HCCI in a Variable Compression Ratio Engine: Effects of Engine Variables

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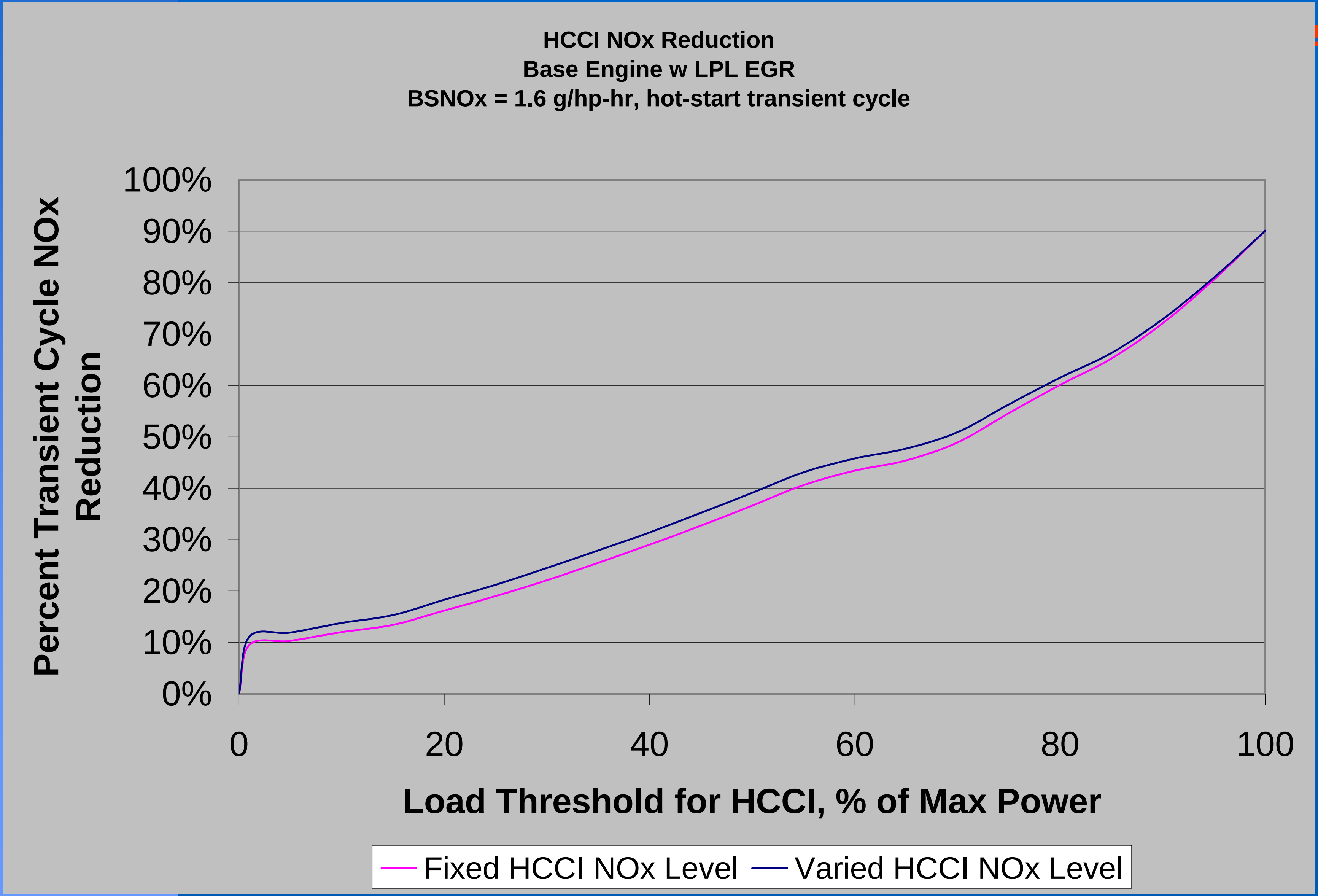
Prediction of HD FTP NOx with Various Levels of HCCI



Outline of Presentation

- Background
- Description of Experimental Matrix
- Experimental Procedures
- Graphical Analysis
- Conclusions

Background - SwRI HCCI Program

- Fifth in the Series of HCCI Presentations
  - Prediction of the Start of Reaction
  - Control of the Start of Reaction
  - HCCI Fuel Requirements
  - Engine Heat Release
  - Interaction of Engine and Fuels
- Practical Full Time HCCI Operation Will Require Specific HCCI Fuel
  - Low Octane gasoline

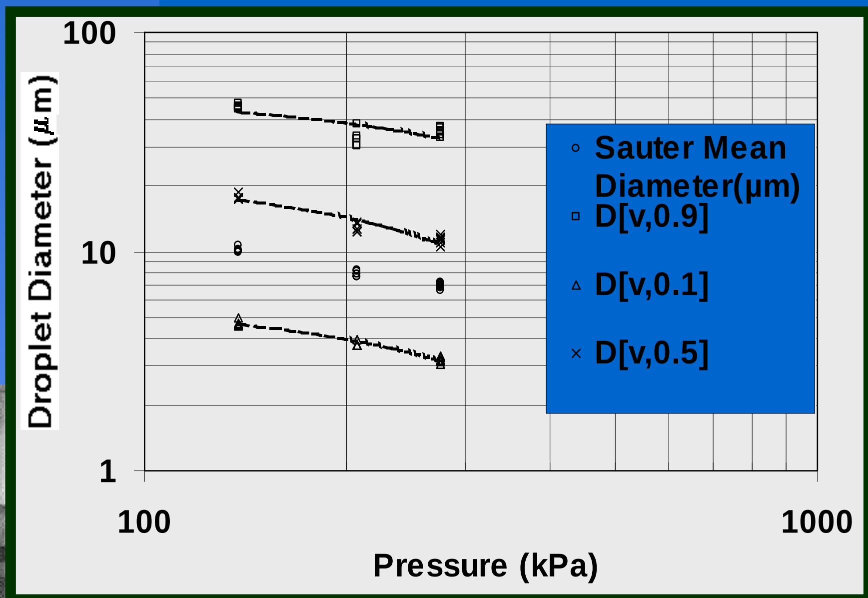
Experimental Variables

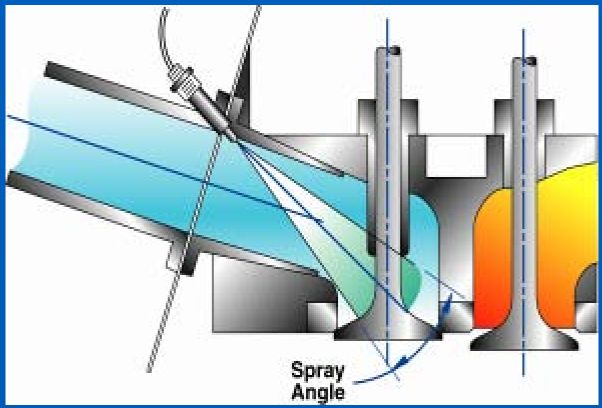
- Engine Variables
  - Intake Manifold Temperature and Pressure
  - Exhaust Gas Recirculation Level
  - Compression Ratio
- Fuel Variables (Selection)
  - Boiling Point Distribution
  - Cetane/Octane Number
  - Composition

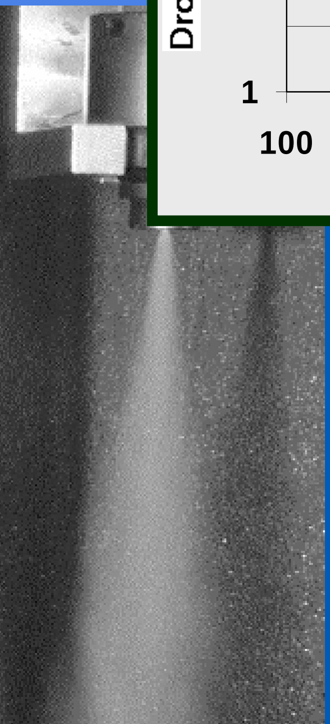
Test Engine Specifications

Bore	96.8 mm
Stroke	95.3 mm
Rod Length	166.5 mm
Displacement	702 cc
Compression Ratio	7.5:1 to 16.5:1
Swirl Ratio	Less Than 0.7
Combustion Chamber	Shallow Dish

Combustion Chamber Design







- Bowl In Piston
  - Shallow Dish
  - Squish Area of 51%
- Two Valve Head
- Low Swirl Ratio
  - 0.7 Swirl Number
- Intake Port Fuel Injection
  - Air Assist Swirl Atomizer


Powertrain Consulting Service
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Test Fuels

- Diesel Fuel (Typical US)
- Gasoline (Pump Grade 87 RON)
- Fischer Tropsch Naphtha
- Blends of Gasoline and Diesel Fuel

Test Fuel Properties

PROPERTY	FT NAPHATHA	DIESEL FUEL	GASOLINE
Heat of Combustion, MJ/kg			
Net	44.3	42.5	32.9*
Gross	47.7	45.3	45.4*
Sulfur, mass %	0.0	0.039	.023
Specific Gravity	0.7095	0.8485	.7436
IBP, ^{o}C	61	187	29
50%	141	263	105
95%	186	328	188
FBP	194	339	201
Carbon, mass %	83.98	86.83	86.74*
Hydrogen mass %	15.92	13.24	13.22*
Cetane Number (IQT)	51	43	13

