HAT CYCLE TECHNOLOGY DEVELOPMENT PROGRAM

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Advanced Turbine Systems

Annual Program Review Meeting

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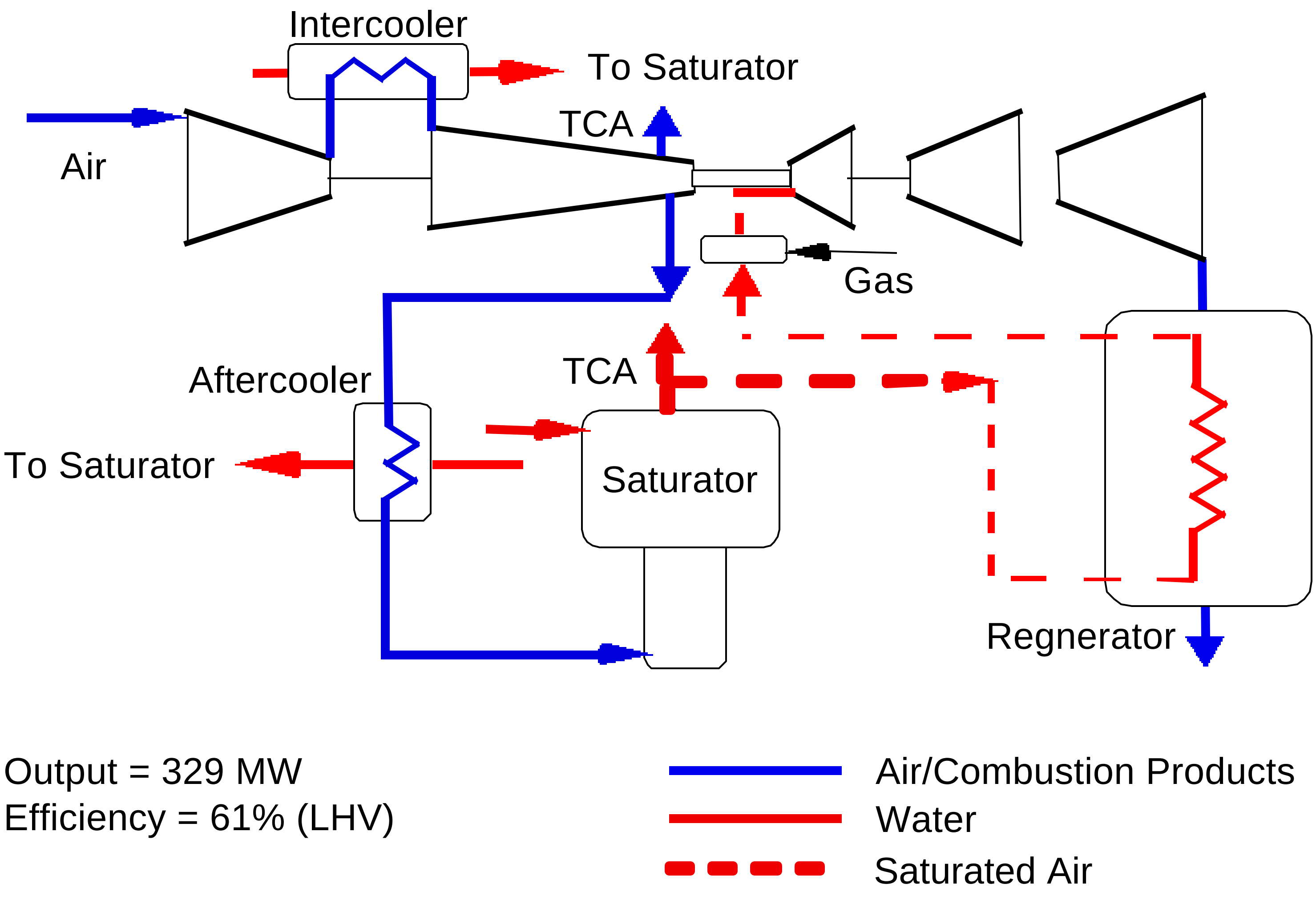
Simplified HAT Schematic



Output = 329 MW
Efficiency = 61% (LHV)

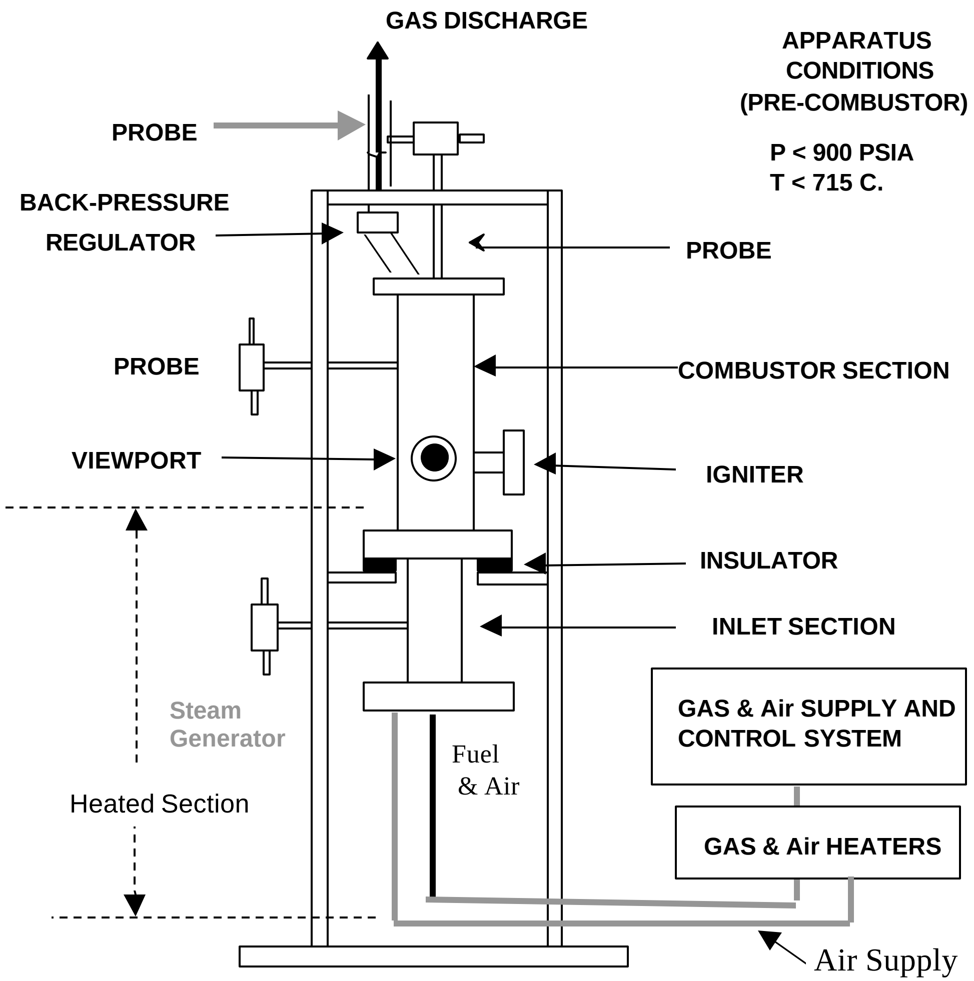
Program Objectives

- Identify the effect of moisture content in the air stream on emissions, stability limits, operational trades and ignition
- Evaluate the importance of nozzle and liner design parameters at HAT operating conditions
- Evaluate the effect of nozzle scale on performance: 1-4 in^2 Effective Flow Area (ACd)

