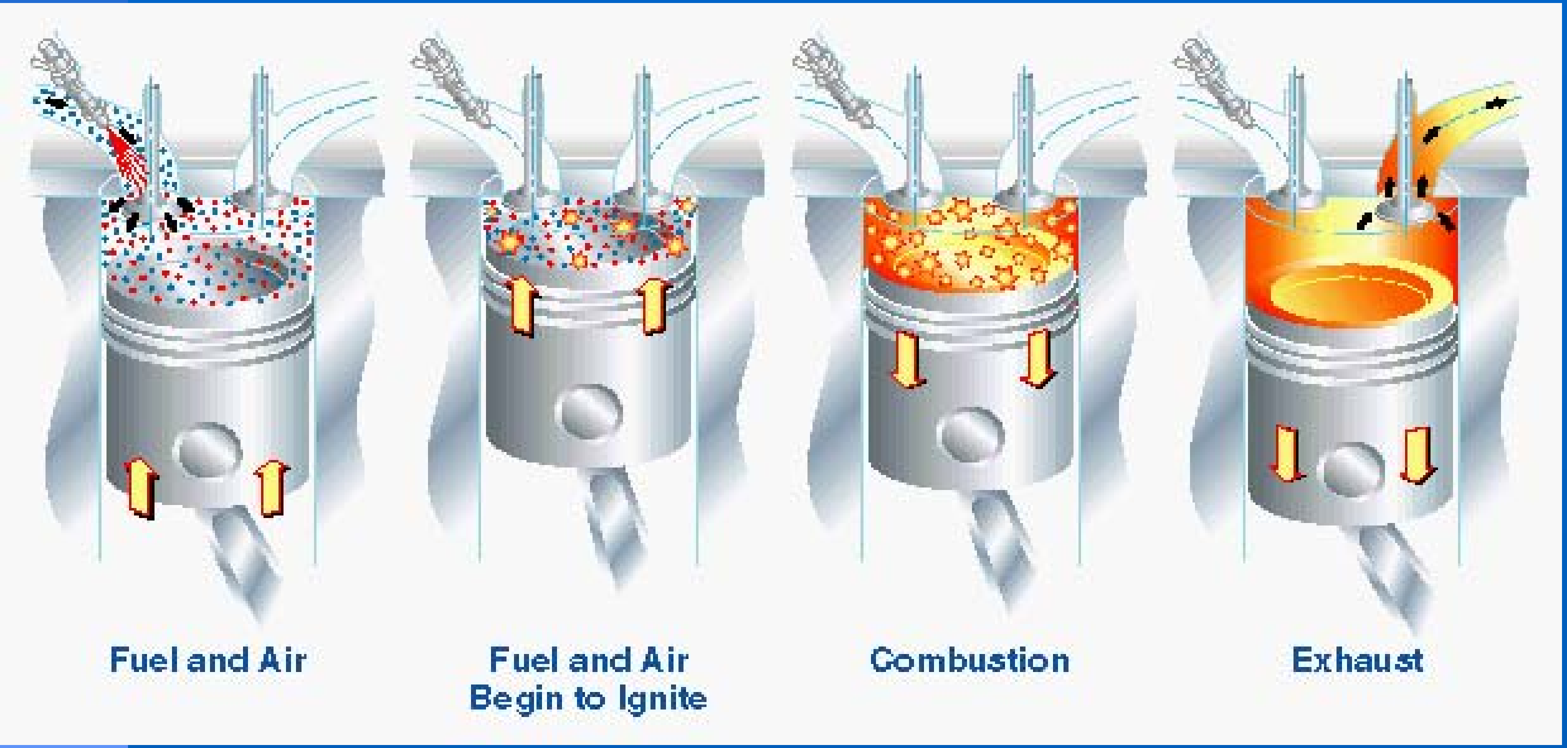
Fuel Requirements for HCCI Engine Operation

Tom Ryan
Andrew Matheaus
Southwest Research Institute

HCCI



- Fuel & Air Charge Undergoes Compression
- Spontaneous Reaction Throughout Cylinder
- Low Temperature and Fast Reaction Gives Low NO_x

Fundamentals of HCCI Reaction 1

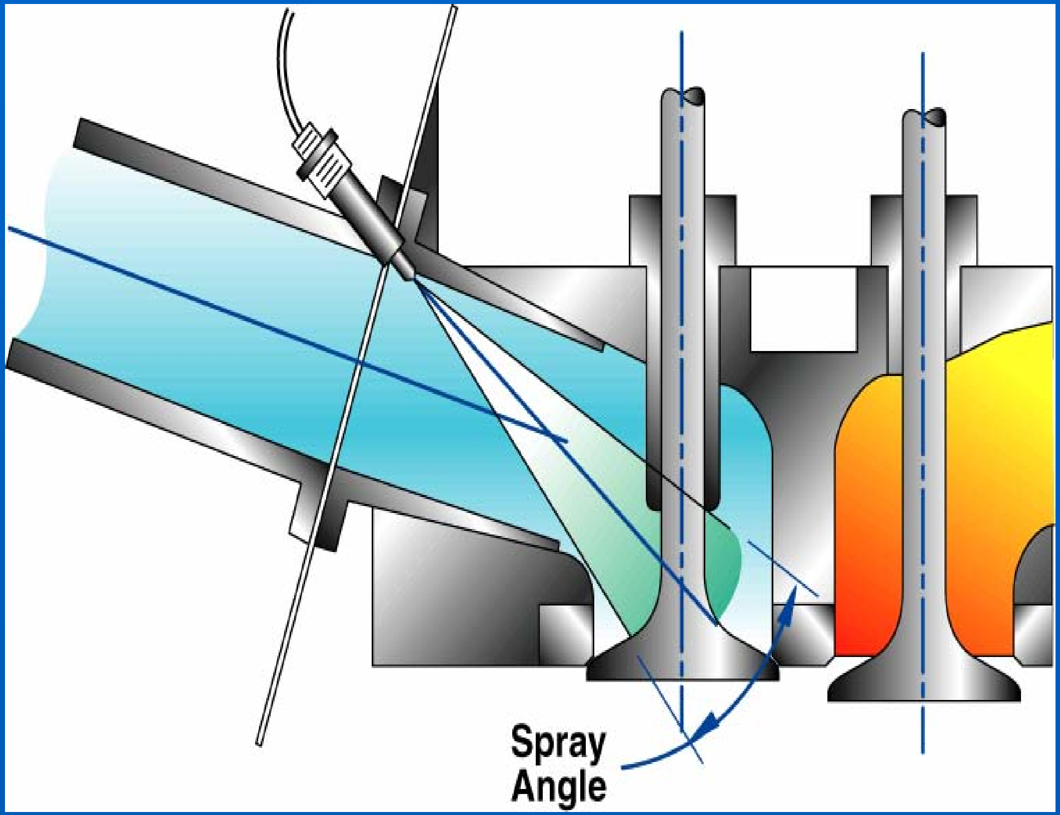
- Ideally, a Homogeneous Fuel-Air Mixture is One in Which the Composition and the Thermodynamic Conditions are Uniform Throughout the Reaction Phase
  - Reaction Starts When the Thermodynamic Conditions are Sufficient to Initiate Chain Branching Reactions
  - Reaction Rates and Reaction Duration are Kinetically Controlled

Fundamentals of HCCI Reaction 2

- Practical Fuel-Air Mixtures Have Both Compositional and Thermodynamic In-Homogeneities
  - Reaction Begins in the Fuel Richest and the Highest Temperature Locations
  - Reaction Rates and Reaction Duration are Affected by Mixing and Heat Transfer

Port Injection Configuration

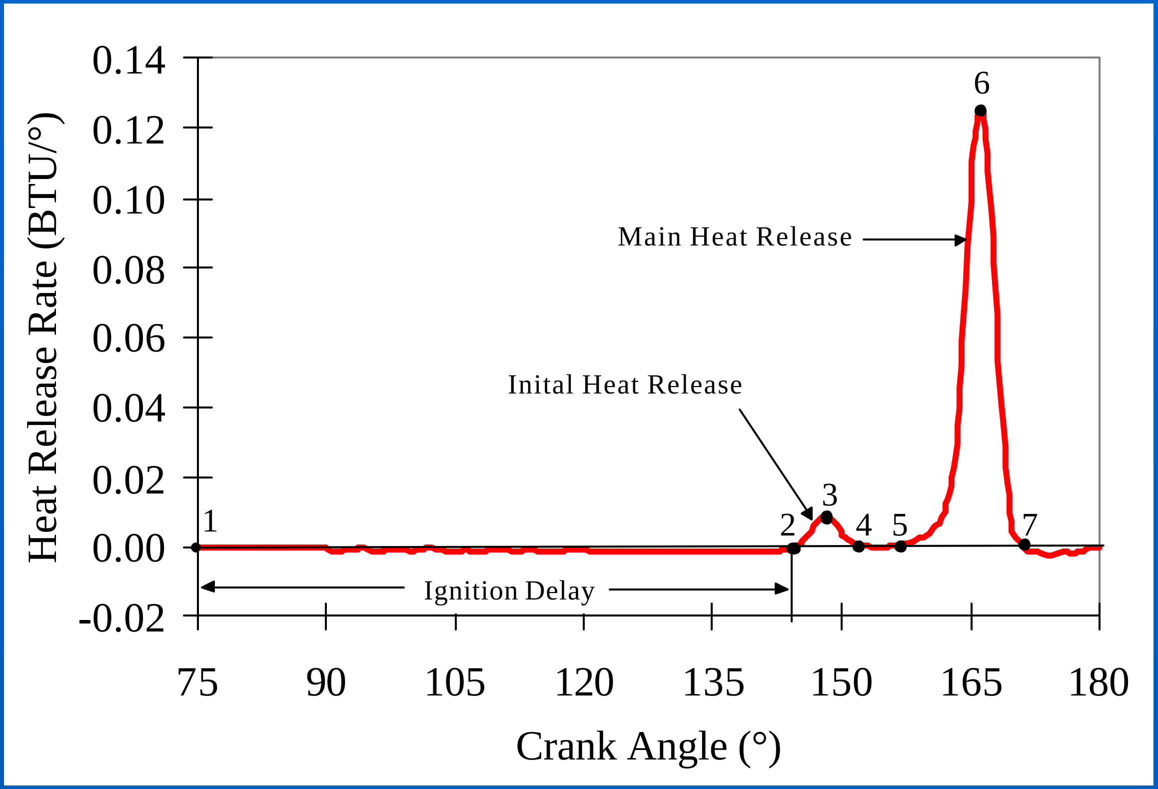
- Air-Assist Pressure-Swirl Injector
- Timed to Valve Opening
- Liquid Drops Acceptable
- Evaporation During Compression