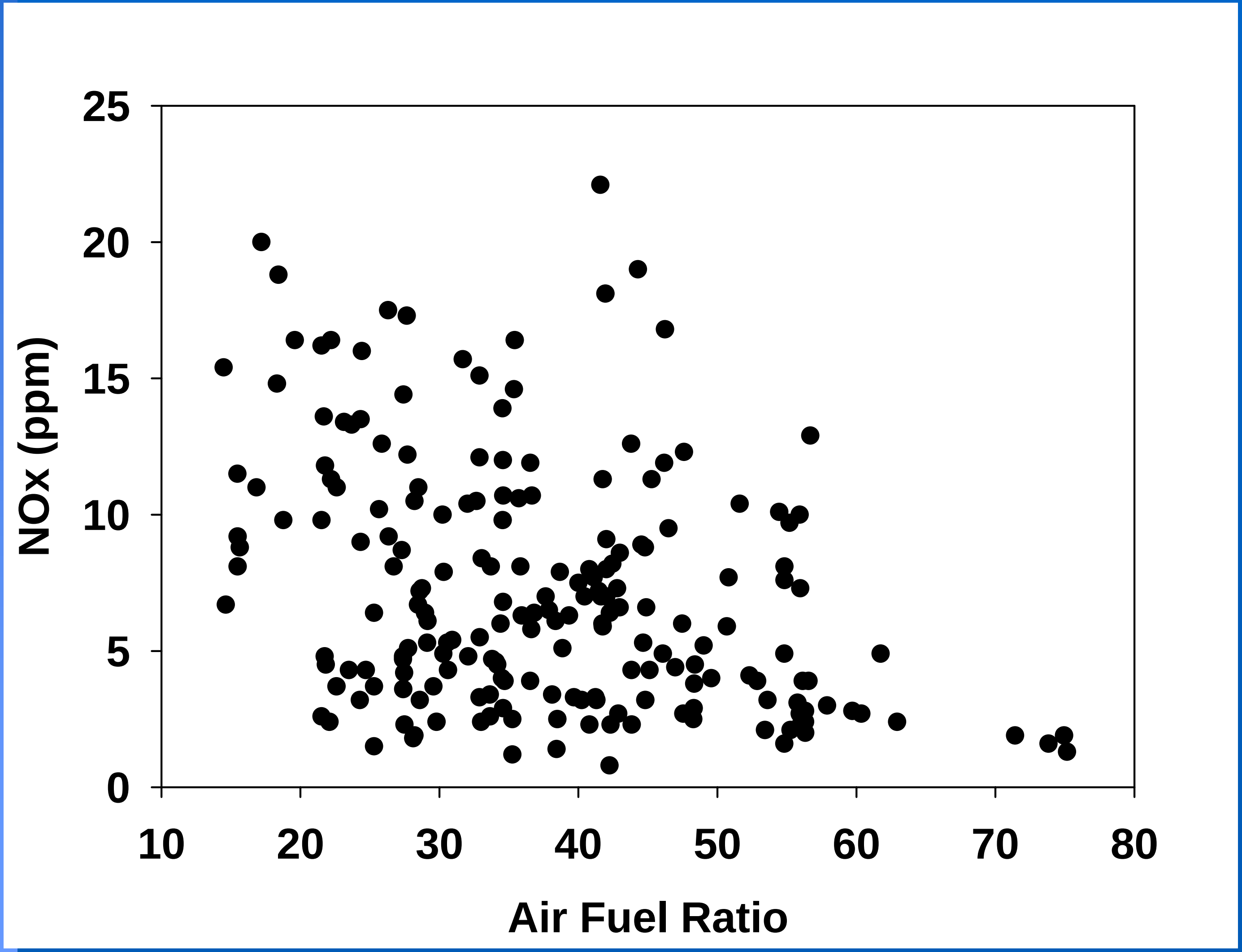
Test Matrix

CR	8 to 16.5:1
EGR	0 to 50%
A/F	12.5 to 75:1
MAT	28 to 220^{o}C
MAP	1 to 2.1 Bar
Speed	600 to 2000

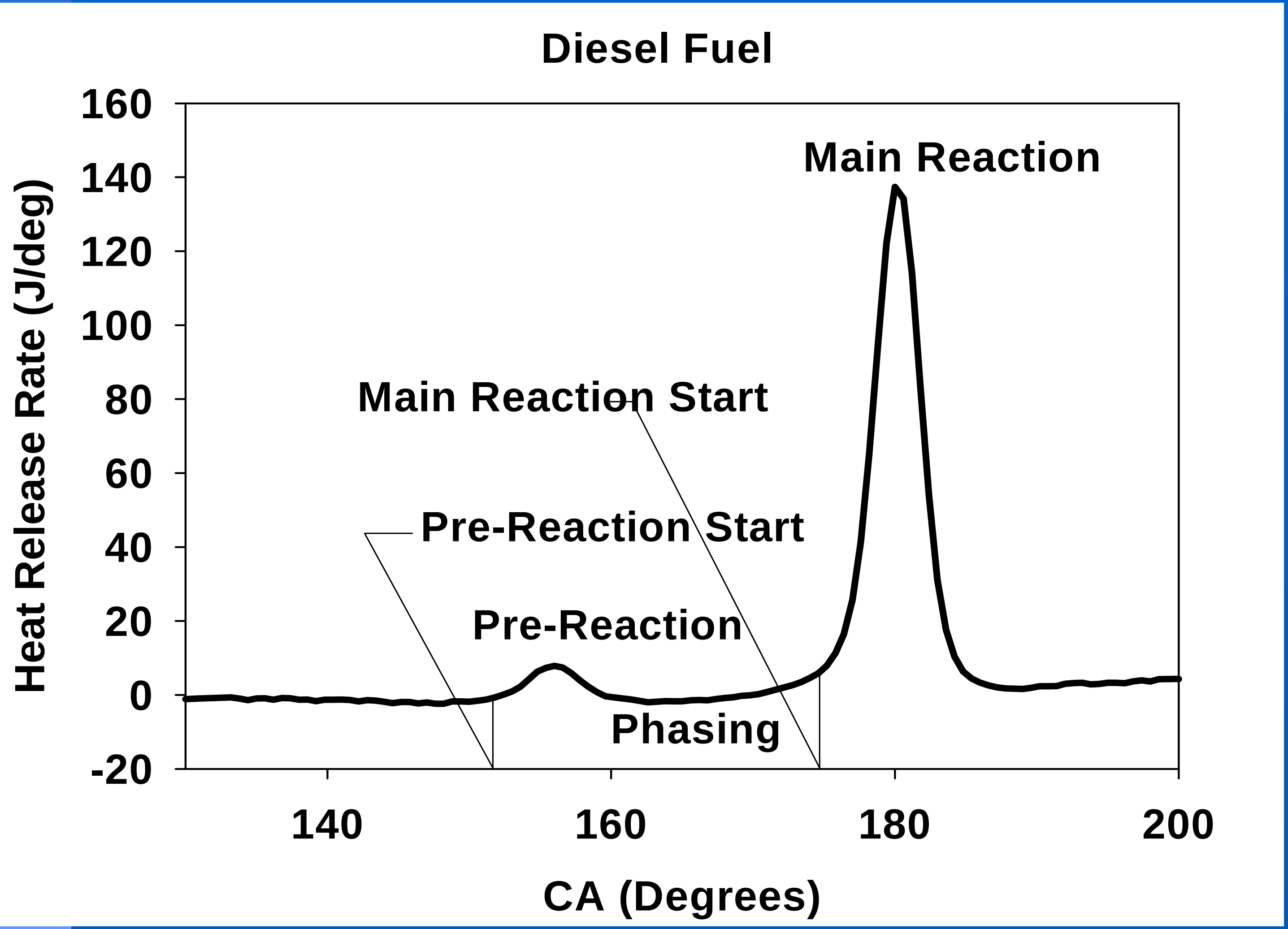
Test Procedure

- Full Factorial or DOE was not Possible
- Engine Warmed Up
- Speed Selected
- CR Fixed
- Varied A/F, EGR, MAT, and MAP
- Mapped Region of HCCI Operation
  - Zero Soot (BSN)
  - Less than 25 ppm NOx (revised Recently down to 15 ppm NOx)