Program Approach

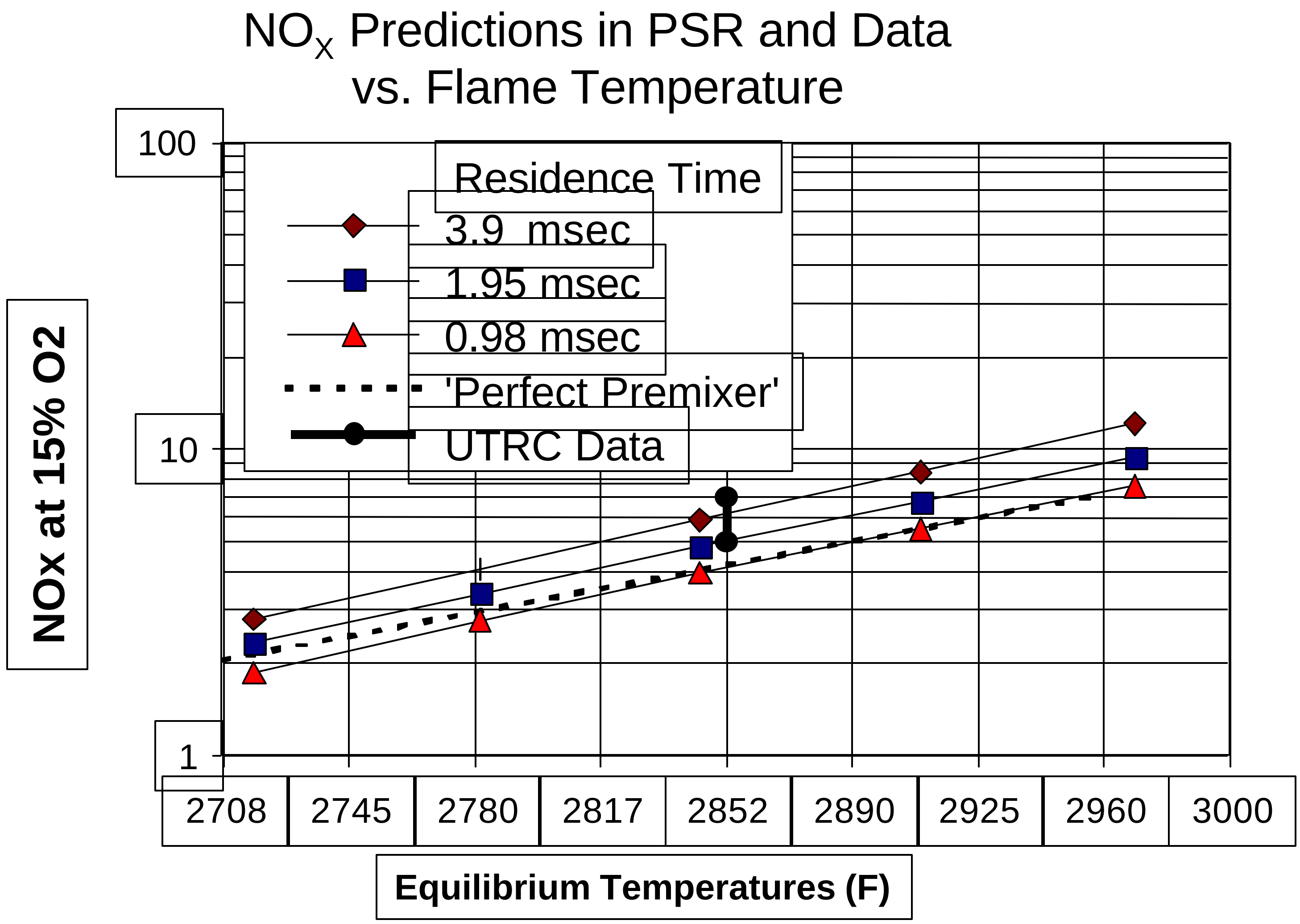
- Perform bench scale tests and modeling at UTRC
  - Determine stability limits and emissions at high temperature / pressure, with / without moisture
  - Use the test results and existing models to guide the design of larger scale combustors
- Perform three phases of tests at FETC on different combustors with and without moisture
  - Use the results to test the model

Schematic of High Pressure, High Temperature Combustion Facility



Premixer Data Acquisition

- Data acquired at 10, 20, 30 and 40 atm with inlet temperature of 700K (800F) with different ratios of air in central premixing tube to secondary air swirling around tube
- This configuration allows parametric study of the effects of premixing on flame stability and emissions


NOx Predictions in PSR and Data
vs. Flame Temperature
NOx at 15% O2
100
10
1
Residence Time
3.9 msec
1.95 msec
0.98 msec
'Perfect Premixer'
UTRC Data
2708
2745
2780
2817
2852
2890
2925
2960
3000
Equilibrium Temperatures (F)

Chemical Kinetic Code Development
Progress to Date

- NO_X emissions as a function of flame temperature predicted using modified CHEMKIN II codes and GRIMECH2.11 for a perfectly premixed flame

- Equilibrium flame temperature predicted for various flame equivalence ratios at each pressure level and equivalence ratio tested

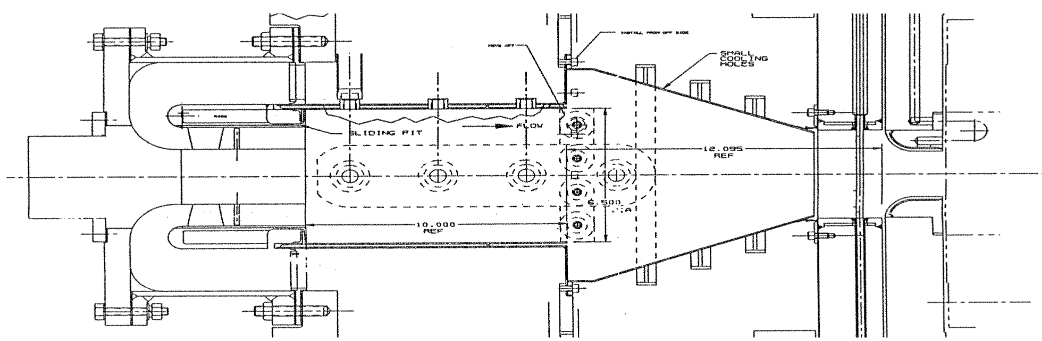
Approach for Phase I Tests at FETC

- Fuel Nozzle Screening
  - Conduct tests at FETC facility by adding steam to dry air to simulate HAT conditions
  - Vary fuel nozzle scale to operate at a range of pressure conditions (up to 400 psi)
  - Examine different nozzle designs leading to the selection of a preferred design
  - Map stability margins, NOx, CO, efficiency and combustor pressure dynamics