HCCI Development Problems

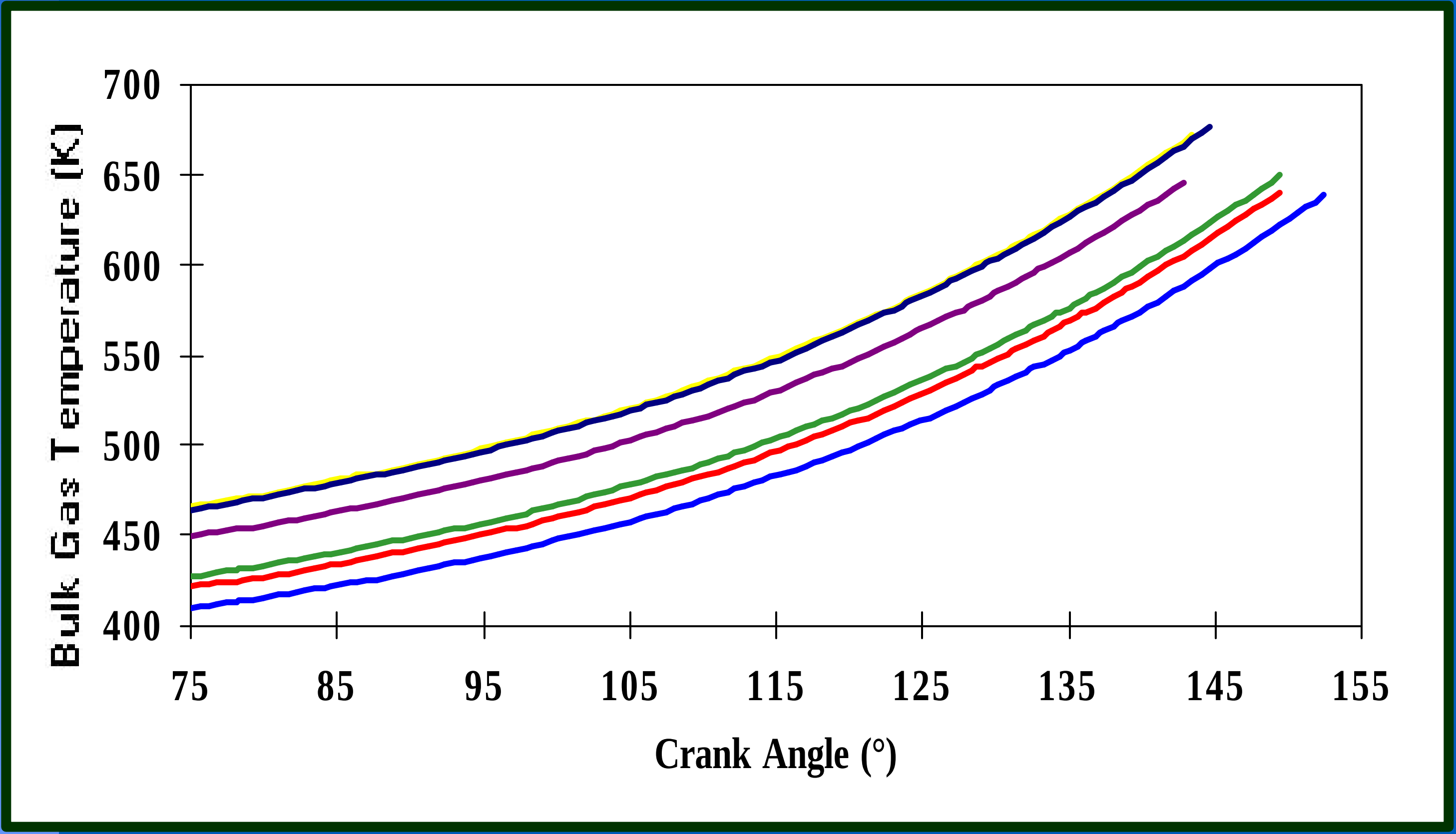
- SOR Control
  - No SOR Property Defined
- Mixture Preparation
  - Total Evaporation Before the Start of Reaction

Typical HCCI Engine Heat Release



Start of Reaction

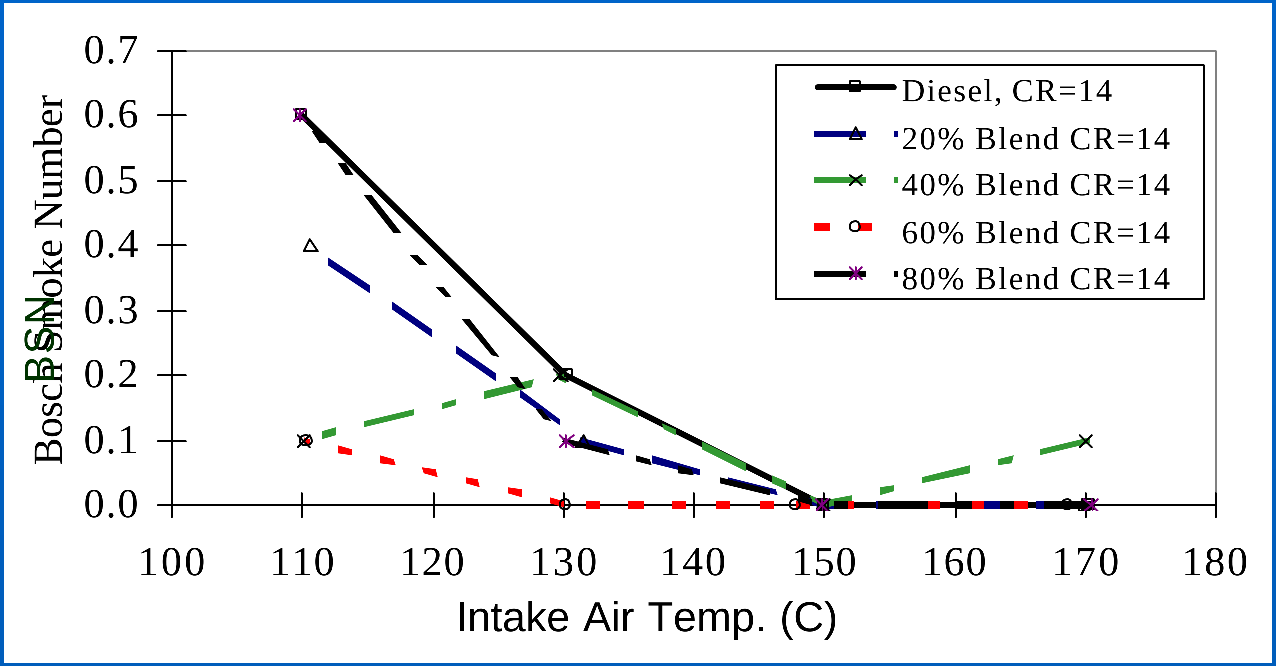
Effects of Compression Temperature History



