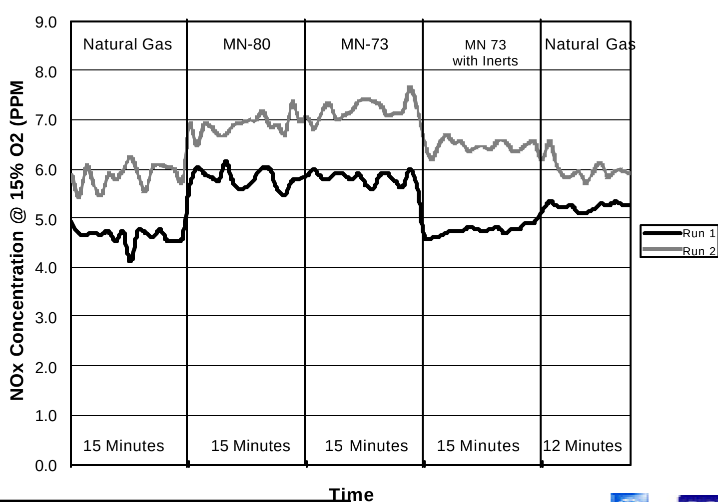
Results: MTG Studies

- **NOx @ 100% Load**



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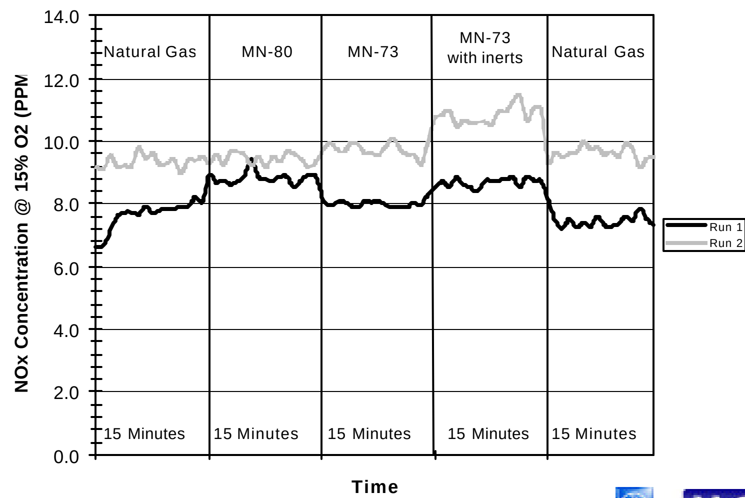
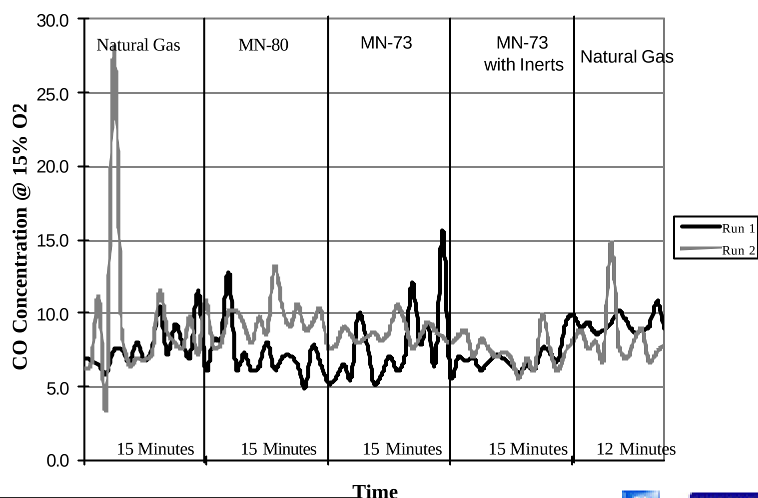
Results: MTG Studies