Approach for Phase II

- Liner Screening
  - Examine different liner concepts from ceramic adiabatic walls to convectively cooled designs (more realistic engine geometry and acoustic boundary conditions)
  - Utilize two fuel nozzle concepts
  - Characterize stability boundaries, emissions and pressure dynamics at simulated part power operating conditions

Convectively Cooled Liner Concept



Approach for Phase III

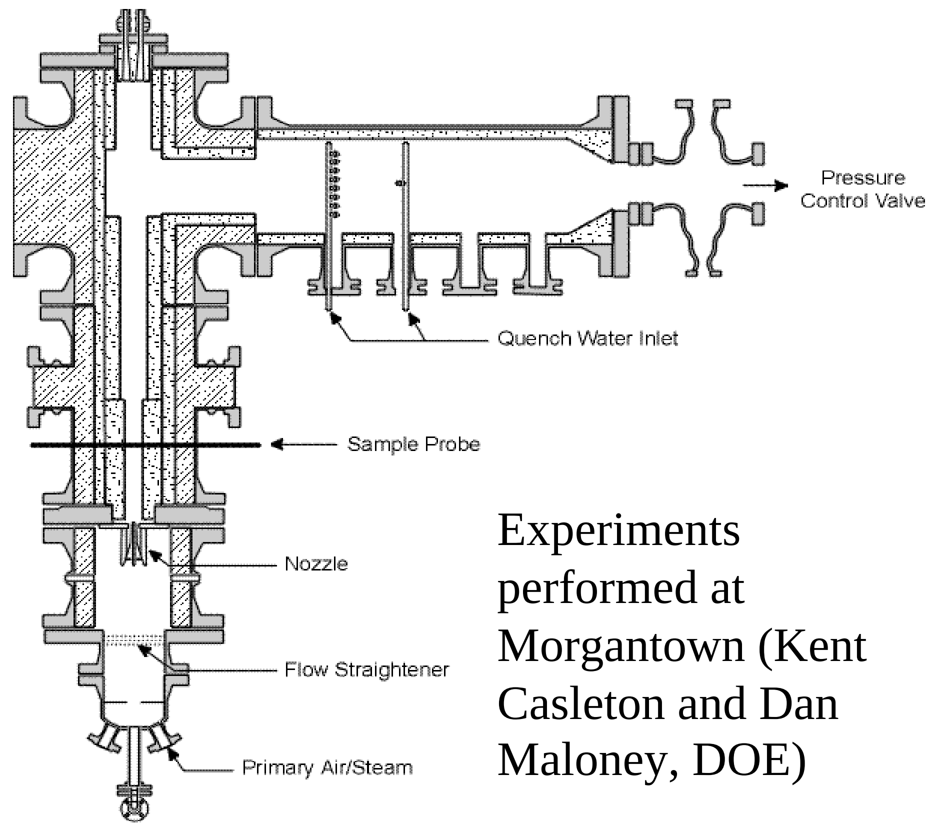
- Conduct tests at FETC facility at simulated HAT conditions to Investigate:
  - Two Stage Fuel Injector
  - Catalytic Pilot Design
  - Liquid Fuel Design

Hardware used at DOE-FETC facility in Morgantown for collecting the data

- Experiment with moisture content to test viability of moist flames
- Test Performance of model

Test parameters:

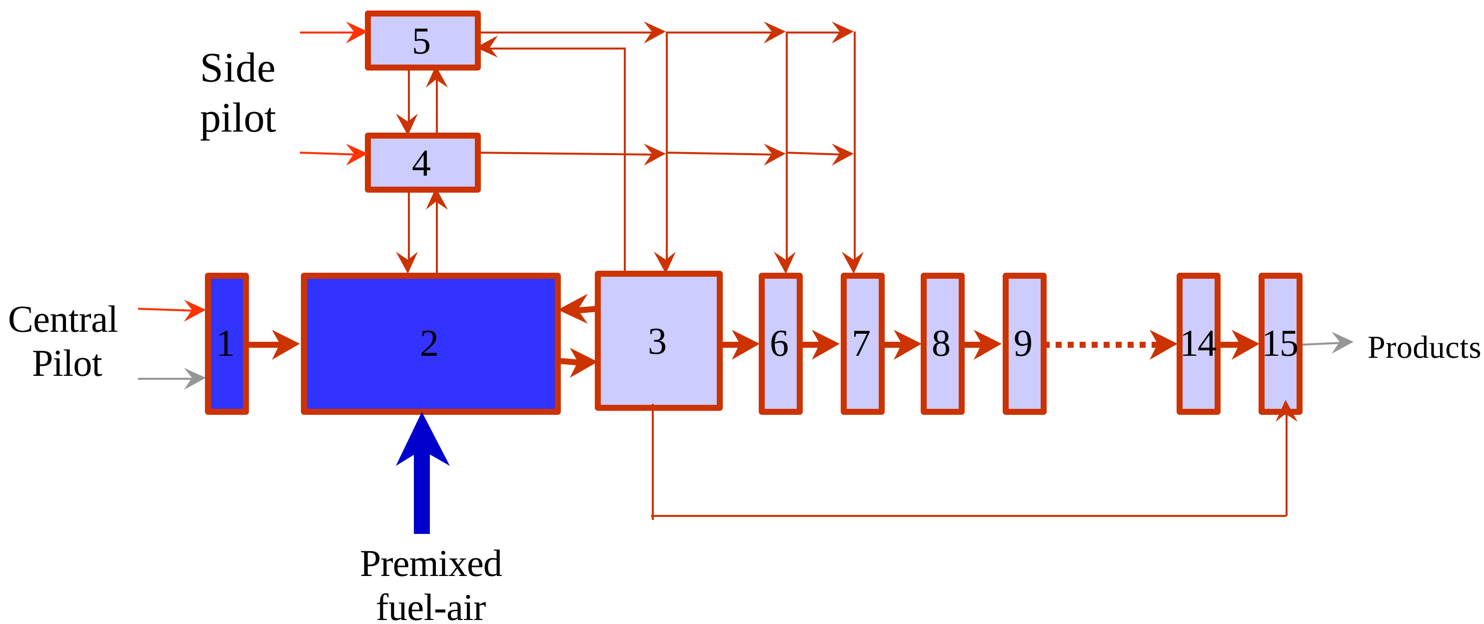
- Side-wall pilot levels (0, 1 or 5%),
- Center-body pilot (0, 1, 3, or 5%),
- Moisture (0, 5, 10, 15, or 20 %) in the air flow
- Air/moisture mixture temperature (935 to 725°F)
- Pressure (100-400 psi)
- Scale-ups (quarter, half, and full scale)



Experiments performed at Morgantown (Kent Casleton and Dan Maloney, DOE)

A PSR Network design was implemented to best describe the experimental rig

Experiments performed in DOE-FETC facility in Morgantown. Need to develop a reactor network to model the effect of different parameters on NO_x and CO emissions.