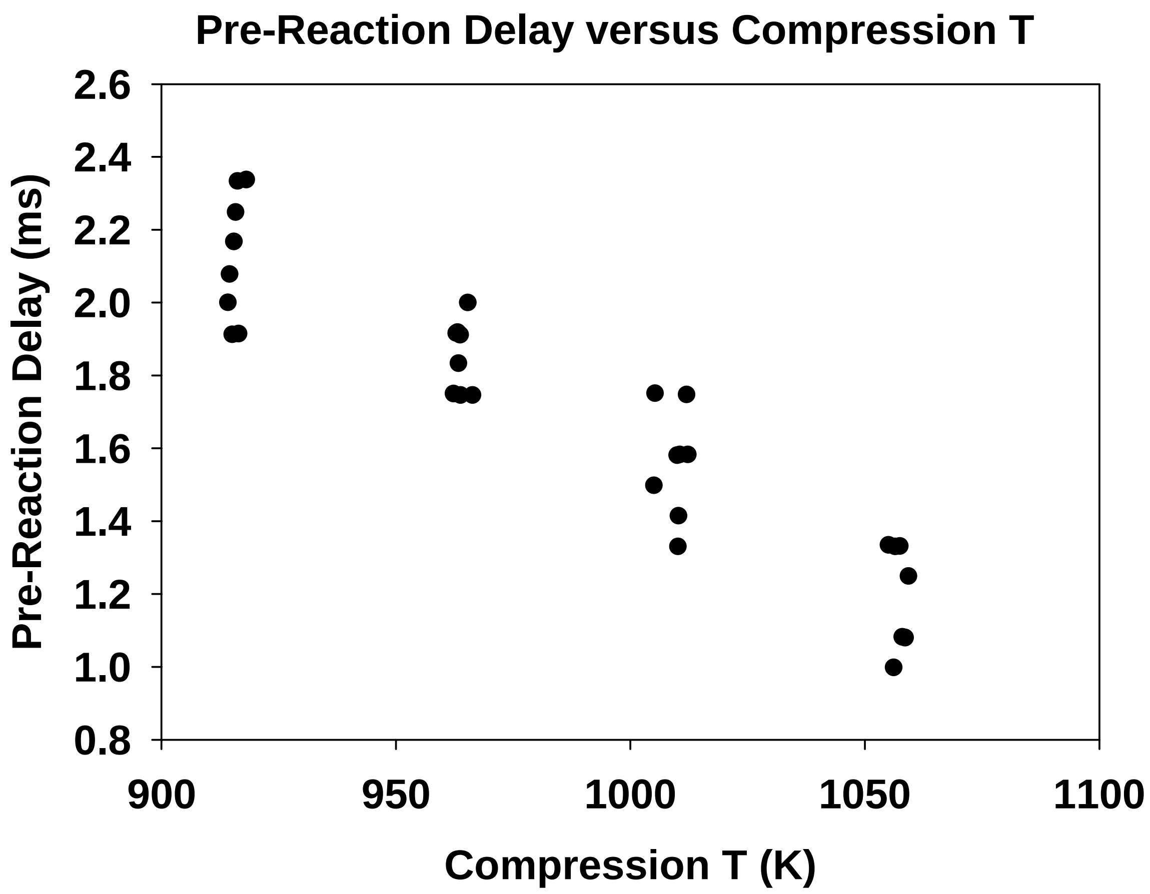
NOx Emissions versus A/F



Definition of Terms

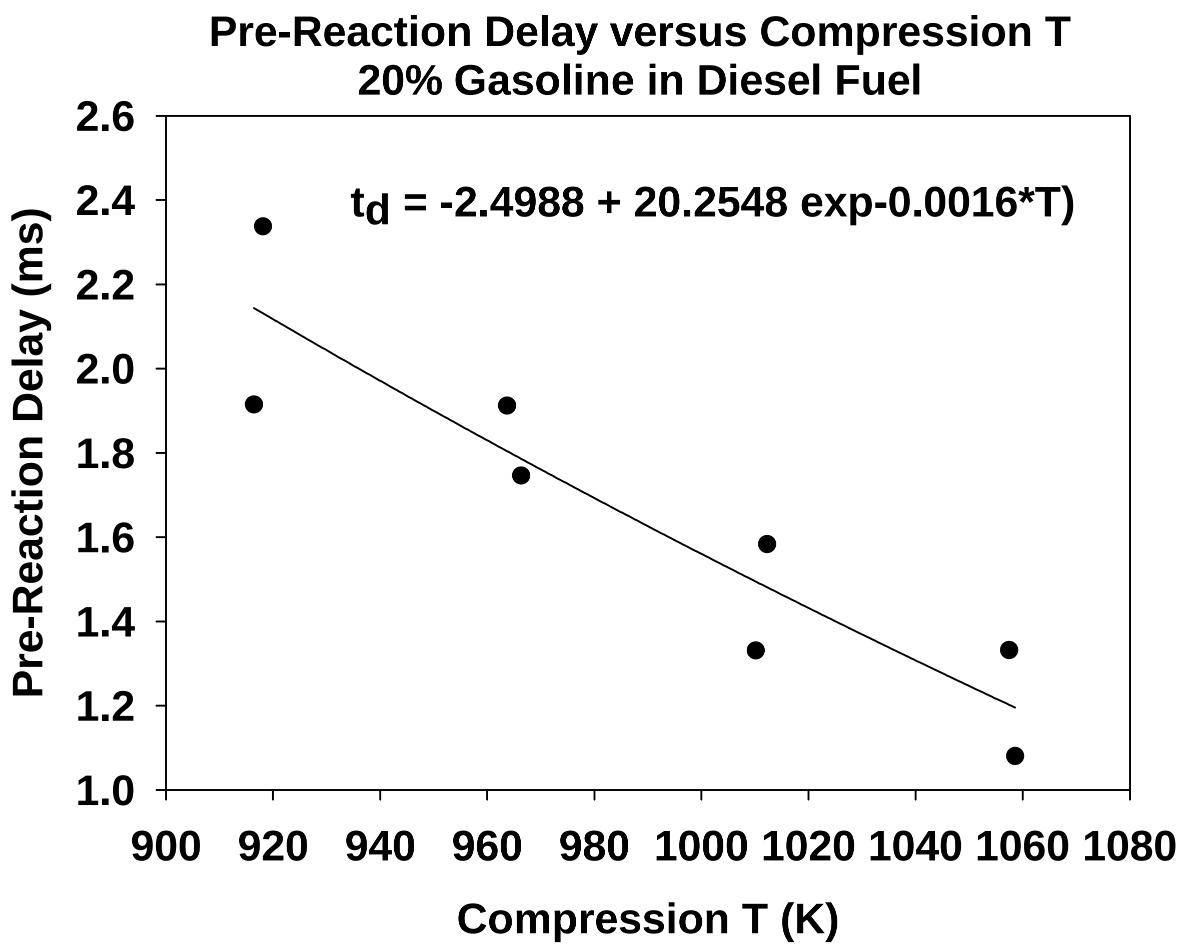


Diesel Fuel - Gasoline Tests



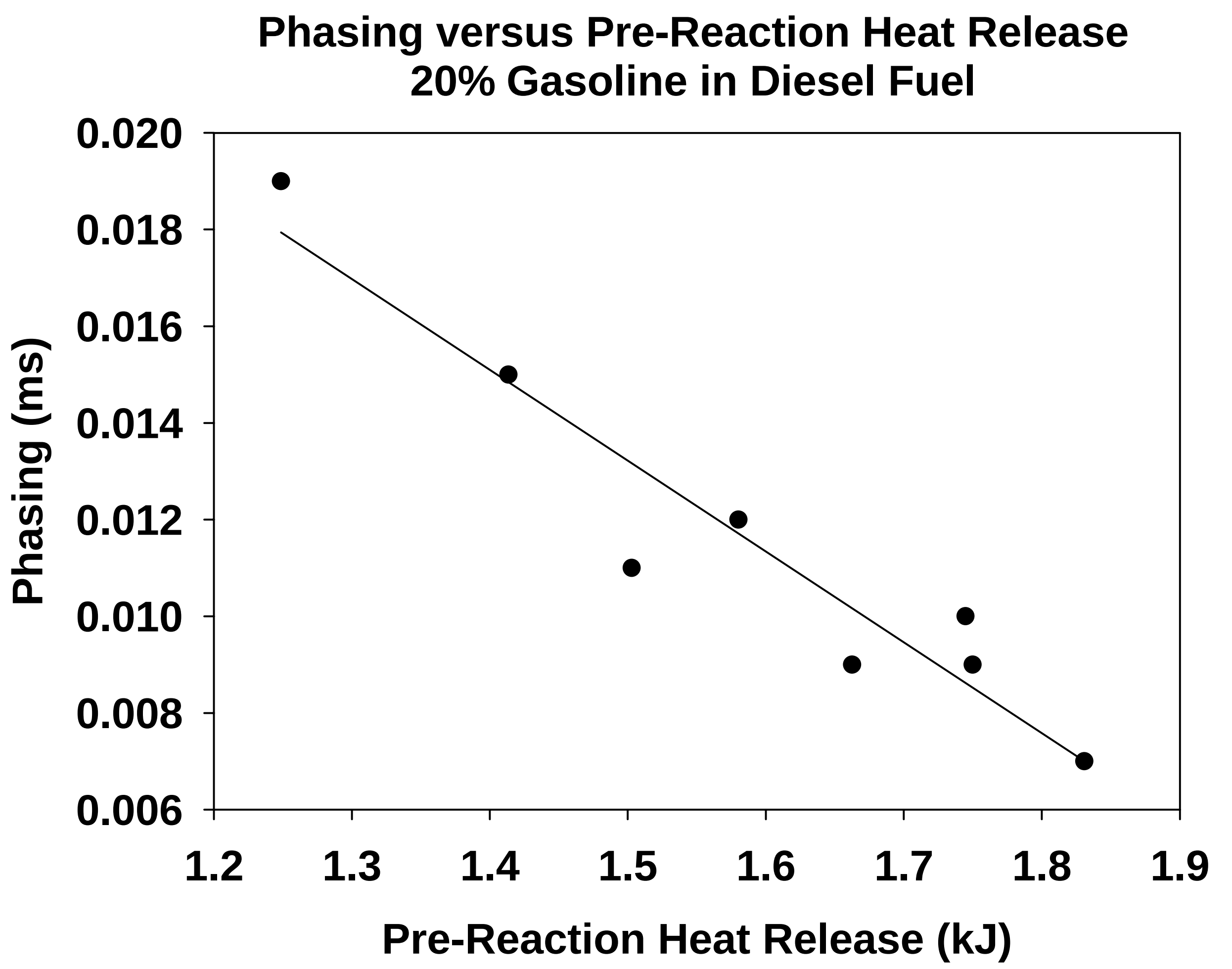
- Gasoline Added to Diesel to Affect the Volatility and Ignition
- Tests at Zero EGR and 14:1 CR
  - Gasoline Required 16:1 CR
- Delay Decreases with Compression Temp

Pre-Reaction Delay - 20% Gasoline



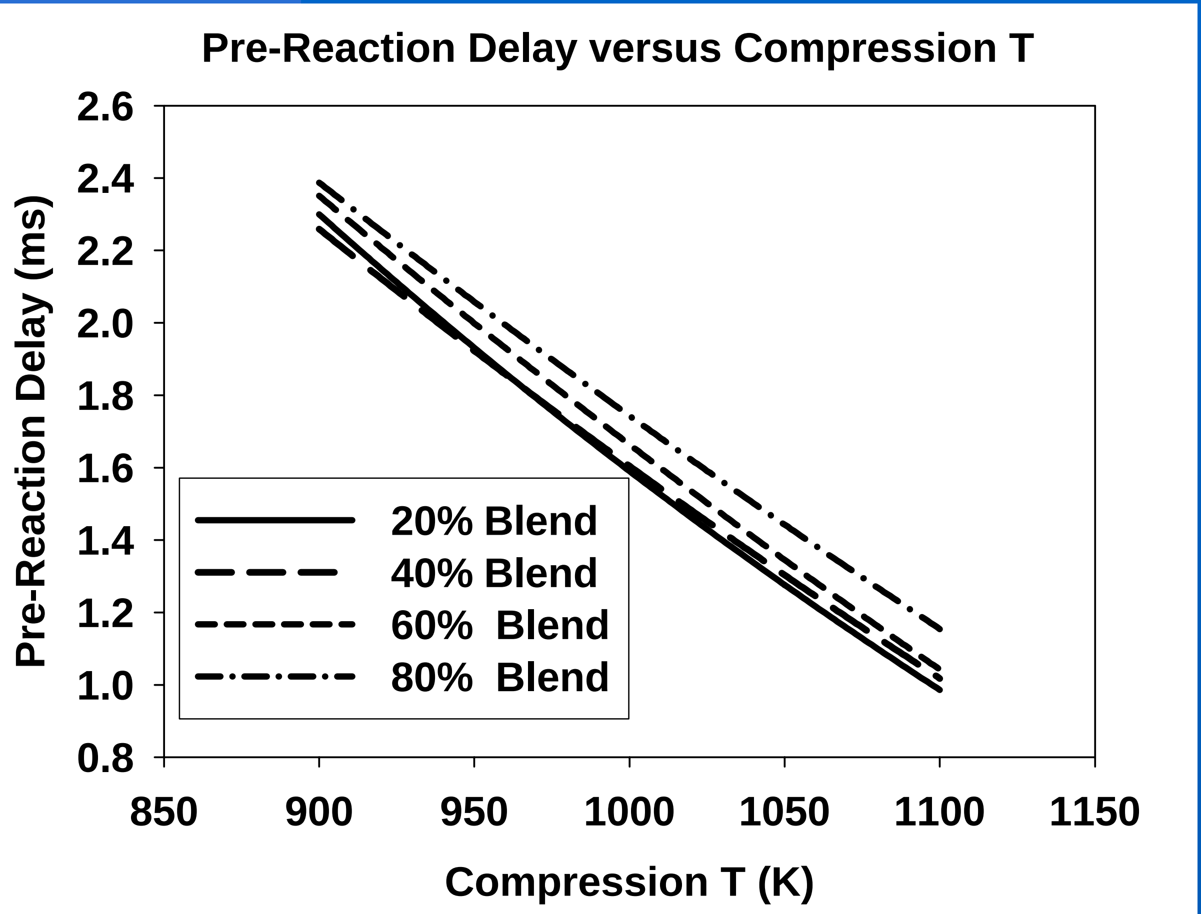
- Linear Relationship - Exponential Curve Fit
- Relationships for Other Blends are Similar