- Various Intake Temperatures and EGR
- In All Cases SOR is Very Near 650 K

Mixture Preparation

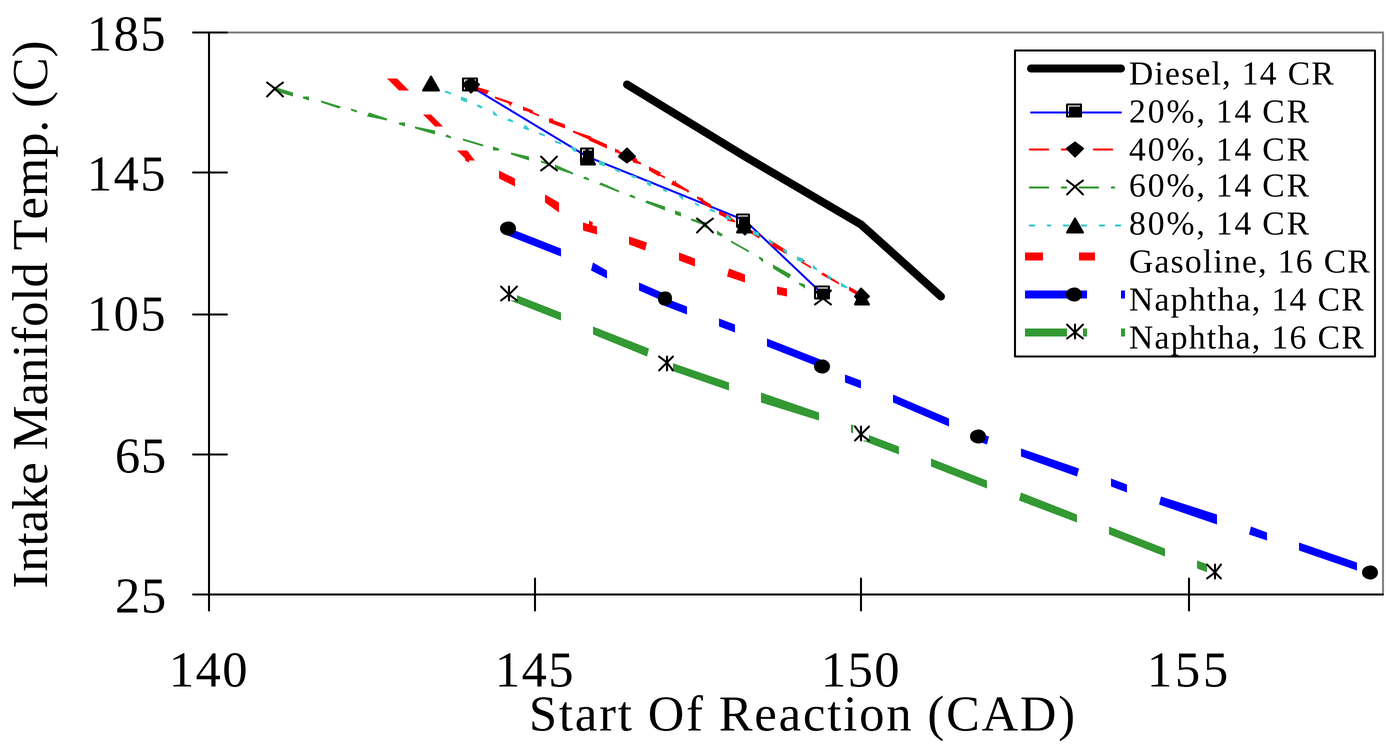
Effects of Intake Temperature



- Slight BSN Advantage With Blends
- Critical Temp. For These Conditions 150C
- Naphtha & Gasoline Had Zero BSN for All Conditions

SOR and Mixture Preparation

Effects of Intake Temperature



- All Fuels Advanced SOR Compared to Diesel
- Naphtha Operates at Lower Intake Temp.

HCCI Rules

Fuel Related

- All Fuel Must Be Evaporated Prior to the Start of Reaction
  - Liquid Fuel Drops Burn As Diffusion Flames With High NOx and PM
- Fuels Must Have Start of Reaction Temperatures and Ignition Delay Times (Ignition Characteristics) Such That Reaction Begins at TDC

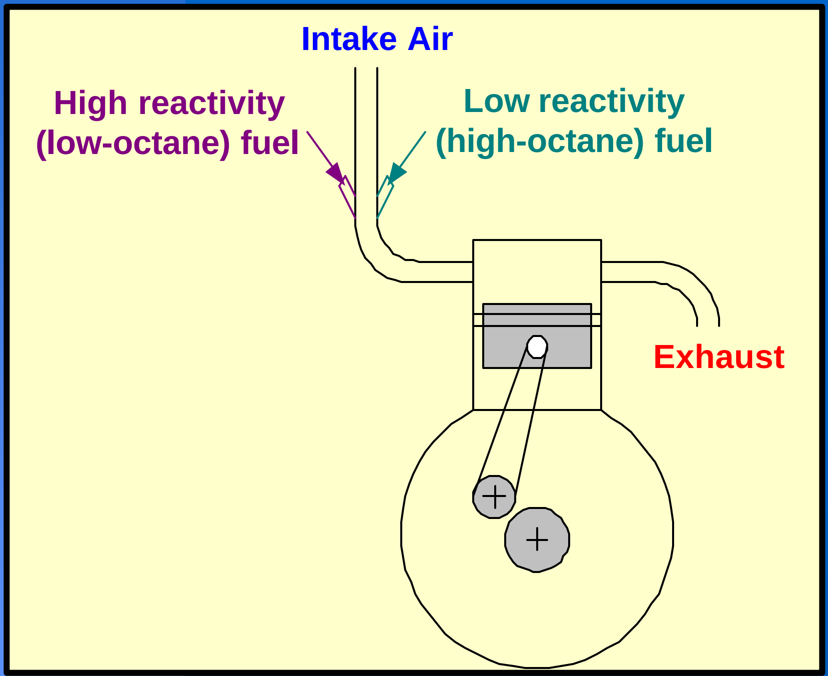
Fuel-Blending with Two Fueling Systems

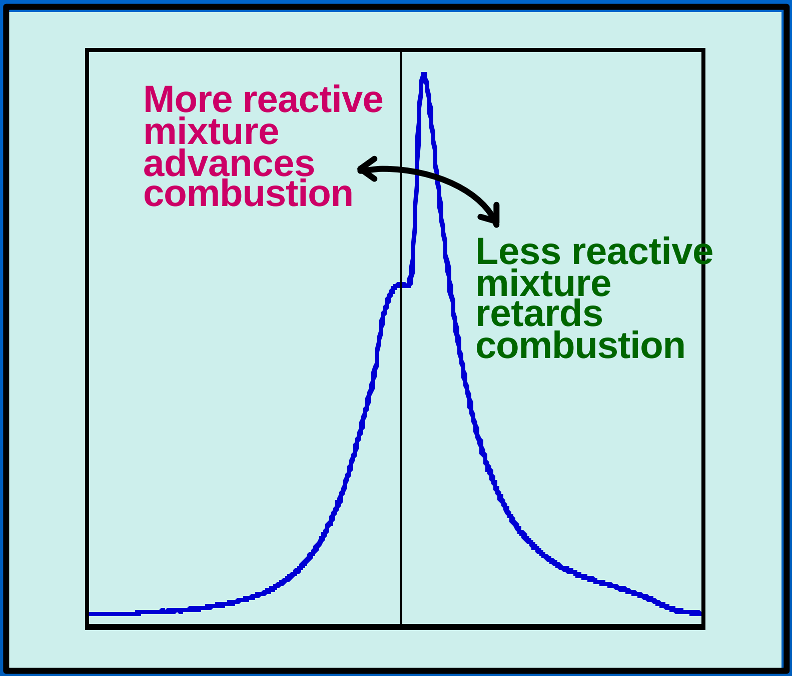
This engine's fuel system accommodates one gaseous fuel and one liquid fuel

Choice of Fuels Used

- Natural Gas used because:
  - This engine was already equipped with fuel system engine can still be operated at full load on spark-ignited natural gas fueling
  - Natural gas has low reactivity (high-octane number)
- F-T naphtha used because:
  - It is sufficiently volatile for use with port injection
  - Its auto-ignition characteristics work with this compression ratio
- Other fuels can be used with this engine concept with slight modifications

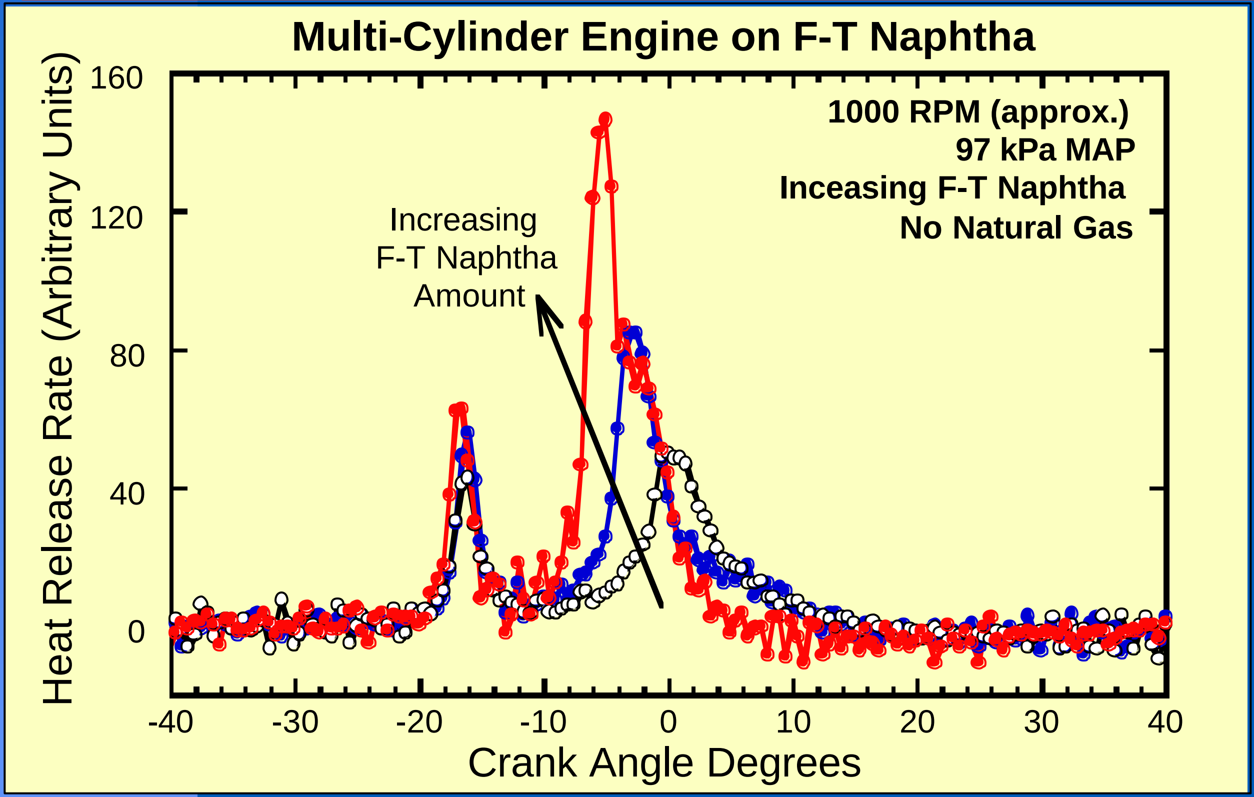
Combustion Phasing Control Through Fuel-Blending