- Reactor volume & residence time defined by hardware and experimental conditions
- T_{flame} is kept constant

PSR codes

- Code for PSR developed at Sandia National Labs, as part of the CHEMKIN Codes
- PSR Network codes developed at UTRC: Allows design of PSR reactors in a network to better represent local conditions
- Extensive chemical kinetics and corresponding thermochemistry is used to model the chemical reactions taking place during combustion
  - Typical reaction sets include hundreds of reactions and more than 50 species
  - GriMech2.1 has been used to model the chemistry
- User specified parameters are reactor volume (residence time), inlet temperature, reactant composition, operating pressure, and energy losses (adiabatic or isothermal operation)
- Computation time dependent on the configuration complexities, number of reactors in the network and on the reaction set

Modeling effects of moisture on CO &NO_x emissions

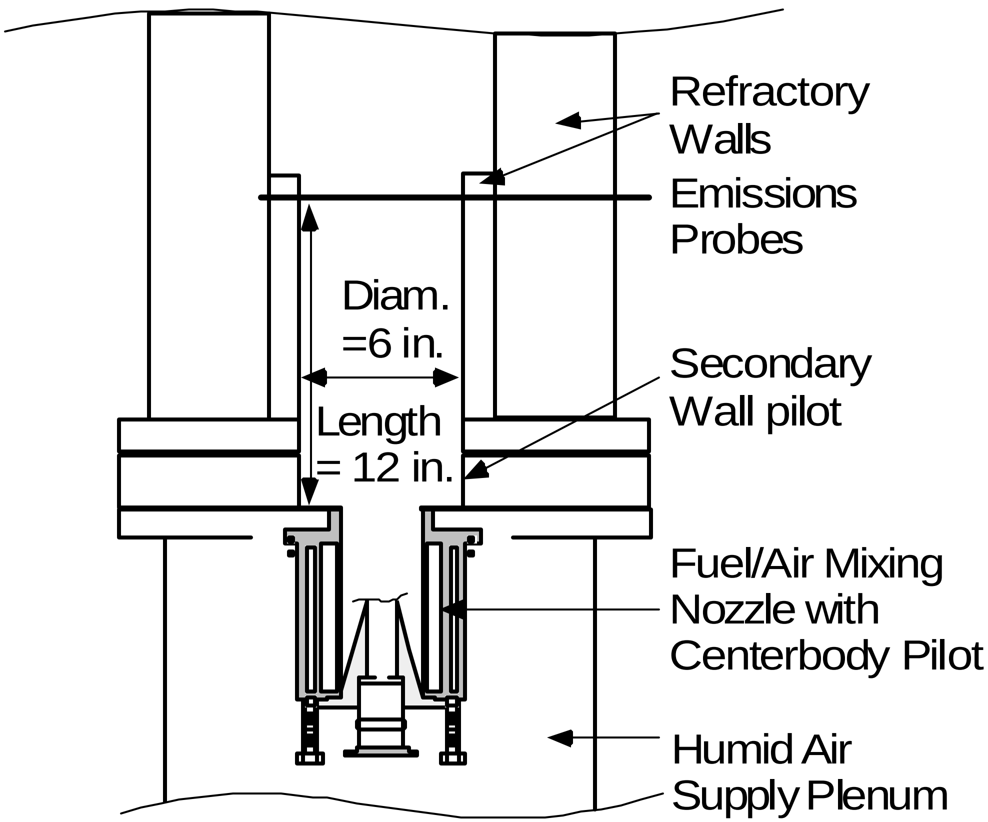
- Chemistry is modeled using GRI Mech. 2.11 (49 species and 277 reactions)
- Single PSR and PSR Network models used to simulate the combustion process
- PSR Network designed to simulate mixing and flow characteristics
- Effect of moisture on the different NO_x formation channels was also studied
- Effect of moisture on unmixedness was also investigated

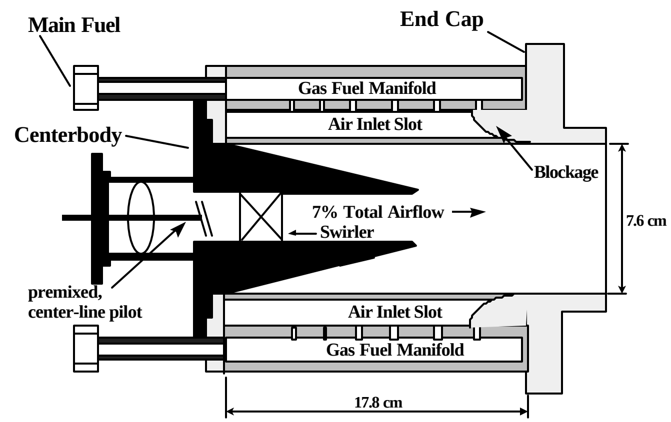
Conclusions from experiments and modeling

- Experiments show that moisture in the feed stream reduces NO_x emissions but does not have a significant effect on CO
- Experiments indicate the effect of pilot levels, pressure, equivalence ratio, and scale-up on emissions
- PSR Network model is a very versatile tool and the network can be designed in order to simulate the flow and mixing characteristics seen in the process.
- The Network is able to predict NO_x emissions for the combustor at the different conditions
- Moisture content mitigates the effect of unmixedness on NO_x emissions

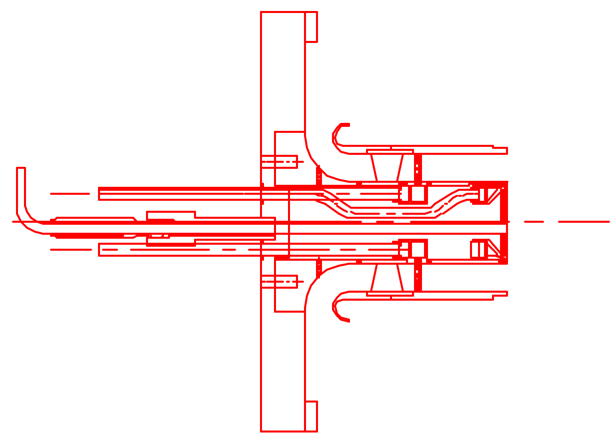
Combustor and Nozzle Setup Used in FETC Testing (Phase I)