Phasing - 20% Gasoline Blend



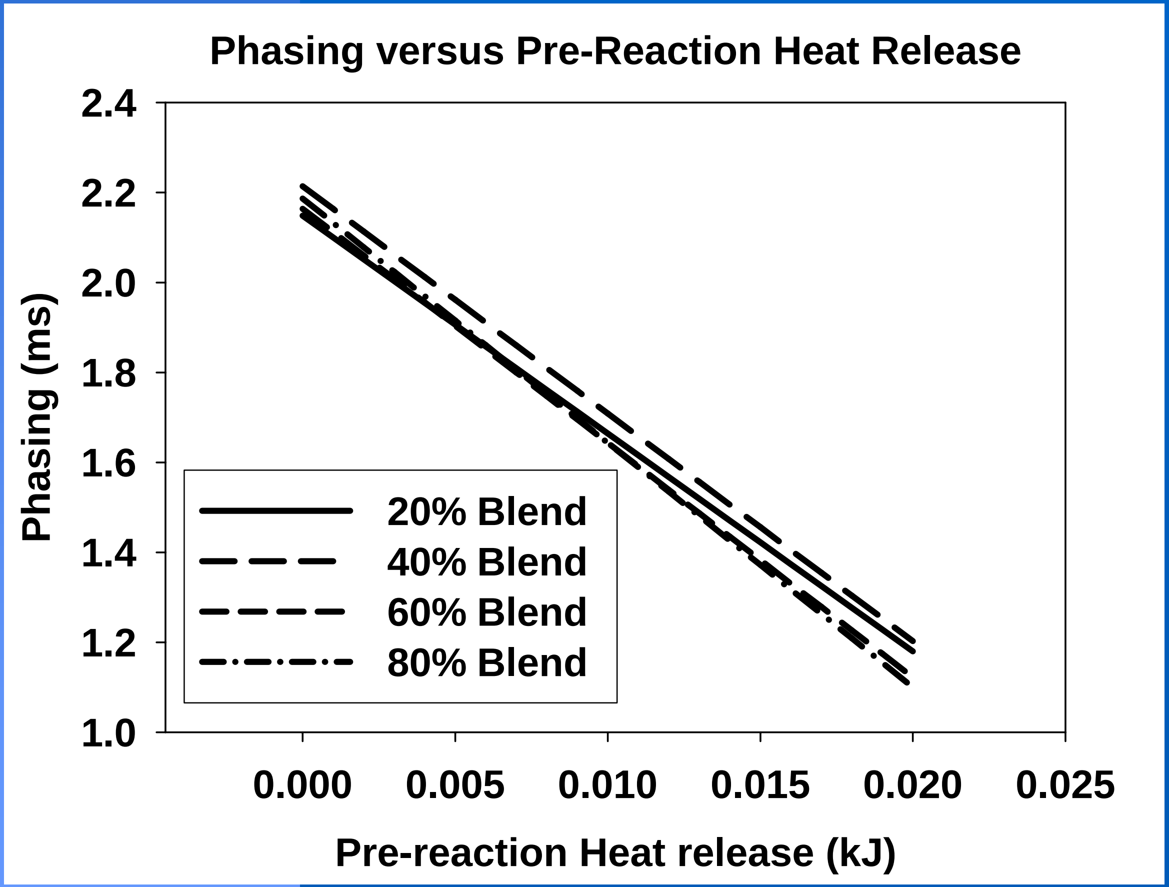
- Phasing Linearly Related to the Magnitude of the Pre-Reaction
- All Blends Demonstrated the Same Trends

Pre-Reaction Delay - Curve Fits Diesel Fuel-Gasoline Blends



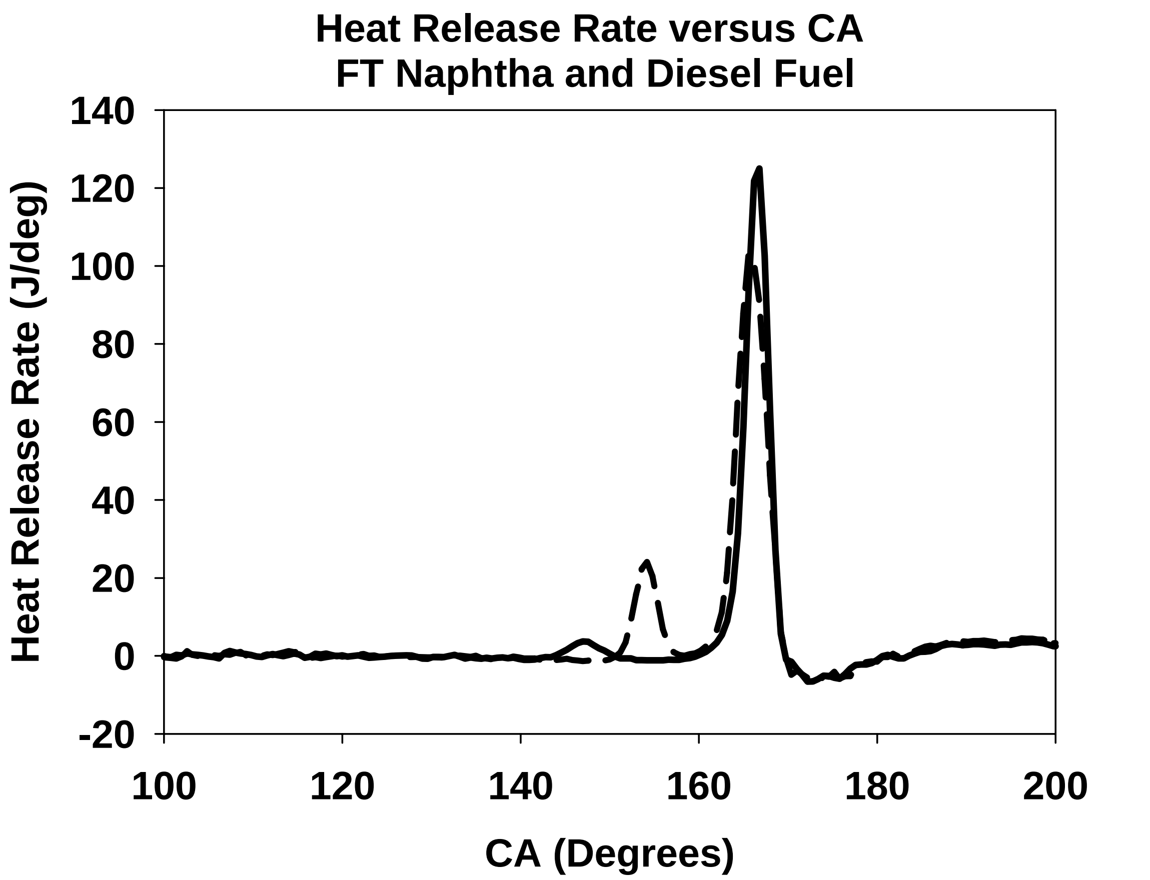
- Blends all Demonstrated the Same Trends
- Reactions Appear to be Dominated by the Diesel Fuel

Phasing - Curve Fits
Diesel Fuel-Gasoline Blends



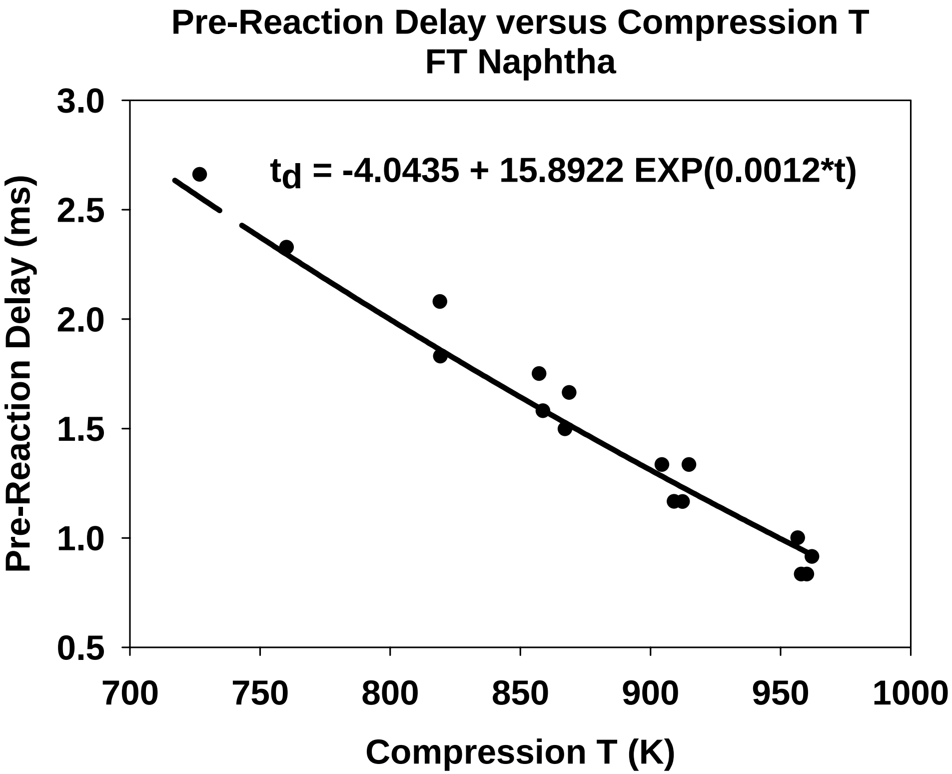
- All Blends Demonstrated Exactly the Same Relationships
- Pre-Reaction Delay and Phasing for these Blends Again Demonstrate the Problem with CN

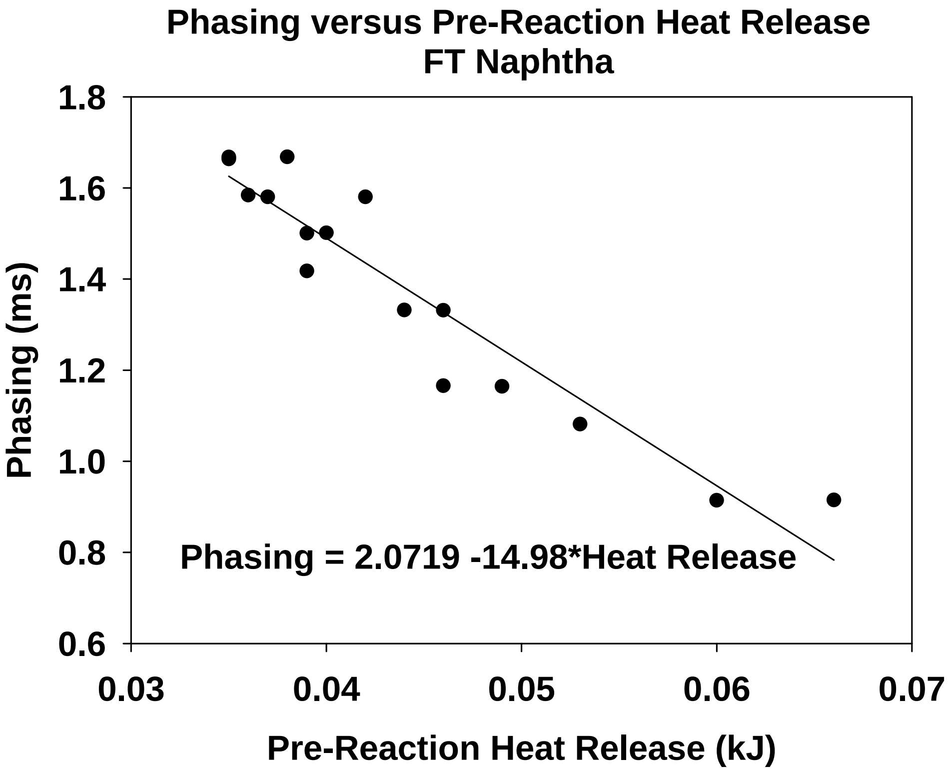
FT Naphtha - HHR Comparison



- FT has much Larger Pre-Reaction Stage
- FT Pre-Reaction Delay is Longer
- Phasing is Much Shorter
- CN of FT is 51 Compared to 43 for DF - CN Problem