- Premise for this approach:
  - By altering the propensity of the air-fuel mixture to auto-ignite, it is possible to control the combustion phasing

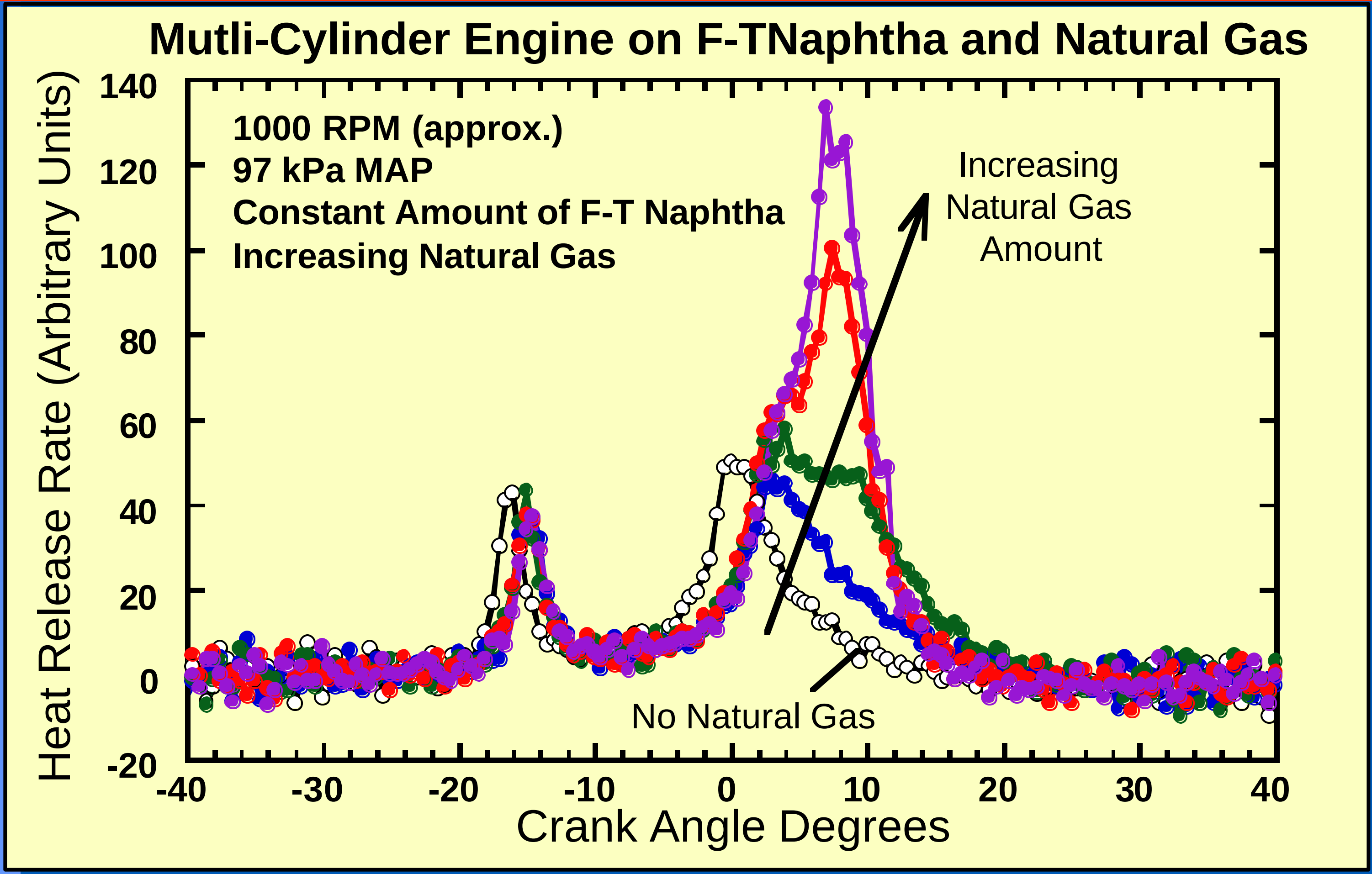
Single-Fuel HCCI



- Varying the amount of F-T naphtha changes the combustion phasing (when no gas is used)
- This is the typical problem experienced with HCCI combustion of a single fuel

Typical HCCI combustion phasing advance with increasing load and vice-versa

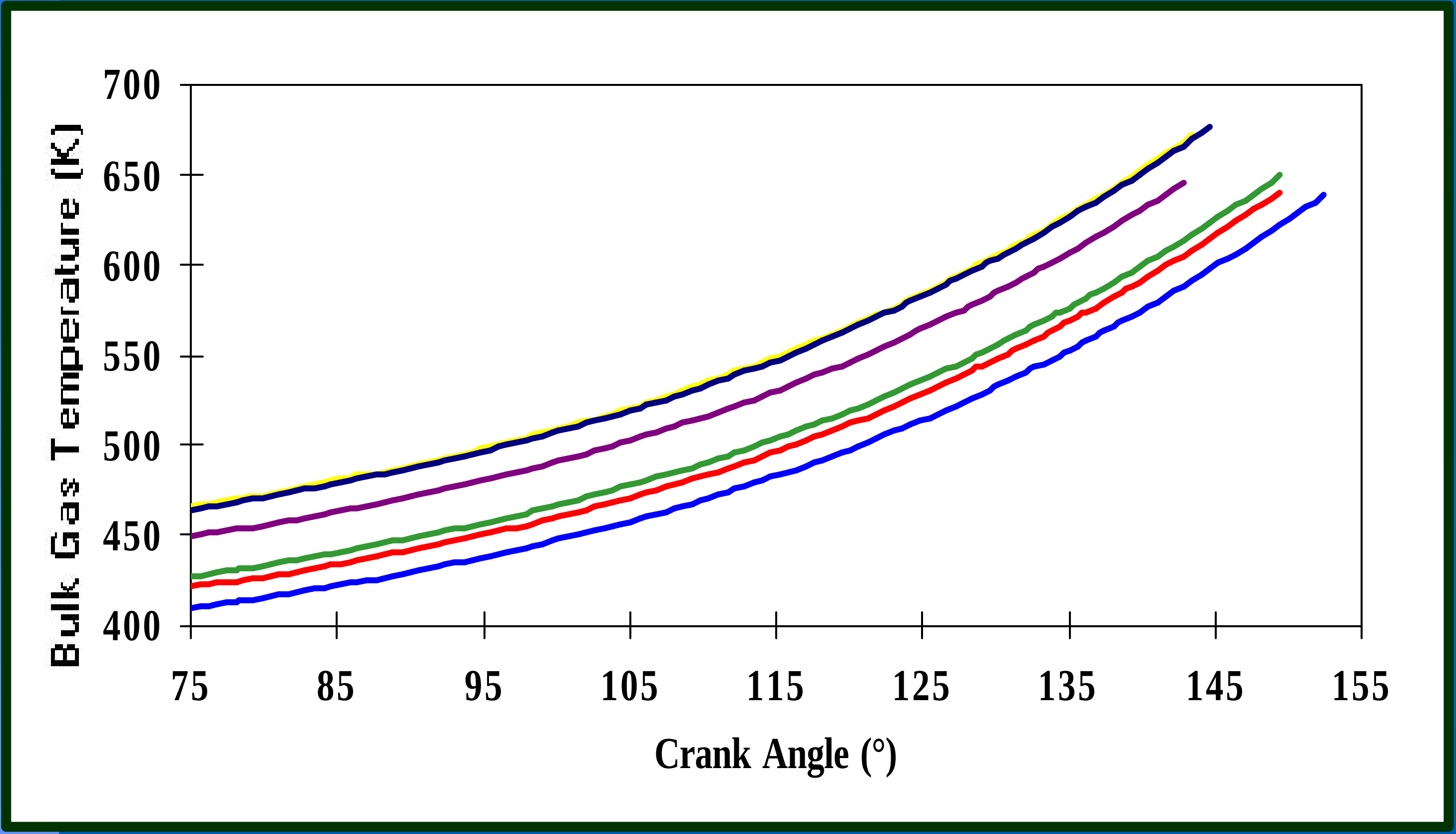
Fuel-Blending Approach



Dual-fuel HCCI combustion phasing is not affected by low-reactivity fuel (natural gas) amount