- **NOx @ 50% Load**



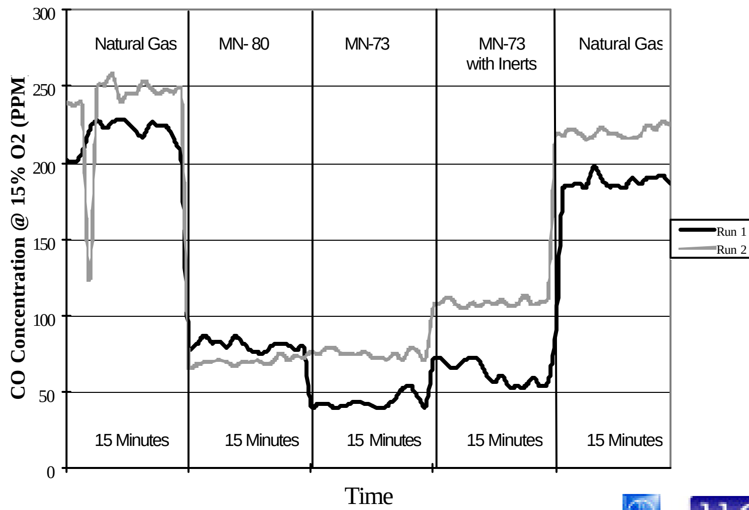
Results: MTG Studies

- **CO @ 100% Load**



Results: MTG Studies

- CO @ 50% Load



Results: MTG Studies

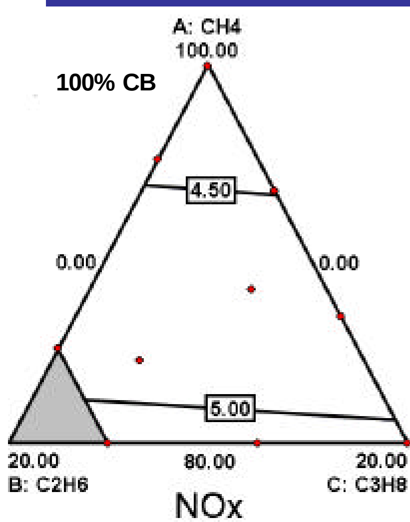
- **Summary**
  - Methane Number Impacts Emissions of both CO and NOx
    - Despite Fixed Firing Temperature
    - Impact Depends on Load
  - No Apparent Impact on Operability of MTG
- **Question**
  - Can More Comprehensive Results from Model Combustor Study Be Utilized to Characterize the MN Impact?

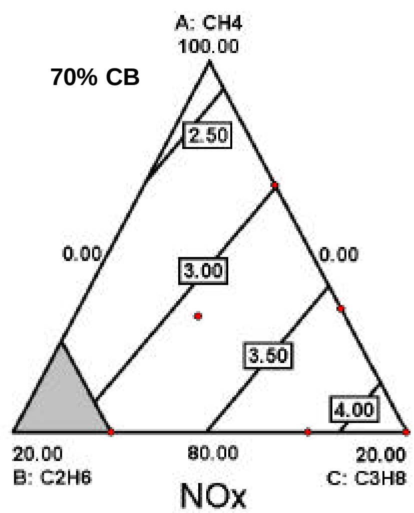
Results: Model Combustor

Statistical Matrix Parameters

- Fixed Conditions
  - Equivalence Ratio = 0.52
  - Air Preheat Temperature = 660 K (730°F)
- Three Mixture Components
  - A: CH_4 = 80% TO 100% (By Volume)
  - B: C_2H_6 = 0% TO 15% (By Volume)
  - C: C_3H_8 = 0% TO 20% (By Volume)
- Two Process Components
  - D: % Pilot Injection = 0% TO 5% (By Volume)
  - E: % Centerbody Inj. = 40% TO 100% (By Volume)
- 84 Combinations of Components Studies
  - D-Optimal Statistical Design

Results: Model Combustor





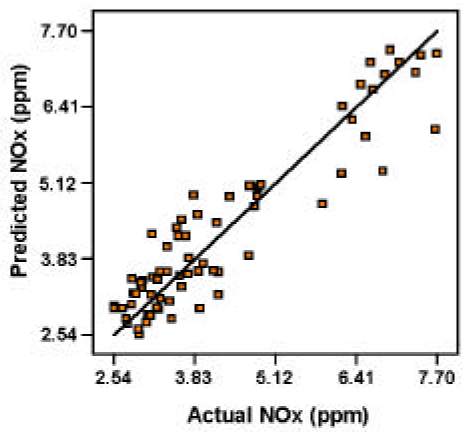
Results: Model Combustor

RESPONSE MODEL ($R^2 = 0.86$)

$$NOx\ [CODED] = 2.93A + 3.37B + 4.58C + 1.27AE + 0.58BD + 0.33CD + 1.58CE + 1.12AE^2 + 1.69BE^2 + 0.54ADE + 0.56BDE + 0.79CDE$$