Ceramic Liner





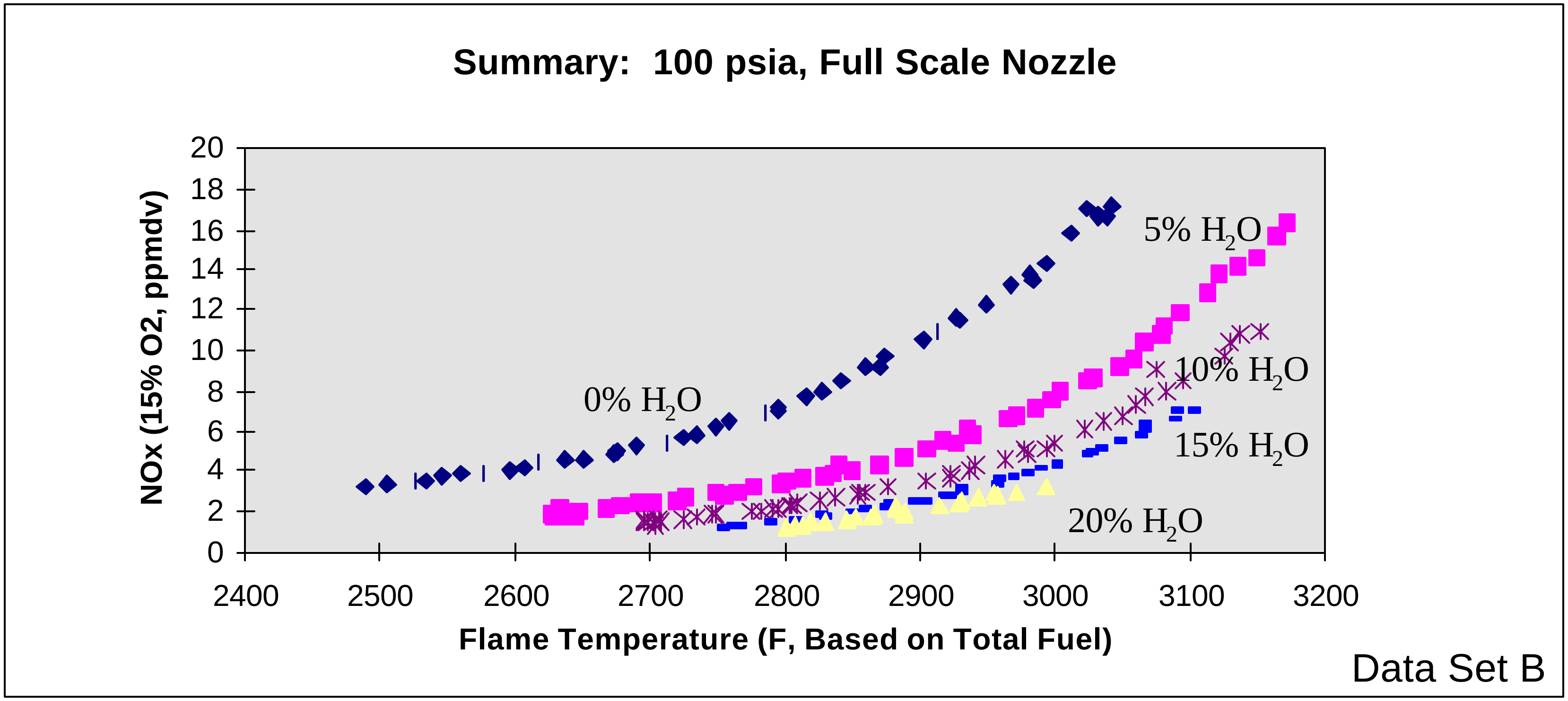
Tangential Entry Nozzle



Axial Nozzle

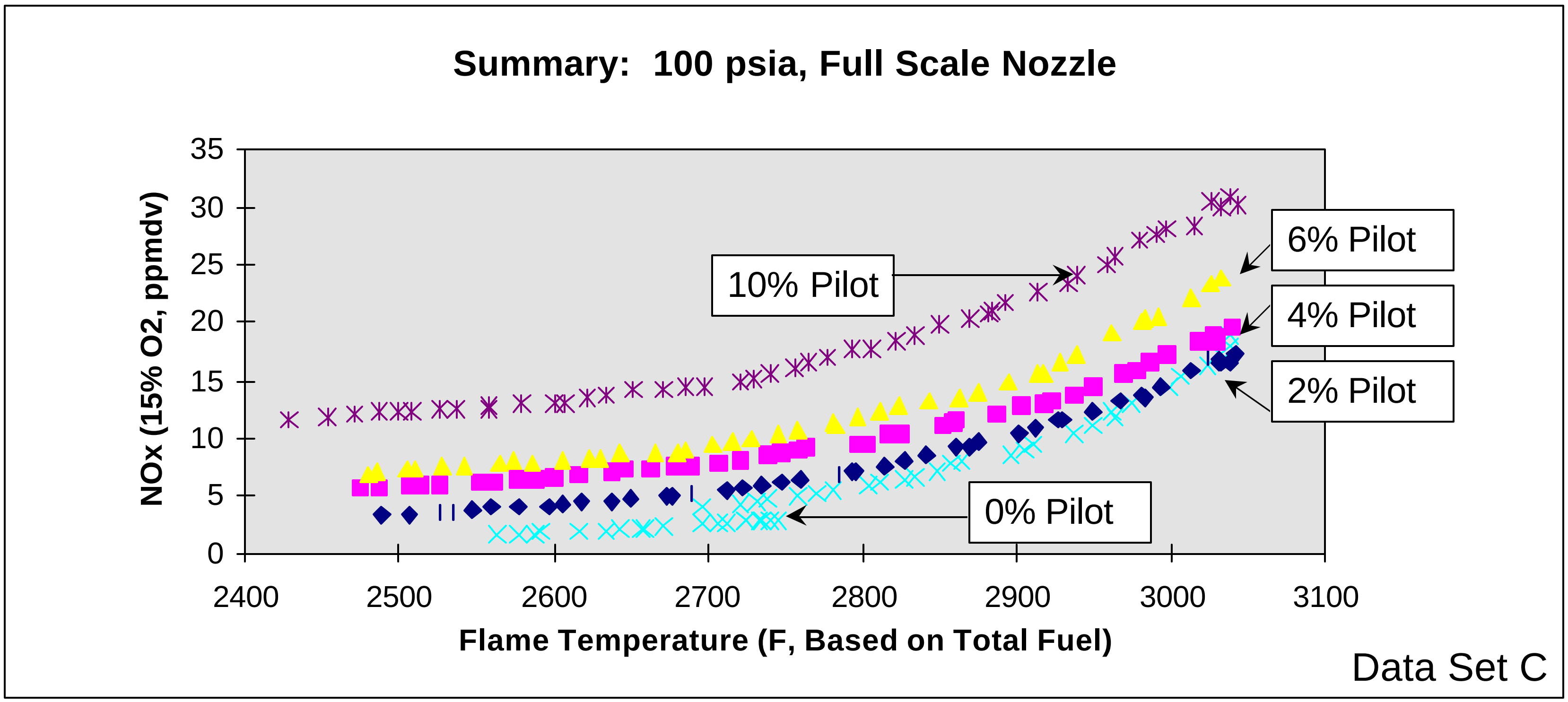
At Constant Flame Temperature, Added Moisture Reduces NOx