FT Naphtha - Delay and Phasing



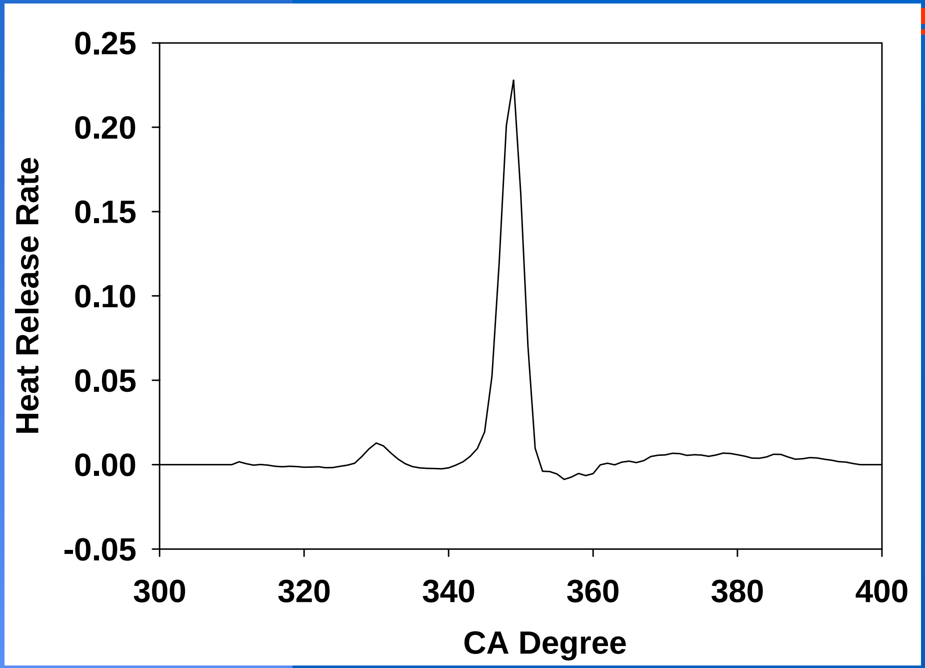


- Excellent Correlations for Pre-Reaction Delay and Phasing
- Large Pre-Reaction and Long Delay Likely to due to Highly Paraffinic Composition of FT

Impact of Pre-Reaction

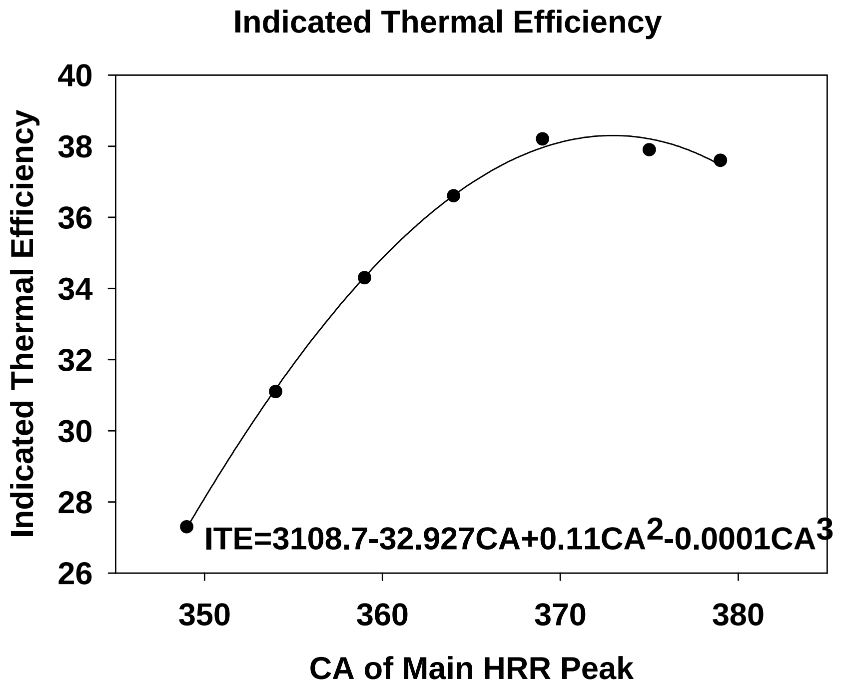
- FTN Demonstrates very Significant Pre-Reaction
- Gasoline Demonstrates Some Pre-Reaction
- Diesel Fuel Fall Between the FTN and Gasoline
- Methane Demonstrates No Pre-Reaction
  - How do the Different Fuels Interact in Blends?

Effect of HRR Timing

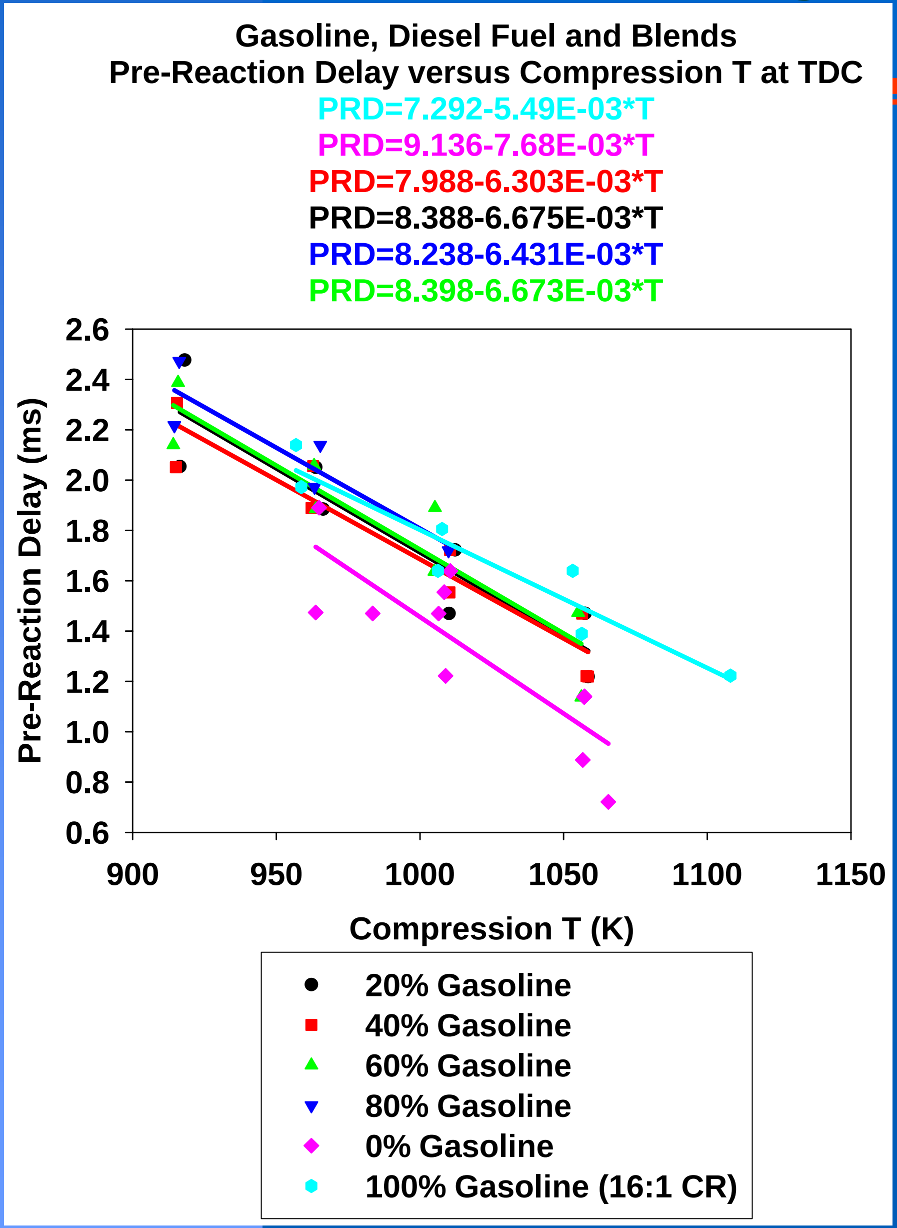


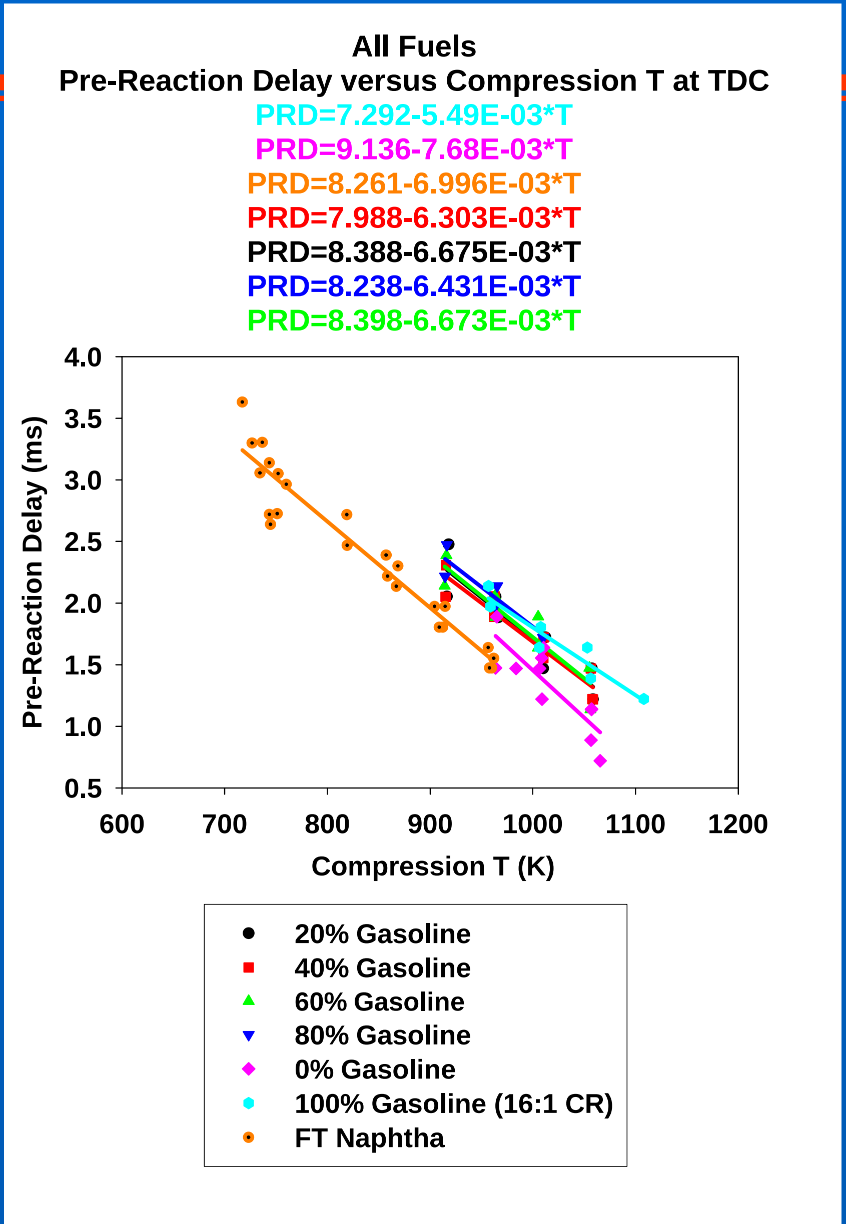
- Actual Heat Release too Early
- Changed the Start of the Main Reaction
- Held Pre-Reaction Magnitude and Phasing Constant