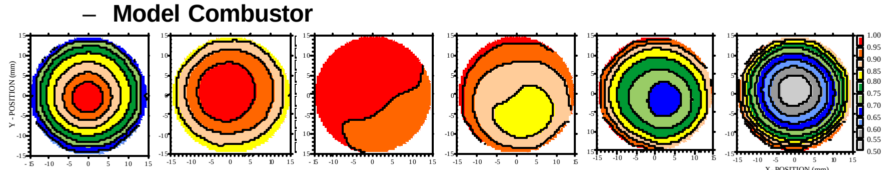
A: NATURAL GAS
B: ETHANE GAS
C: PROPANE GAS
D: PERCENT PILOT
E: PERCENT CENTERBODY

- **Coded Response "Normalizes" Results**
  - **Emissions Driven, But Not Dominated, By Fuel Composition**
  - **Center Weighted Fuel Distribution Increases NOx**
  - **Pilot Fuel Injection Slightly Increases NOx**
- **The Model Successfully Captures The Overall Trend Of The Results**



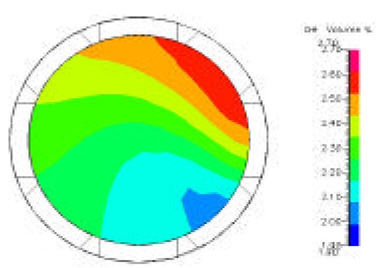
Results: Comparison

- **Fuel Distribution (100% Load)**
  - **Model Combustor**



100% CB **80%** **60%** **40%** **20%** **0%**

  - **MTG**



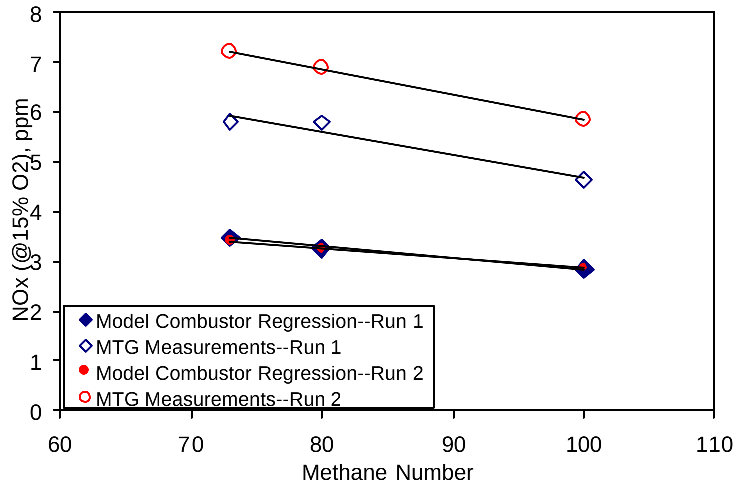
40% CB Representative of MTG Fuel Distribution

--Parameter E set to 0.40

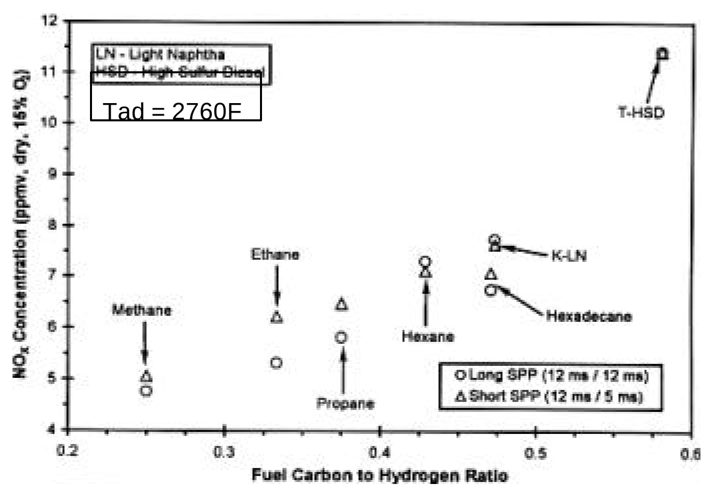
--Fuel Compositions for MTG Study Used to set A, B, C