Tangential Entry Nozzle



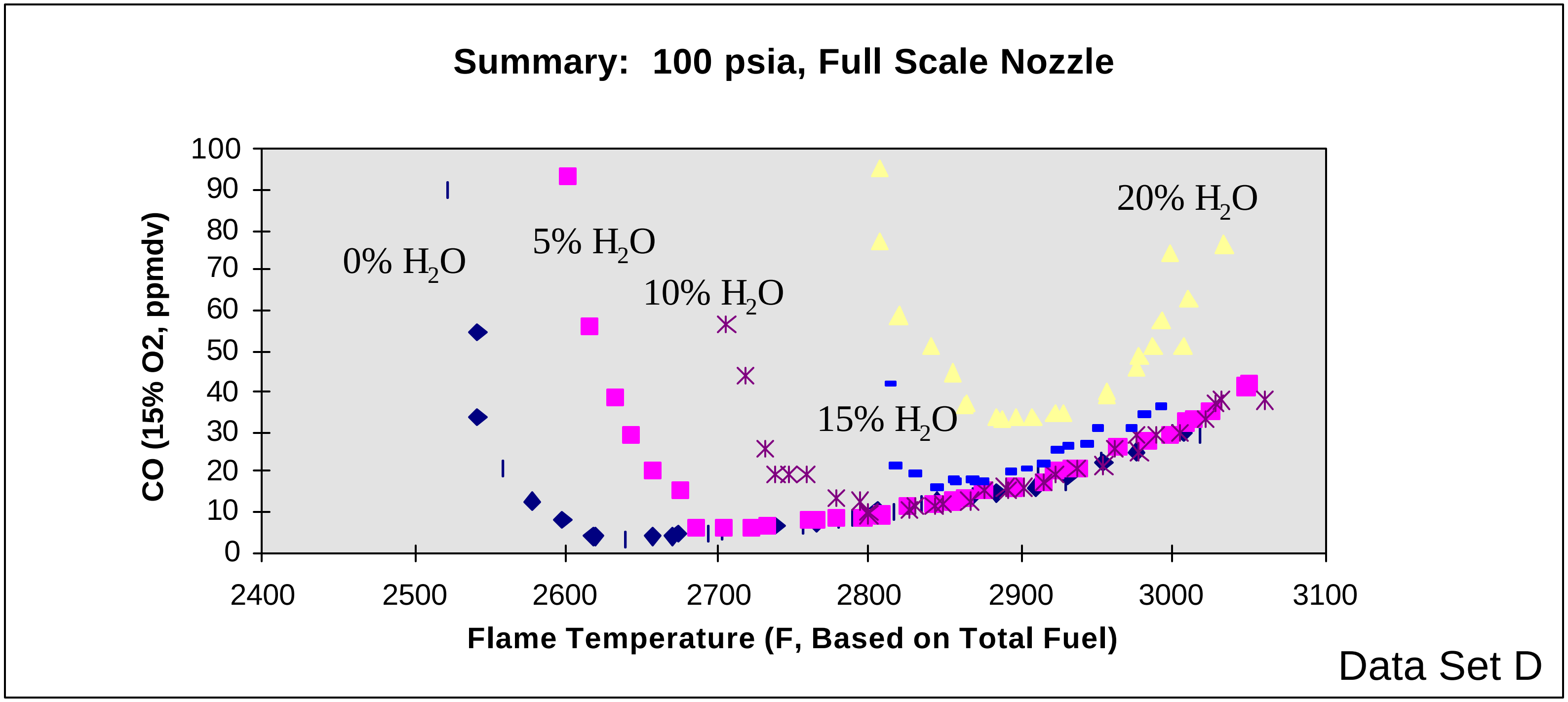
NOx Production Is Sensitive to Amount of Diffusion Piloting

Tangential Entry Nozzle



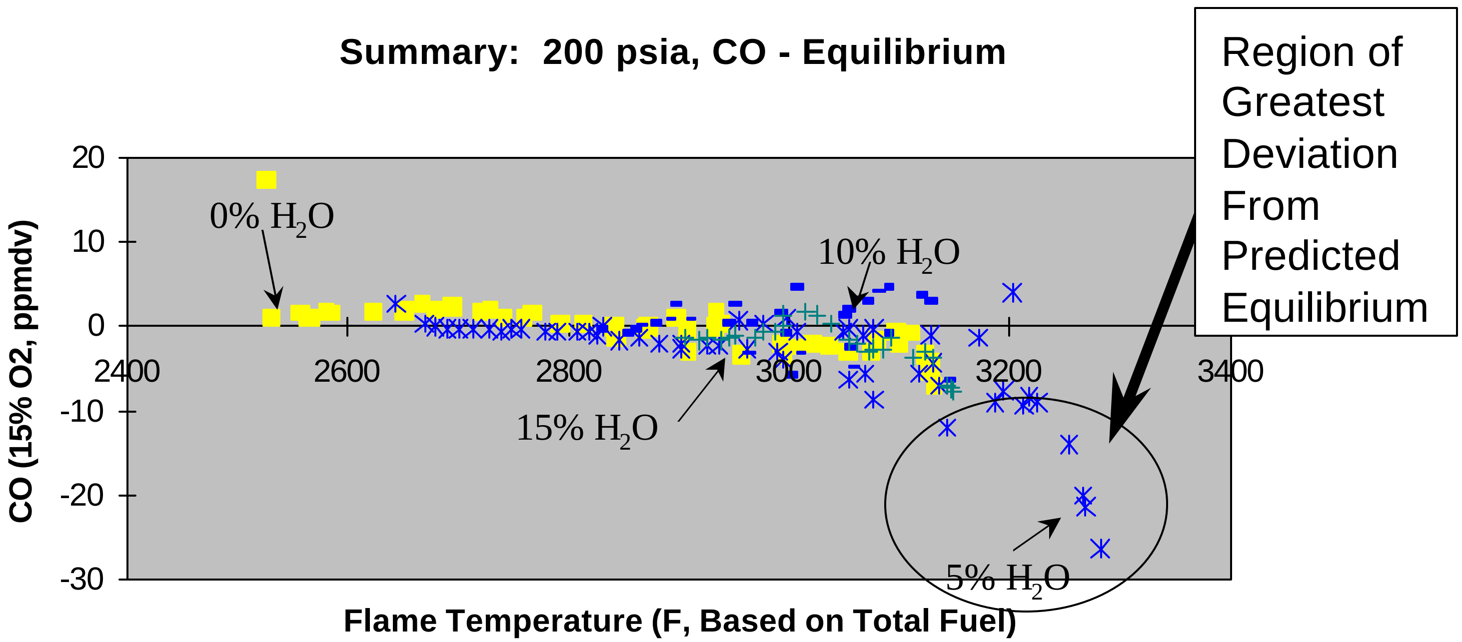
CO Adversely Affected By Moisture Addition