Early SOR and Low Efficiency
ITE = 27%

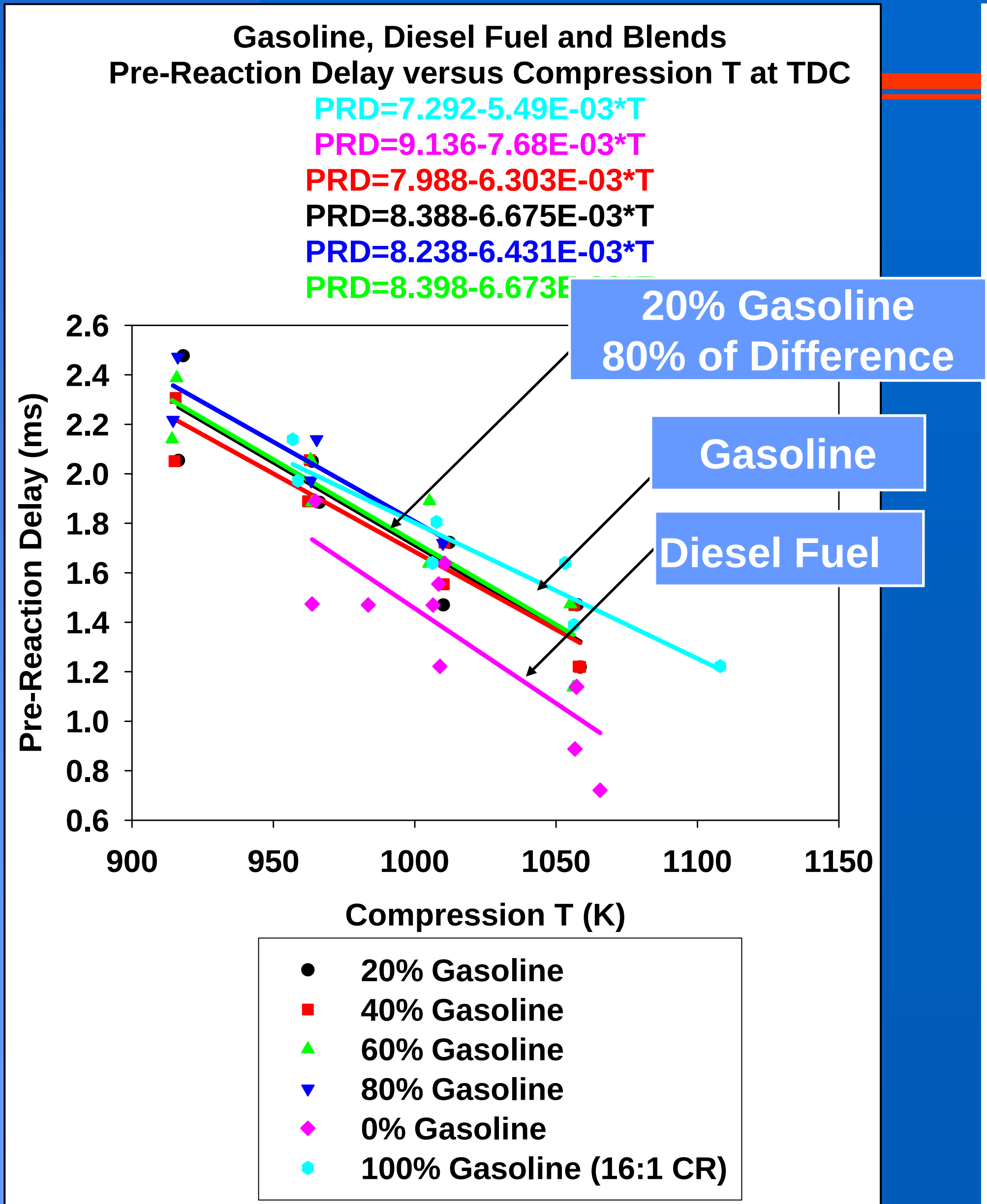


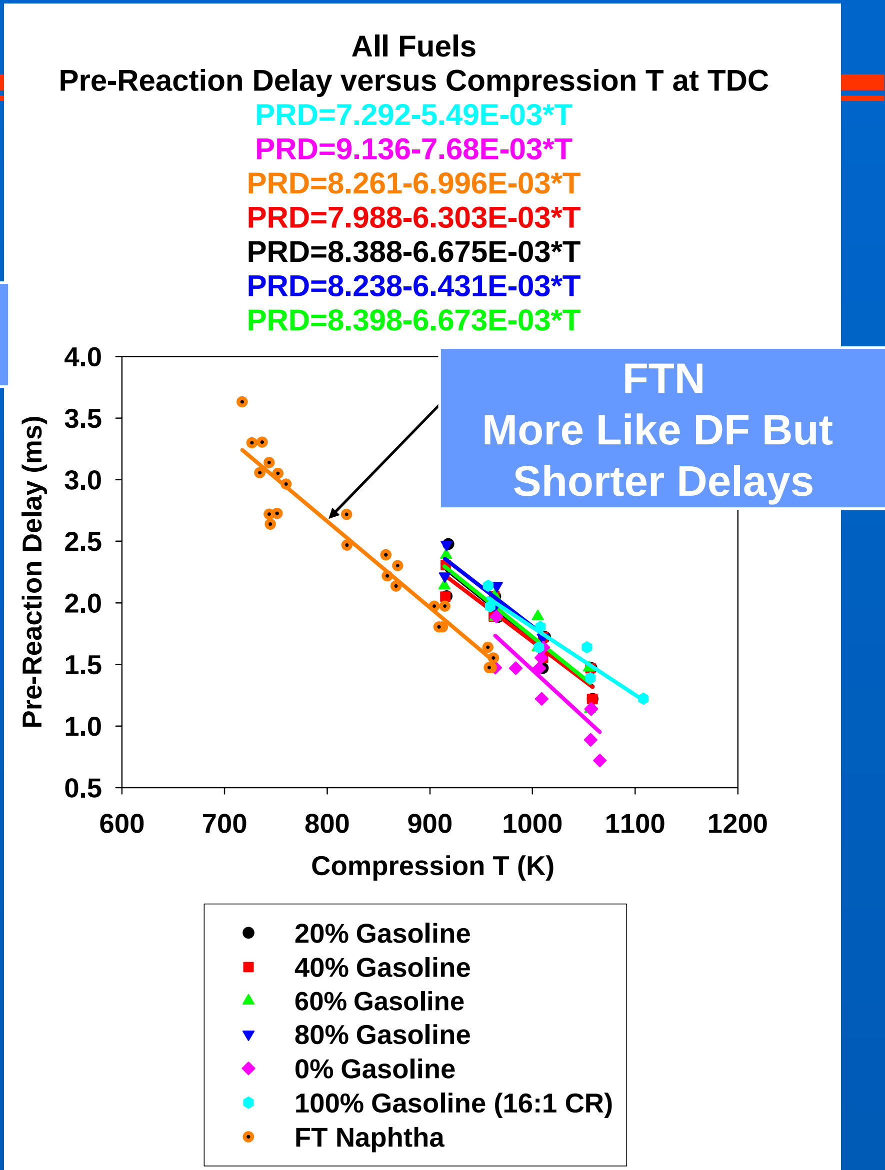
Pre-Reaction Delay



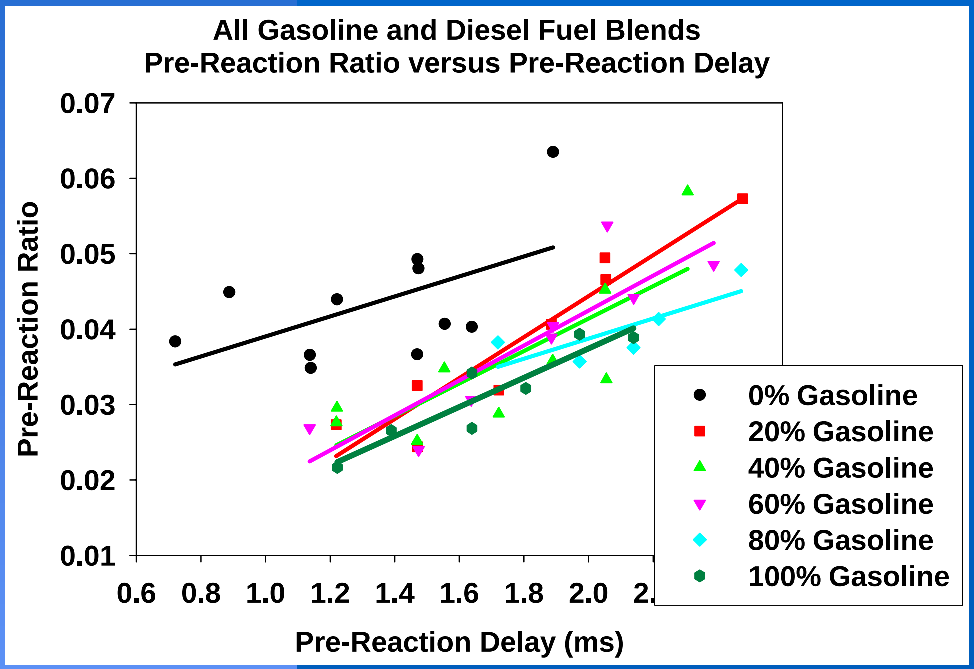


Pre-Reaction Delay



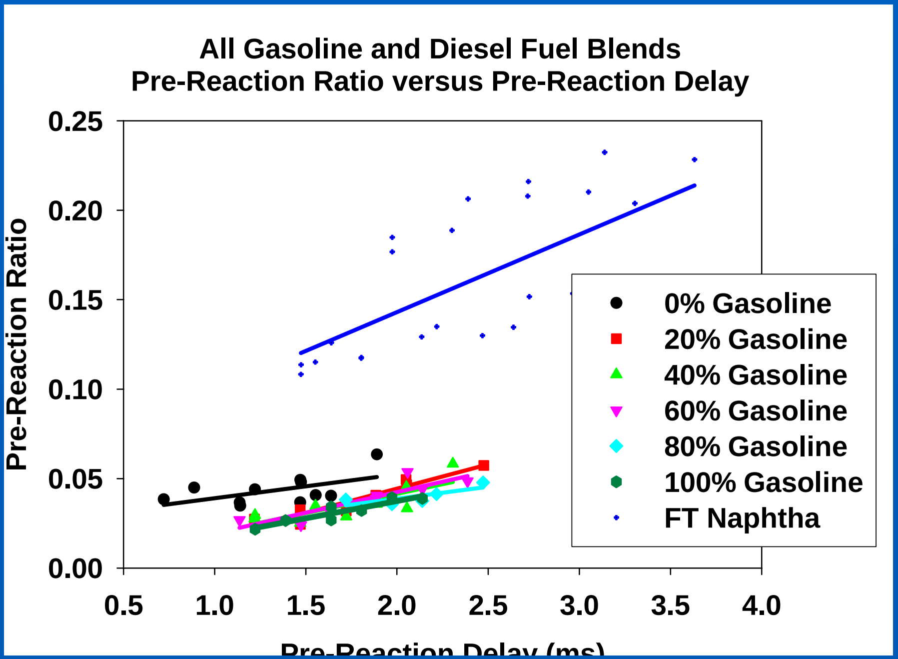


Pre-Reaction Ratio

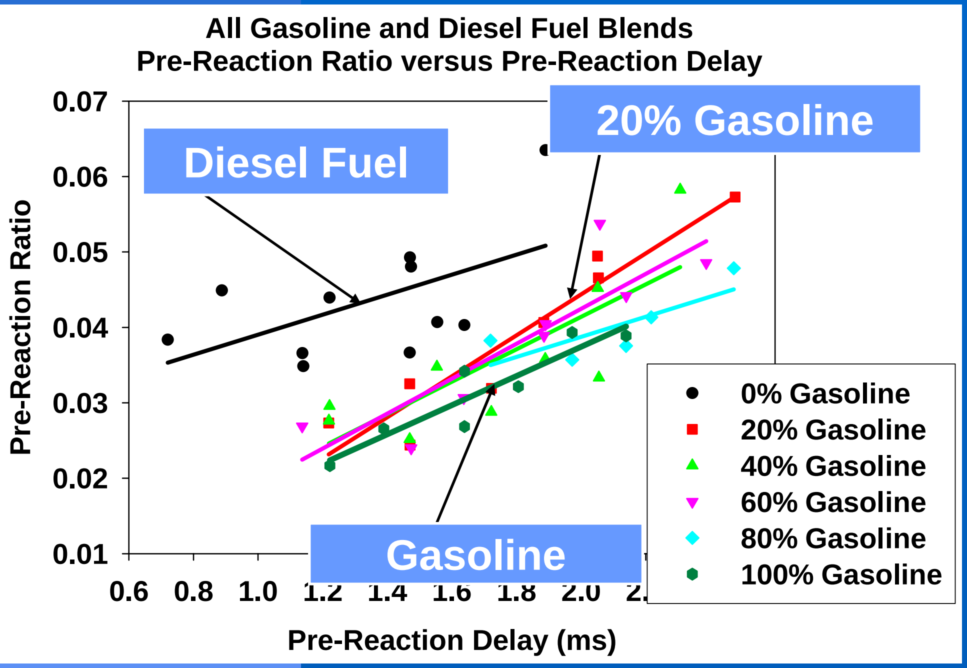


- Pre-Reaction Ratio Increases with Increased Pre-Reaction Delay