Start of Reaction

Effects of Compression Temperature History

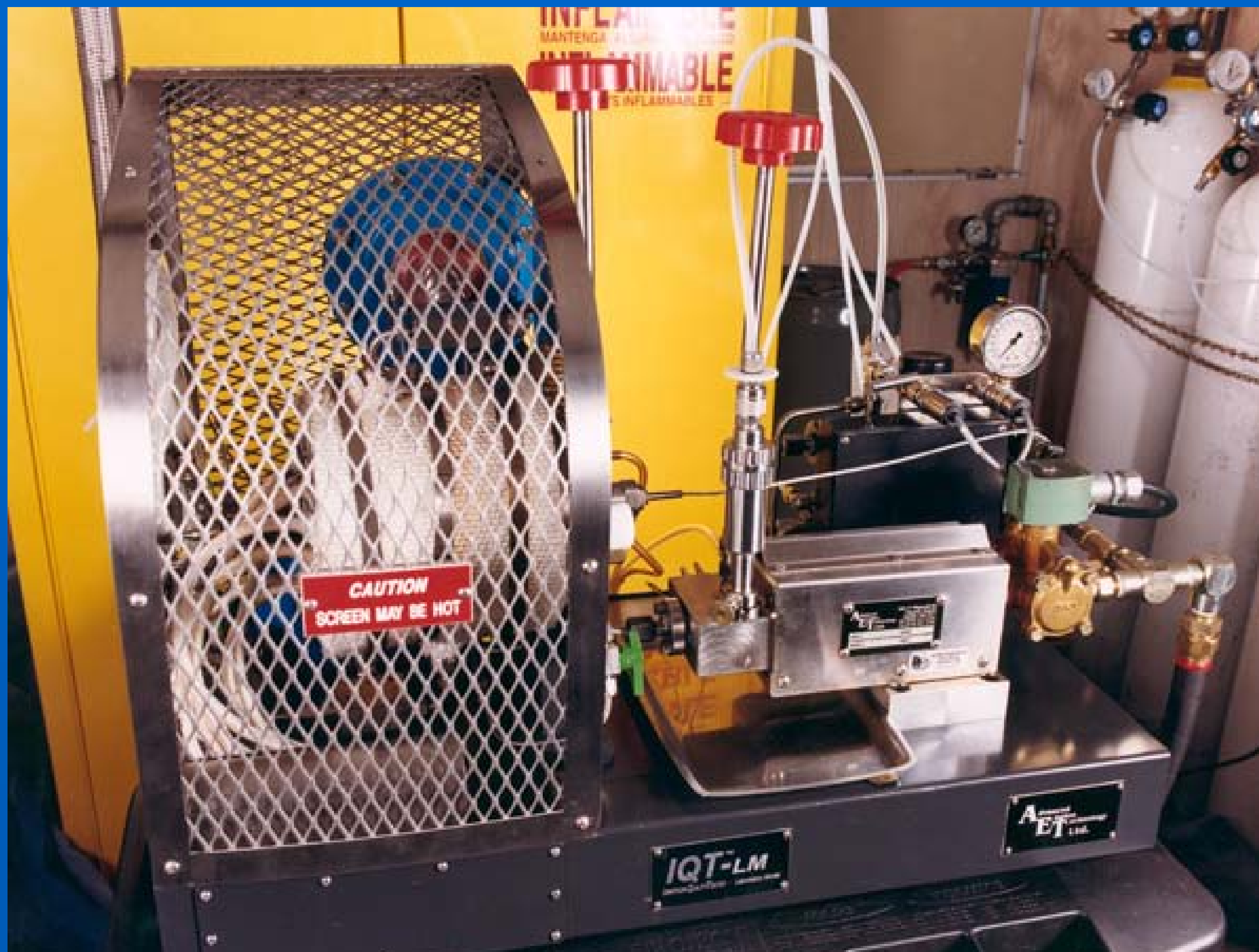


- Various Intake Temperatures and EGR
- In All Cases SOR is Very Near 650 K

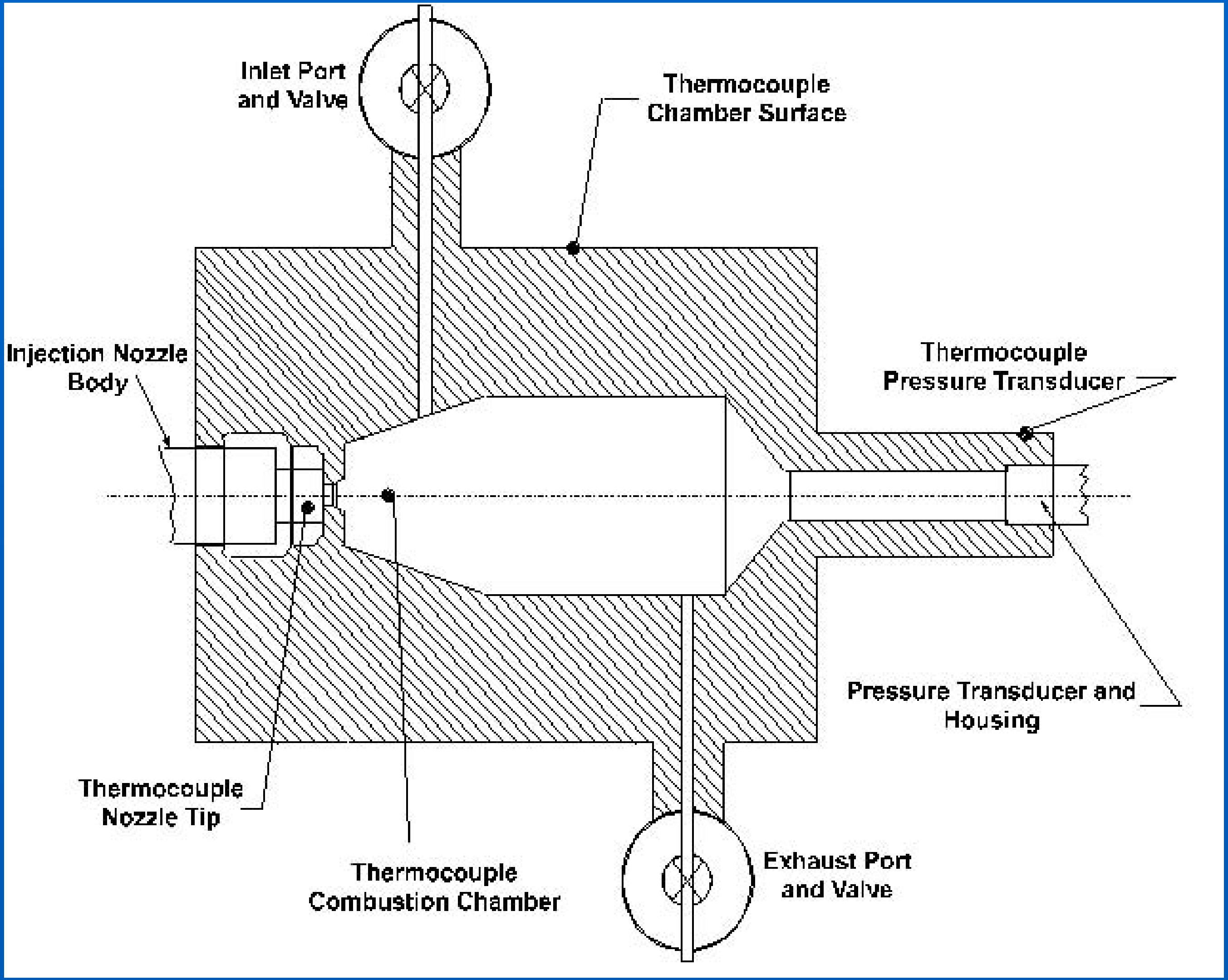
IQT Description

- The IQT is a Constant Volume Combustion Bomb Apparatus
- The System Includes:
  - Heated Pressure Vessel
  - Single Shot Fuel Injection System
  - System Controller
  - Data Acquisition System

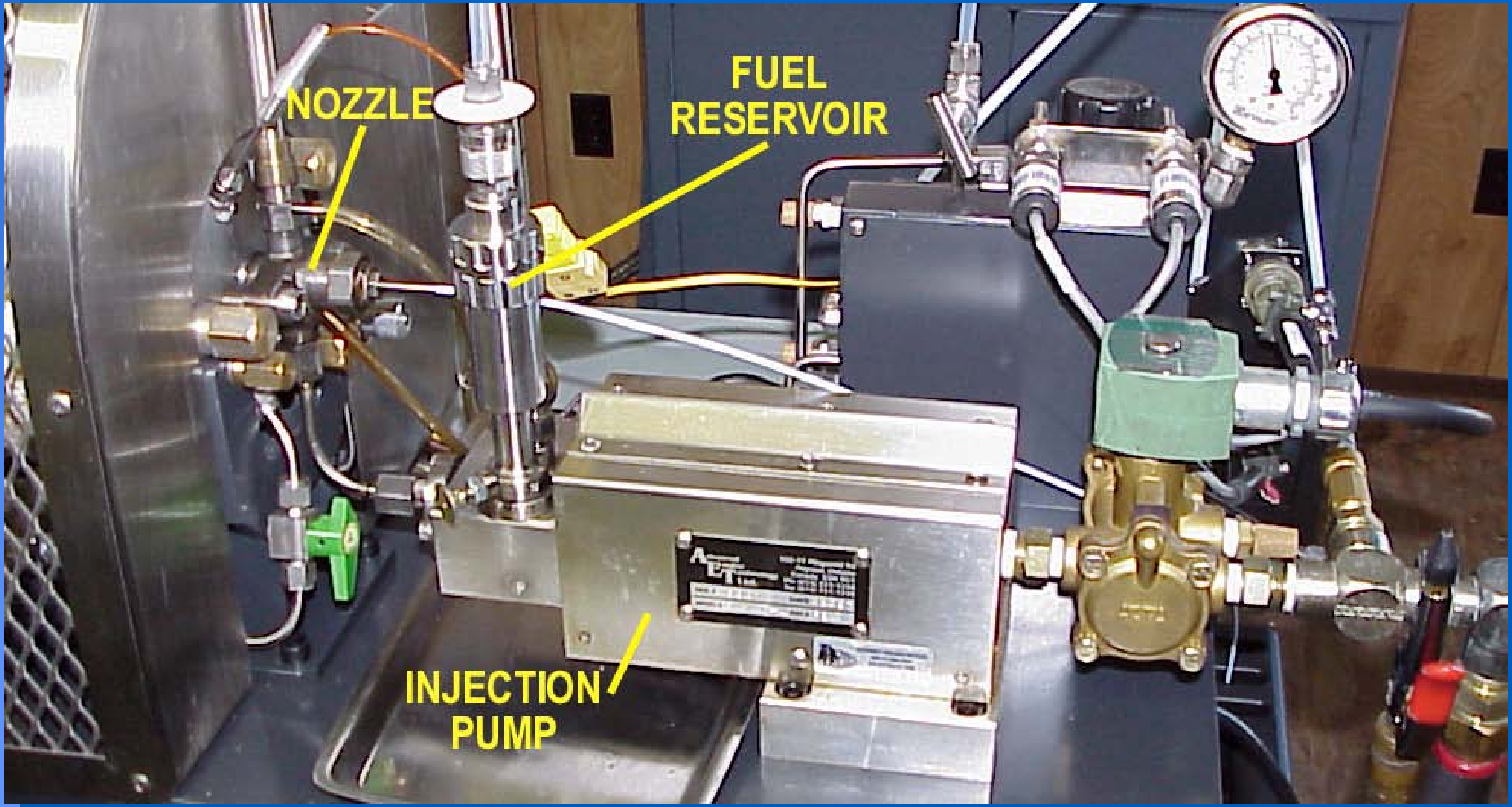
IQT Pressure Vessel and Injection System