Results: Comparison

- **Model Combustor Regression and Measured NOx levels**

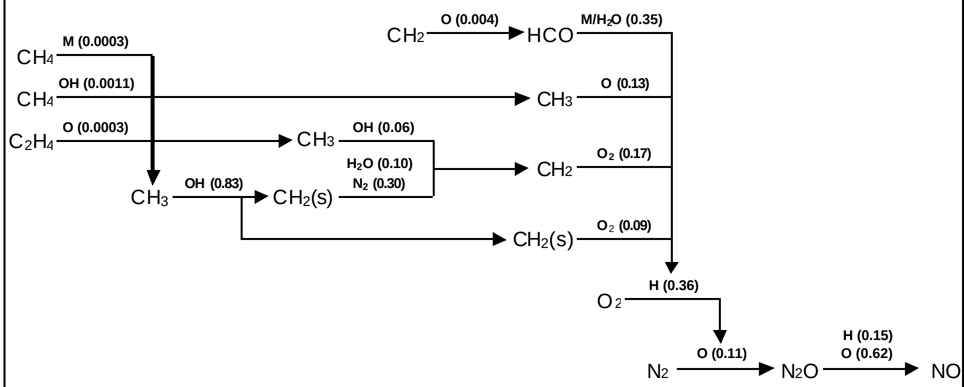


Results: NOx Mechanism Sensitivity



"Reduction of NOx Emissions for Lean Prevaporized-Premixed Combustors"
Ph.D Thesis, John Lee, University of Washington, 2000.

Results: NOx Mechanism Sensitivity

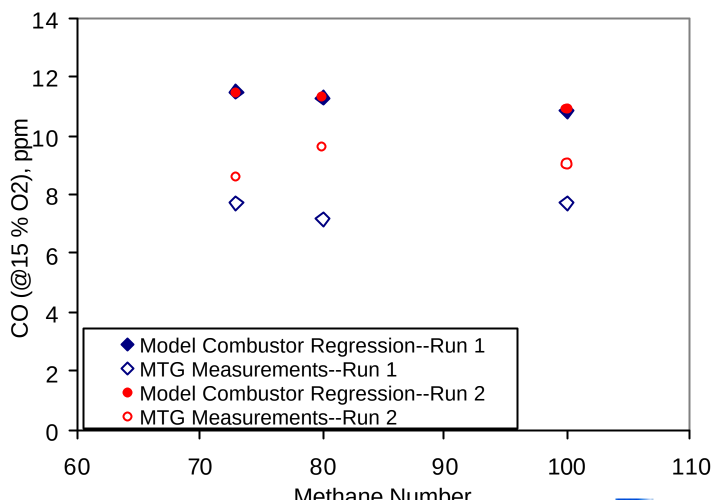


CASE 11 (20%Propane, 80% Methane, 730 F, 0.52):
N_2O pathway appears to dominates

Consistent with Steele, et al., (1998): Prompt less important <0.65 and long residence time.

Results: Comparison

- **Model Combustor Regression and Measured CO levels**



Summary

- **Addition of Ethane and Propane Impacts Emissions from MTG system**
  - **No noticeable impact on operability (e.g., flashback, stability)**
  - **Increased NOx at Full Load**
  - **Reduction of CO at Part Load**

- **Diluents in Combination with Higher Hydrocarbons Impacts Emissions from Commercial MTG System**
  - **Reduces NOx at Full Load**
  - **Increases CO at Part Load**

- **Empirical Expression for NOx and CO developed for Model Combustor Reflects Actual Trends in MTG System**
  - **Addition of Propane, Ethane Increase NOx Emissions**
  - **N_2O NOx mechanisms appears responsible**