- Pre-Reaction Ratio Defined as the Ratio of the Pre to the Total Heat Release



Pre-Reaction Ratio



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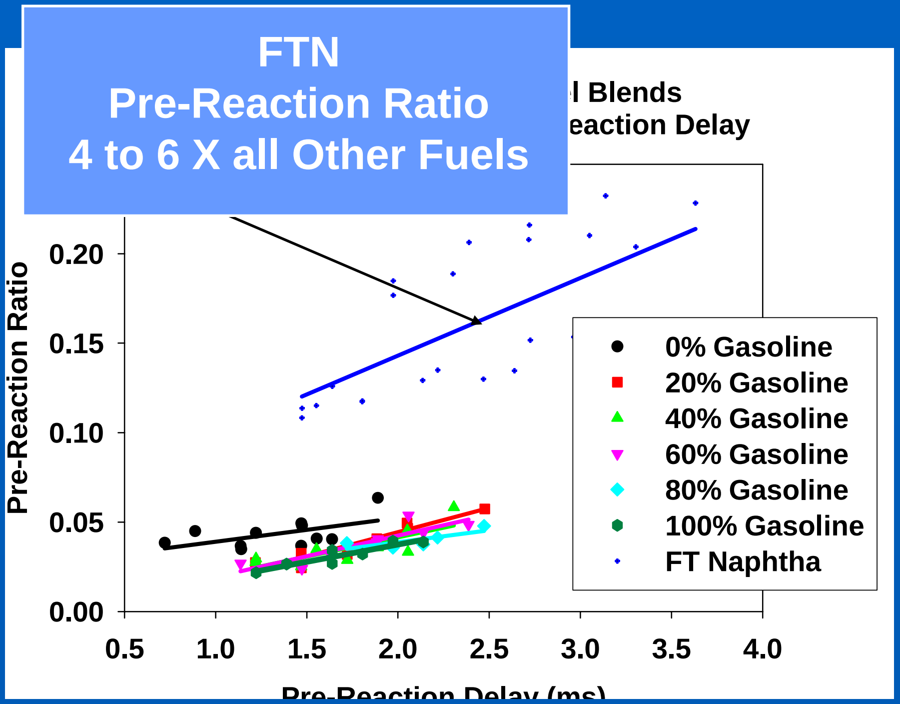
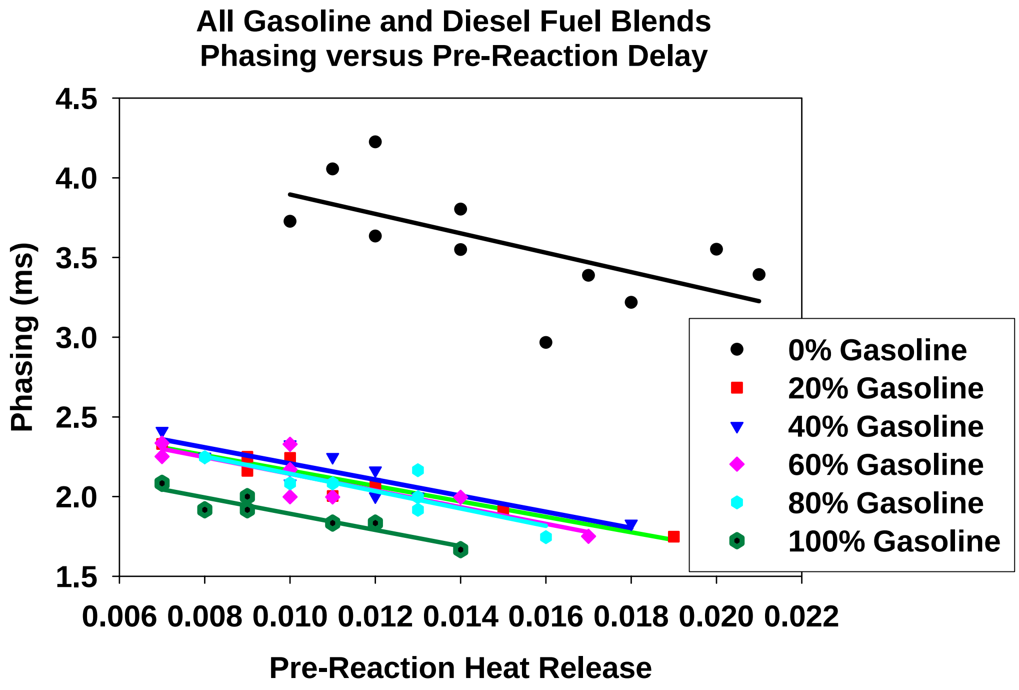


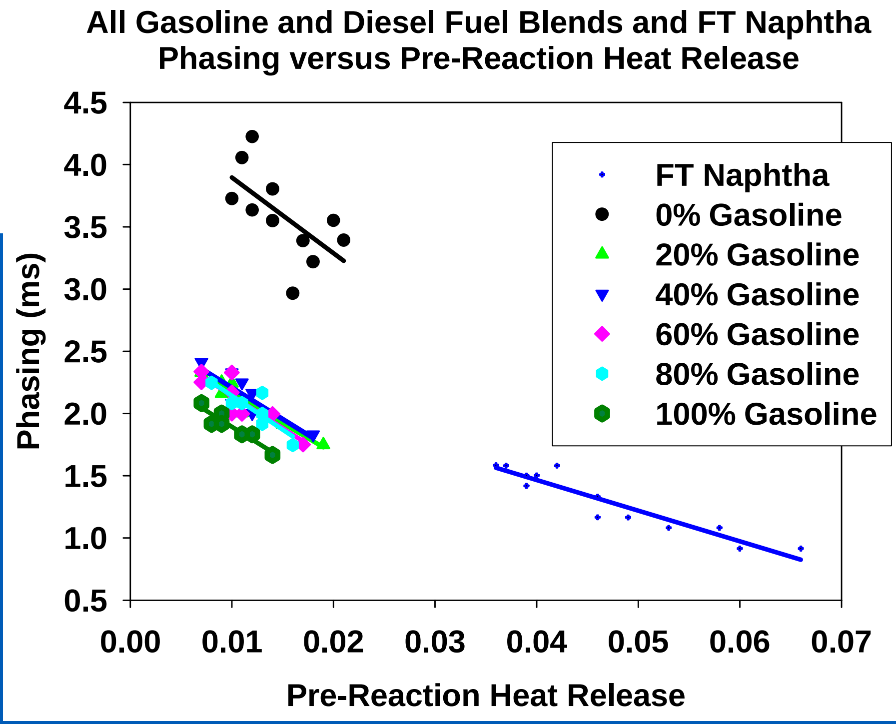
- Pre-Reaction Ratio Defined as the Ratio of the Pre to the Total Heat Release