IQT Pressure Vessel



IQT Fuel Injection System

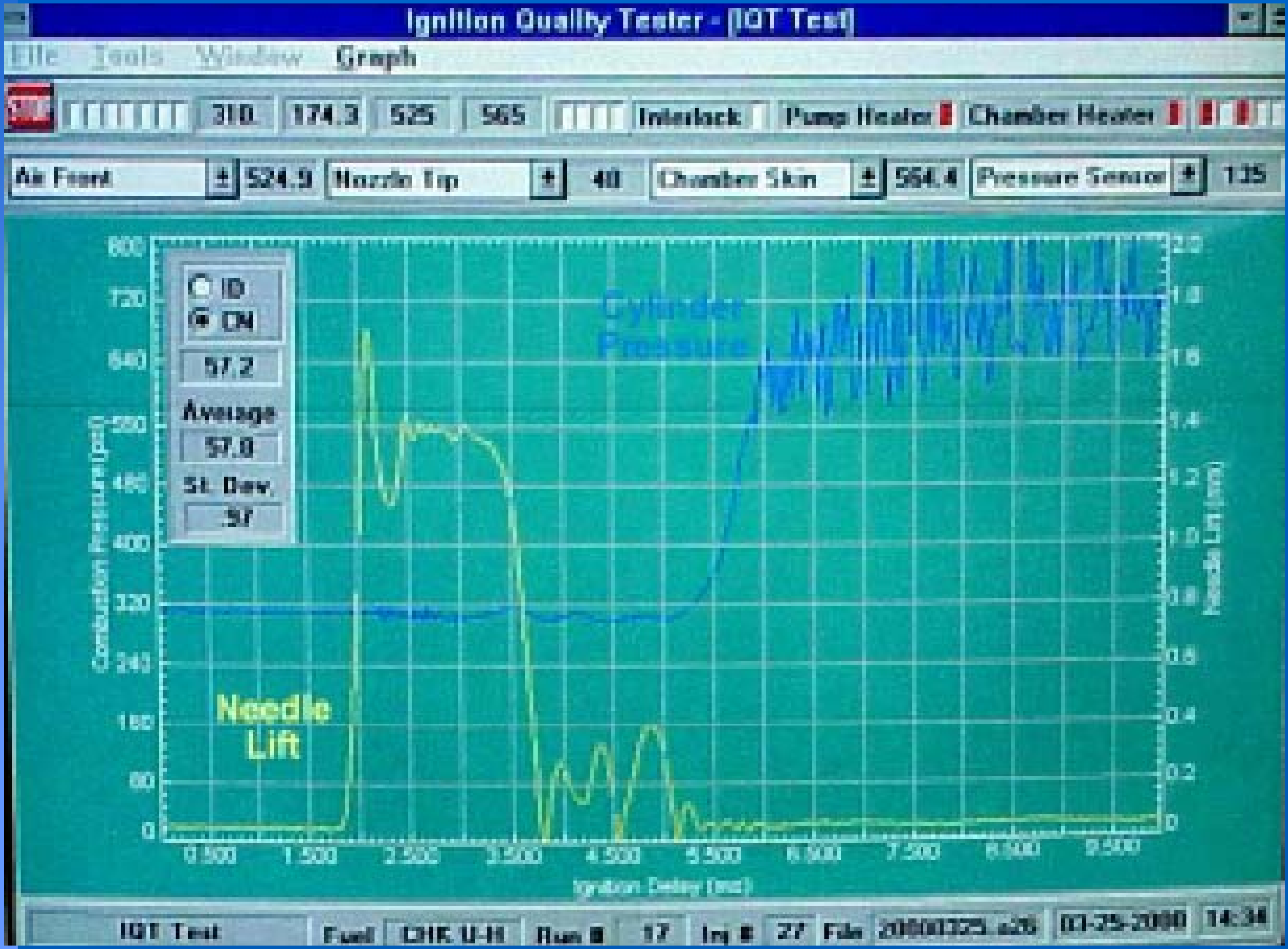


IQT Controller and Data Acquisition System

IQT Operation

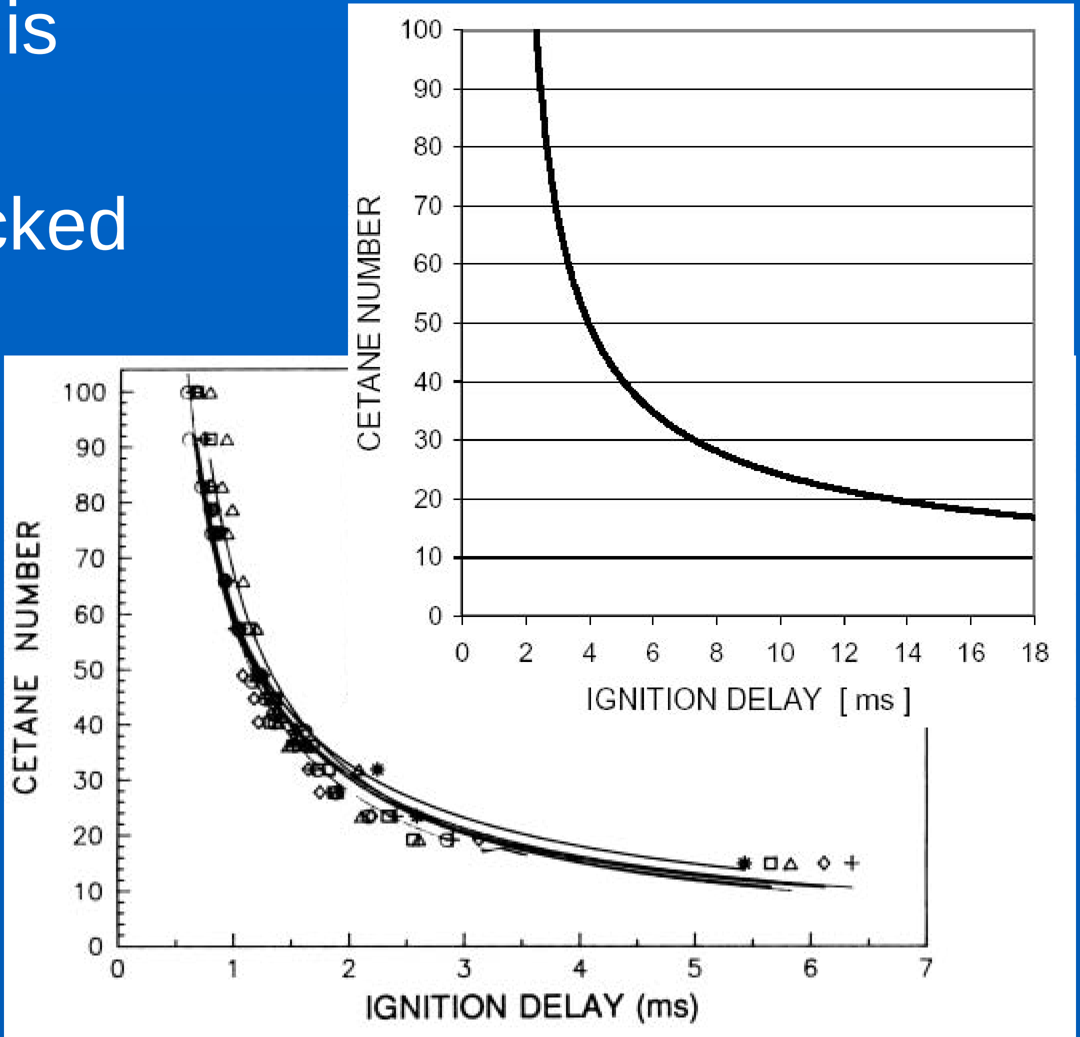
- The Pressure Vessel is Charged with Air at High Pressure and Heated to the Test Temperature
- Fuel is Injected
- Needle Lift and Vessel Pressure are Recorded and used to Determine the Ignition Delay and Other Parameters