Tangential Entry Nozzle



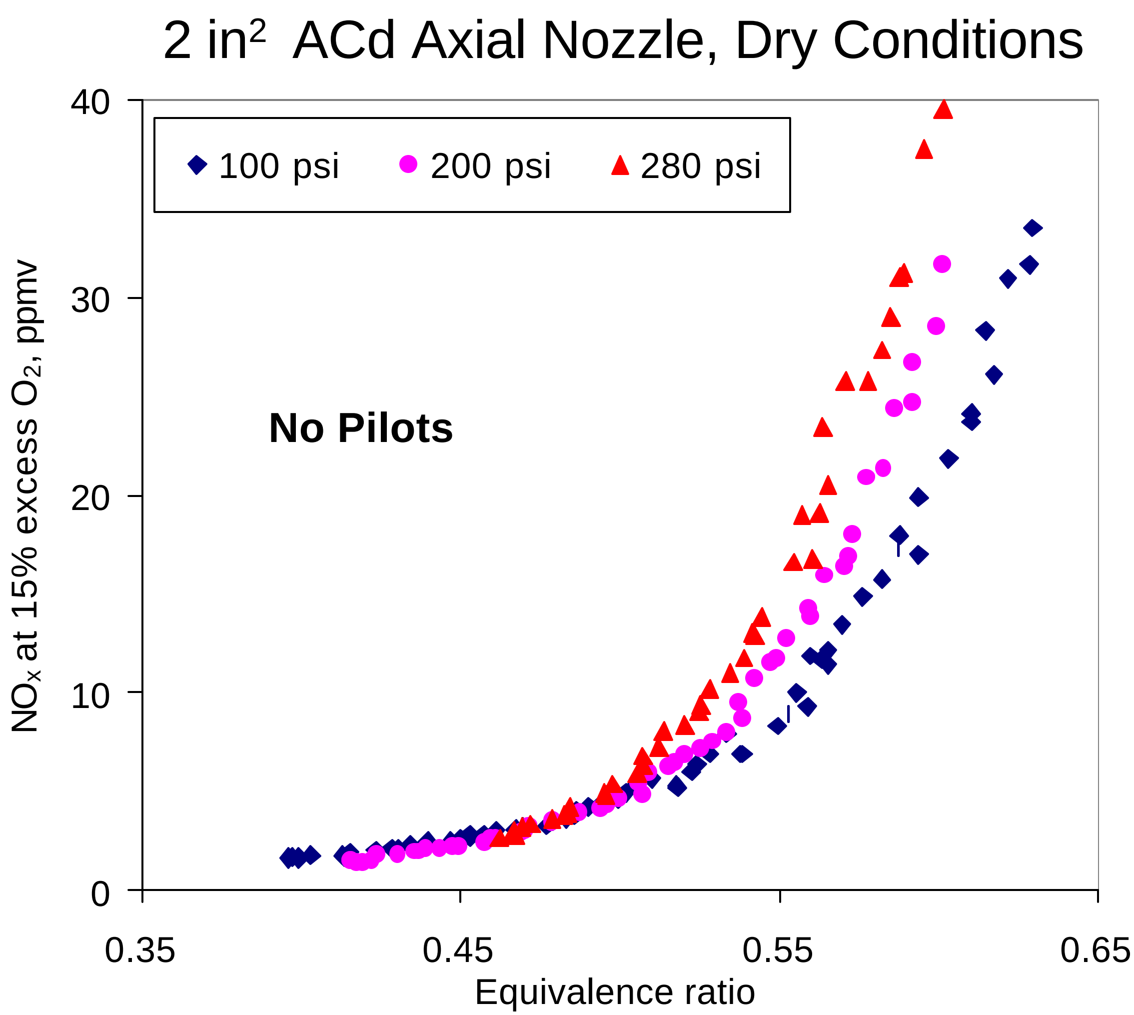
Measured CO at 200 psia and High Water Loadings Does Not Follow the 100 psia Data Trend Relative to Equilibrium CO

Tangential Entry Nozzle



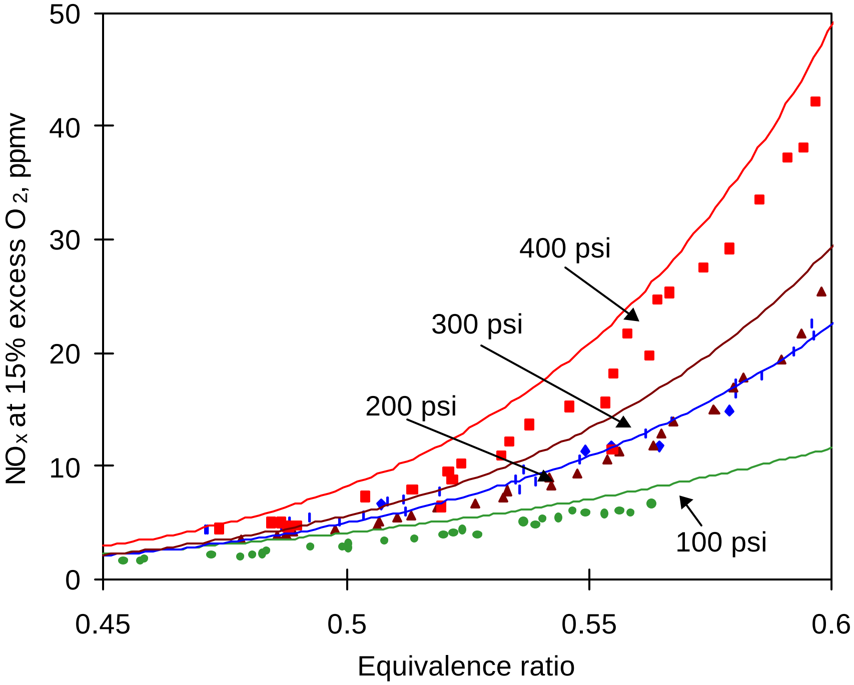
Data Set A

NOx Emissions for Both Axial (below) and Tangential Entry Nozzles Reveal Pressure Dependence