Phasing

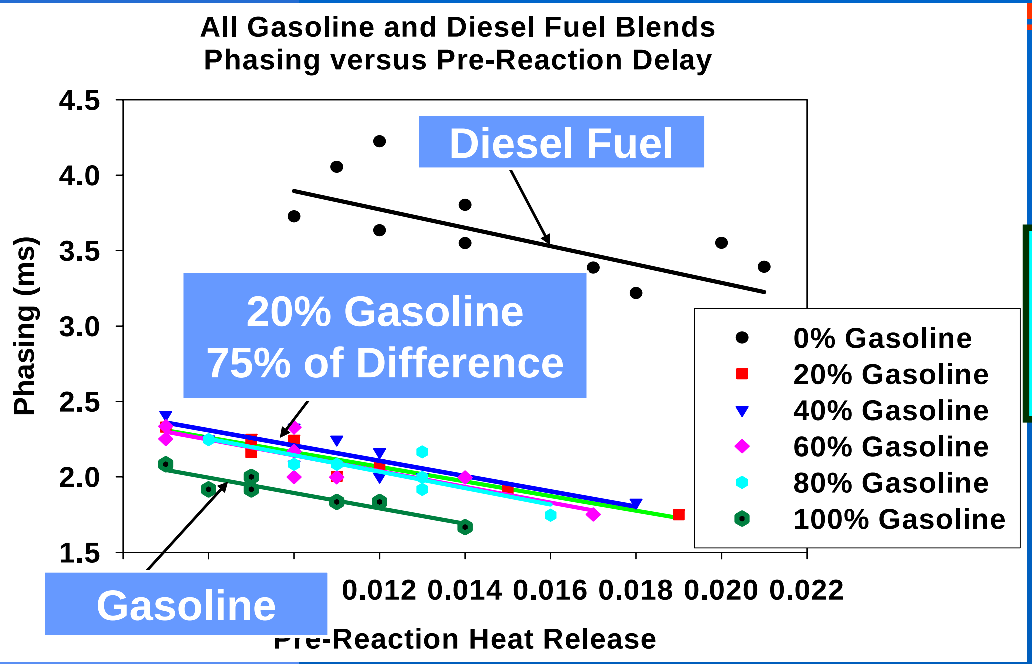


- Larger Pre-Reaction Means Shorter Phasing

- Phasing Related to the Pre-Reaction Heat Release



Phasing



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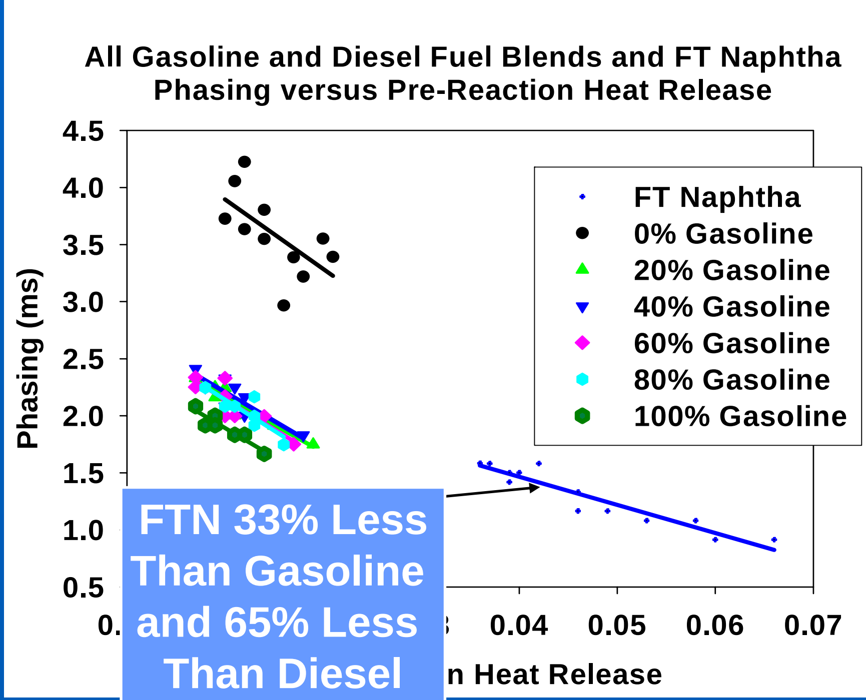


Summary

- Pre-Reaction Delay, Pre-Reaction Ratio (Pre-Reaction Heat Release), and Phasing are all Important
- Diesel Fuel Pre-Reaction Delay (PRD) Shorter than Gasoline
  - Adding 20% Gasoline Increases PRD by 80% of Differences
  - FTN Shortest, but Follows Trend of Diesel Fuel

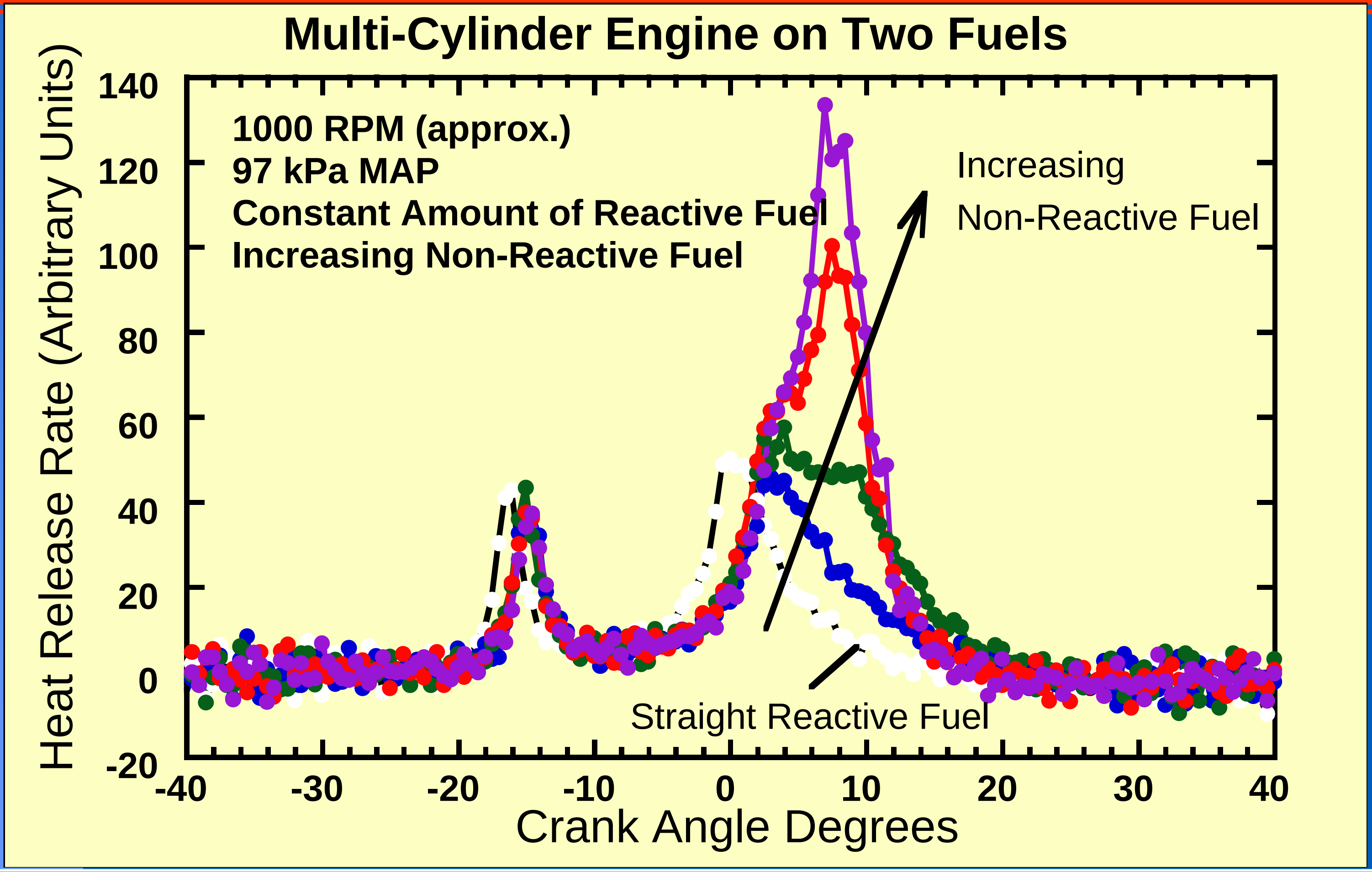
Summary (continued)

- Diesel Fuel Pre-Reaction Ratio (PRR) Larger than Gasoline
  - Adding 20% Gasoline Reduced the PRR by 75% of the Difference
  - FTN has the Largest PRR by 4-6X
- Diesel Fuel Phasing Longer than Gasoline
  - Adding 20% Gasoline Reduced the Phasing by 80% of the Difference
  - FTN has the Shortest Phasing
    - 33% Less than Gasoline and 65% Less than Diesel Fuel

Summary (continued)

- FTN, Diesel Fuel, and Gasoline all Exhibit Pre-Reaction Heat Release
  - On Average, 4-6 X Diesel Fuel and Gasoline
  - Diesel Fuel PRR is Larger than Gasoline
- Methane Doesn’t Exhibit Pre-Reaction Heat Release
- SwRI Used Methane and FTN in a Multi-Cylinder Test Engine (SAE 2001-01-1897)

Multi-Cylinder Engine Test



PRD and PRR not Affected by the Presence of the Methane, but Main HRR Delayed by Methane

Hypothesis

- Gasoline -FTN Blends will Provide Options for Control of the Ignition and Reaction Processes
  - FTN is the Reactive Component
  - Gasoline will Affect the PRD, the PRR, and the Phasing of the Blend
  - 20/80 Blend of FTN in Gasoline is Proposed
    - Gasoline will Inhibit the PRD of the FTN
    - Large PRR of FTN will Decrease the Phasing of the Gasoline

Why 20/80 Blend

- Alamo_Engine (SwRI Cycle Simulation Code) used to Compute the Compression Temperature History in the Test Engine Operating at Equivalent Diesel Full Load Conditions:
  - 25:1 Air-Fuel Ratio
  - 3 Bar Boost
  - 10% EGR

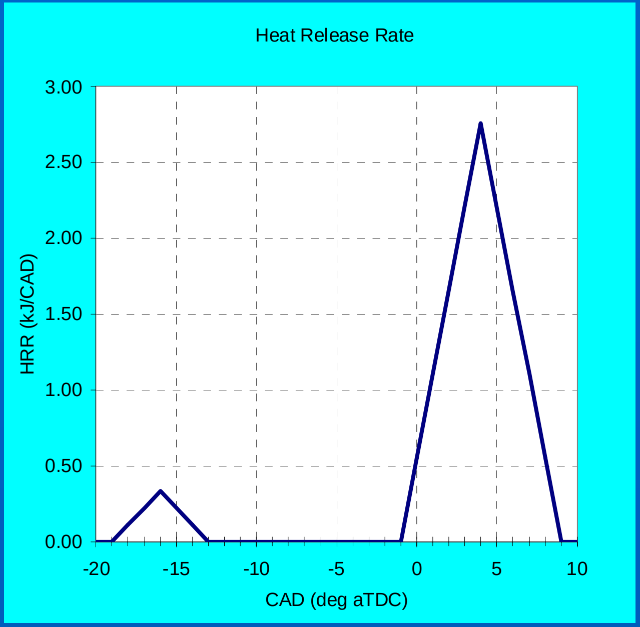
Baseline Engine Result

Parameter	Value
MAP (kPa)	300
Fuel Flow Rate (kg/s)	0.00114
Fresh Air Flow Rate (kg/s)	0.0292
Torque (N-m)	108.7
Indicated Power (kW)	21.76
Indicated Thermal Efficiency	44.2
BSFC ((g/kW-hr)	195.1

Computed TDC Compression T = 860K

Performance Prediction 20/80 Blend

- Used the Relationships Shown Above
  - At 860K
    - PRD
      - FTN = 2.24
      - Gasoline = 2.57
    - PRR
      - FTN = 0.154
      - Gasoline = 0.048
    - Phasing
      - FTN = 1.79 ms
      - Gasoline = 1.61 ms



Thermal Efficiency = 40%

- Assumed Gasoline Affects FTN Same as Diesel Fuel, at 1800 rpm, 3 Bar MAP, 95% Combustion Efficiency
  - Pre SOR at 19^{o} BTDC, Main SOR at 1.1^{o} BTDC, Pre Heat Release = 0.334kJ and Main = 2.76 kJ

Thank You.

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