IQT Raw Data


Ignition Quality Tester - [IQT Test]
File Tools Window Graph
310
174.3
525
565
Interlock
Pump Heater
Chamber Heater
Air Front
524.9
Nozzle Tip
40
Chamber Skin
564.4
Pressure Sensor
135
ID
CN
57.2
Average
St. Dev.
Cylinder Pressure
Needle Lift
Combustion Pressure (psi)
Needle Lift (mm)
Ignition Delay (ms)
IQT Test
Fuel
Run #
17
Inj #
27
File
03-25-2000
14:34

IQT CN Calibration

- Calibration Shift is Minor
- Calibration Checked Daily

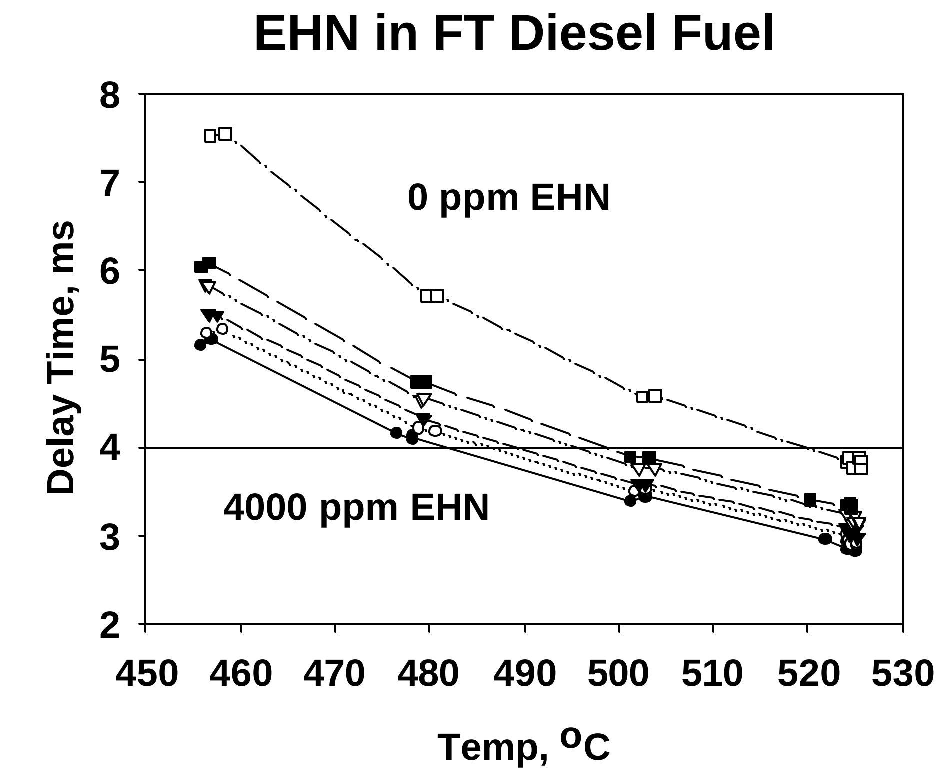


IQT Application
HCCI Fuel Rating

- Octane Number and Cetane Number were Developed for SI and CI Engine Applications
  - Developments were Evolutionary
- HCCI Results Indicate that Neither are Adequate for Reflecting the SOR in an HCCI Engine
  - Data Indicates that some Measure of Autoignition Temperature (AIT) is Needed
  - Elevated Pressure AIT Defined in IQT

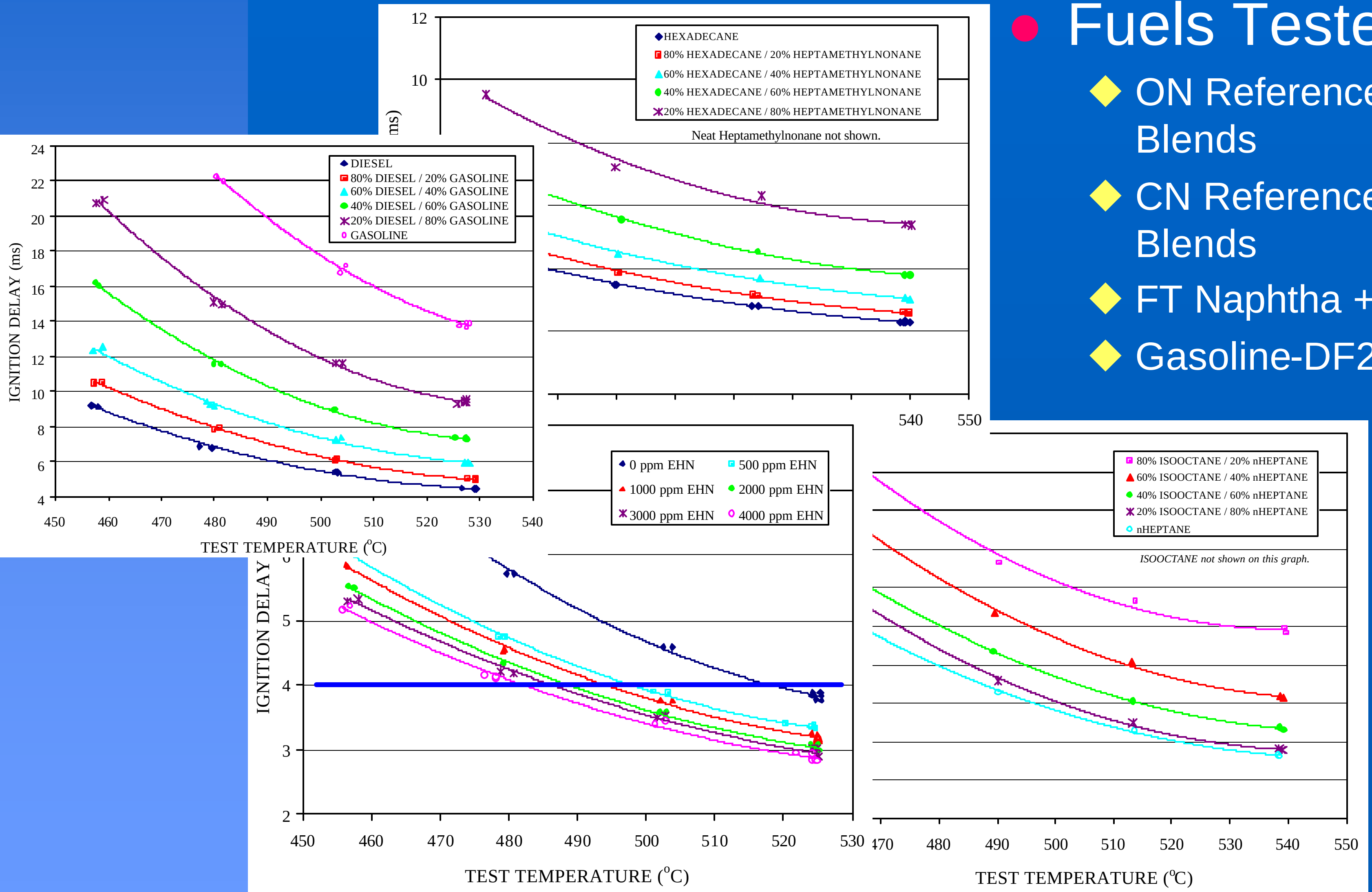
EPAIT Measurement in IQT

- IQT Used to Measure the Elevate Pressure AIT (EPAIT)
- Tests Done at Different Temperatures
- A Fixed Ignition Delay Time is Selected and Used to Define the Ignition Temperature

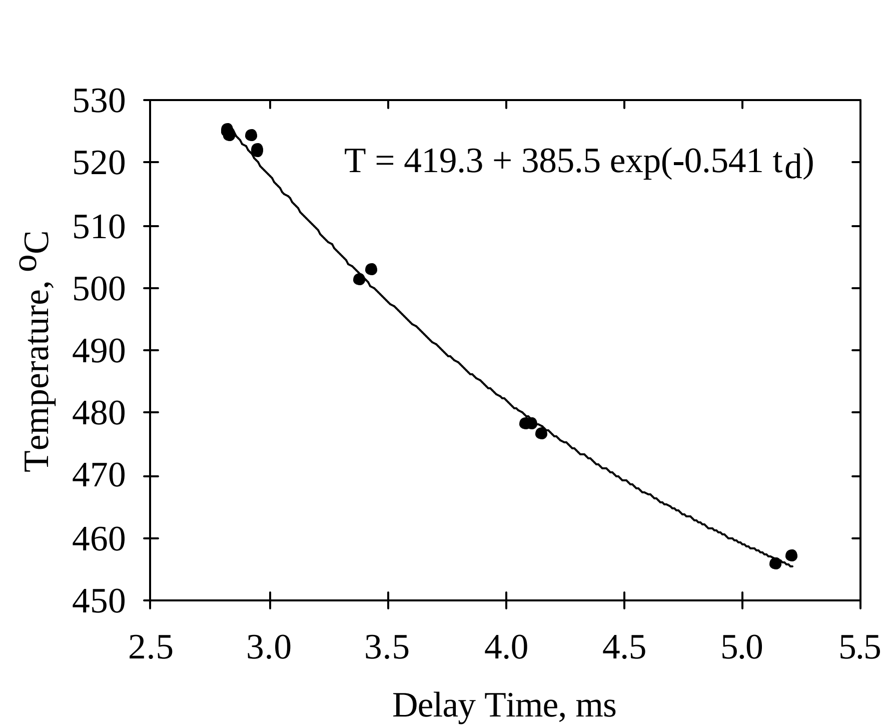


Fuels Tested

- Fuels Tested:
  - ON Reference Fuel Blends
  - CN Reference Fuel Blends
  - FT Naphtha + EHN
  - Gasoline-DF2 Blends