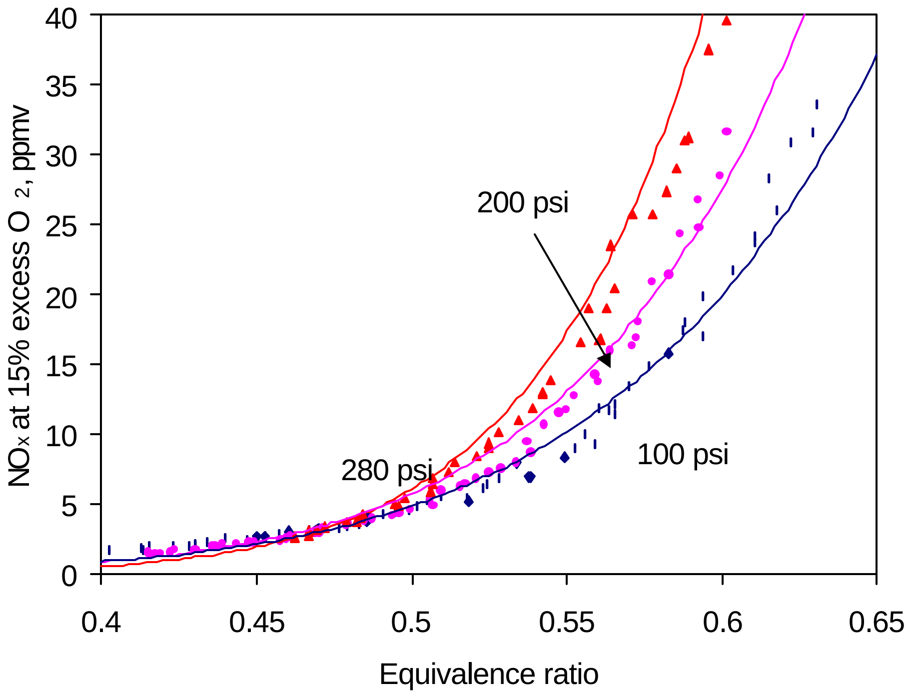


Modified Network Accurately Predicts NOx Pressure Trends & Magnitudes for Both Nozzle Configurations

2 in^2 ACd Nozzles, Dry Conditions



Tangential Nozzle

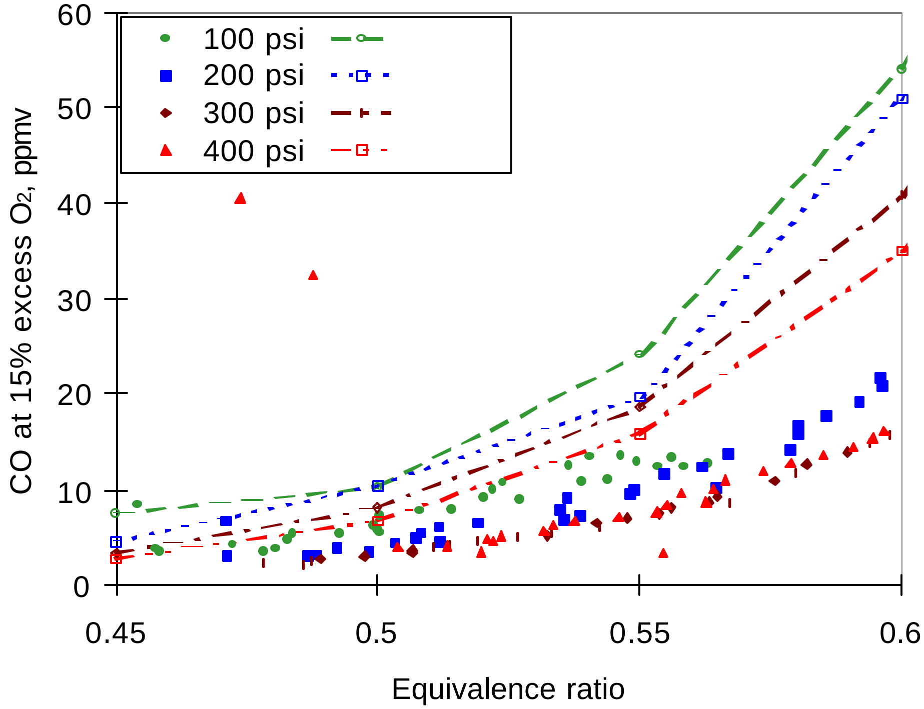


Axial Nozzle

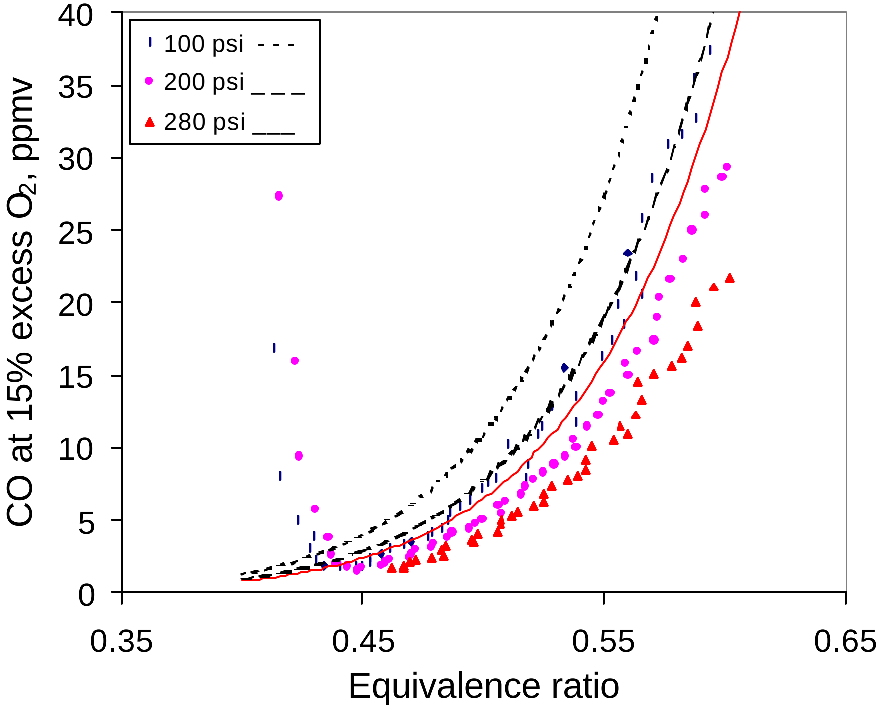
Modified Network Predicts CO Trends but not Magnitudes:

Errors in Mixture Temperature (very sensitive in predicting equilibrium CO)?
CO Oxidation in Emissions Sample Probe?

2 in^2 ACd Nozzles, Dry Conditions



Tangential Nozzle



Axial Nozzle

Summary of Results

- Low Levels of NOx and CO Observed
- Adding Moisture Lowers NOx and Raises CO
- Diffusion Piloting Strongly Affects NOx
- CO Levels Close to Equilibrium Values
- NOx Sensitive to Pressure: Increases with Pressure
- CO Sensitive to Pressure: Decreases with Pressure
- GRI Mech 2.11/Kinetic Model Agreed With NOx Data but discrepancies exist with CO data
- NOx trends linked to unmixedness level variations