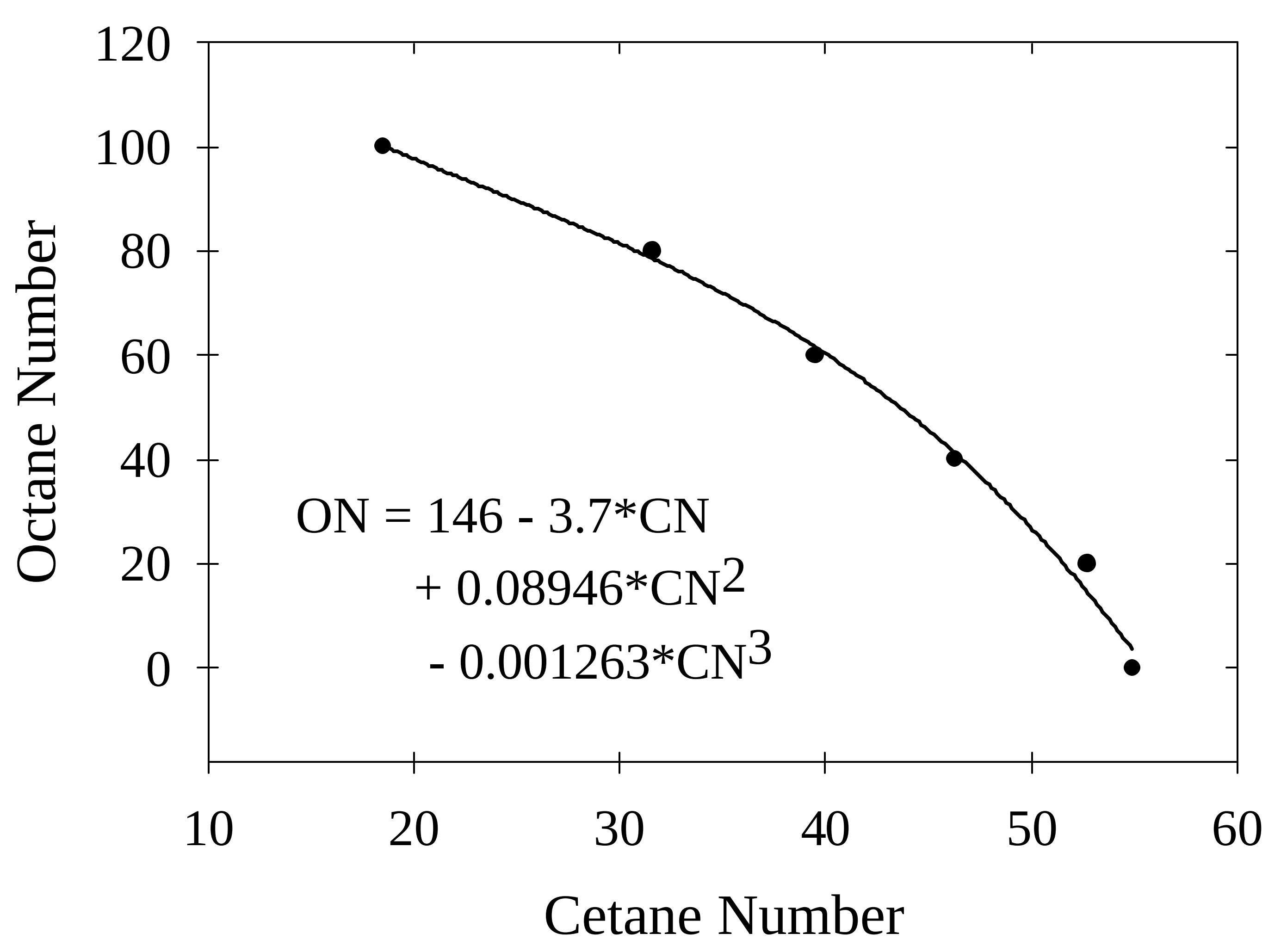
Data Conversion



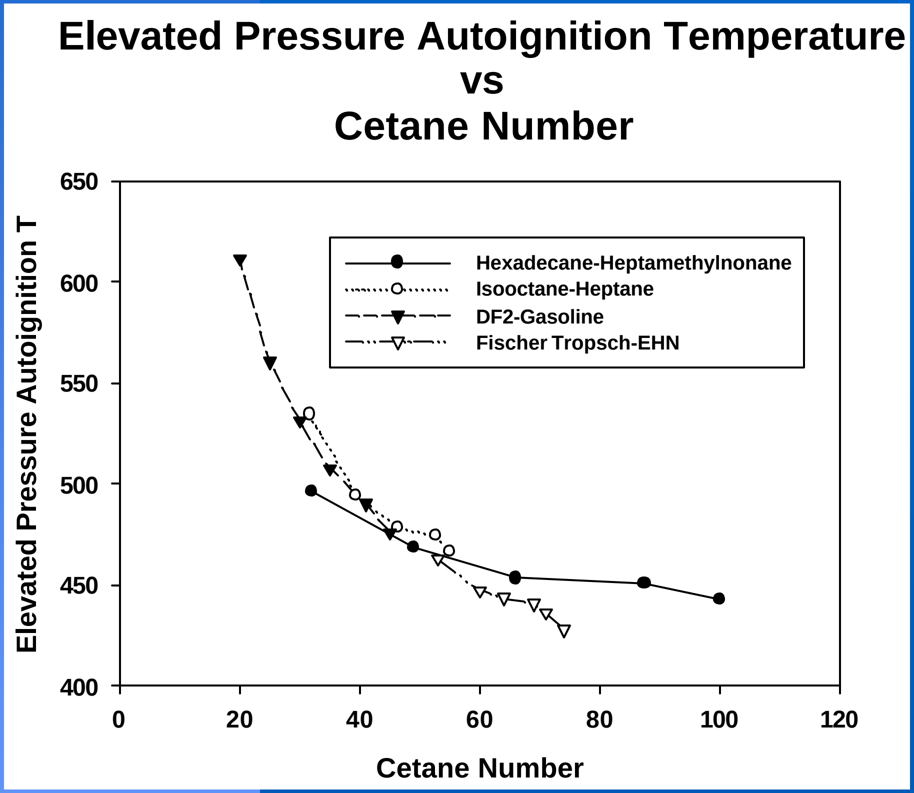
FT Additized with EHN

- Need Temperature at Ignition for Different Ignition Delay Times
  - Simple Inversion and Regression
- Inverted Data Used to Interpolate and Extrapolate to Define a Common Delay time

Octane Number vs Cetane Number



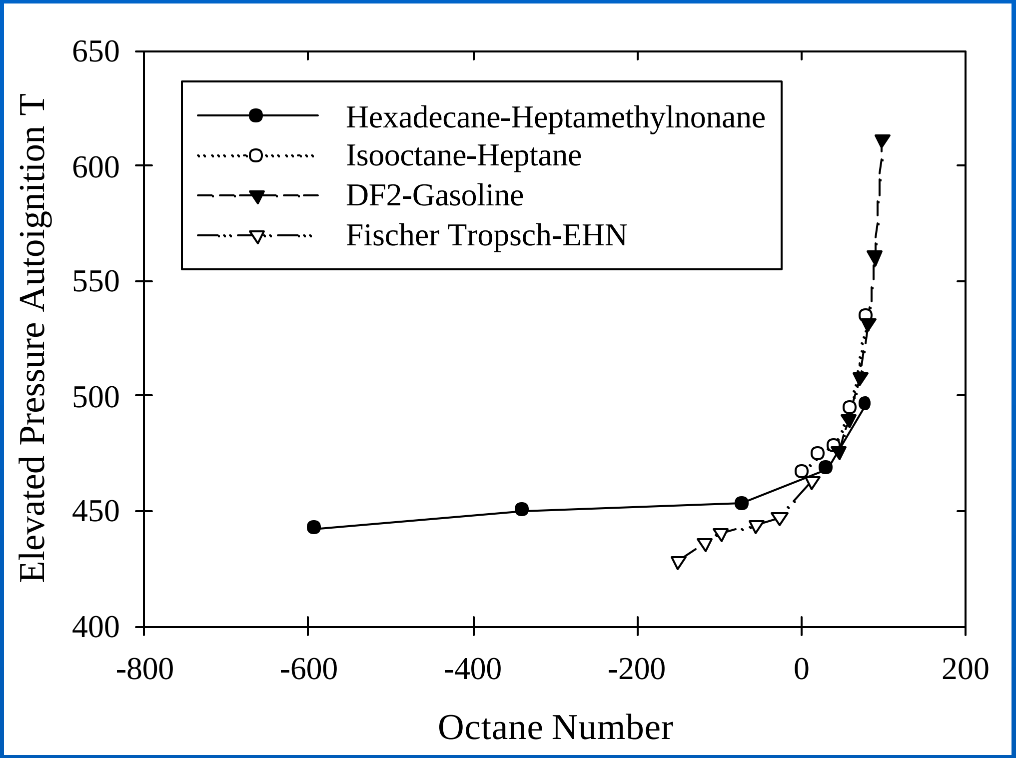
EPAIT vs CN



- CN Has Some Relationship to EPAIT
- CN Does Not Universally Relate to EPAIT
- ON Relationship is Worse Than the CN Relationship

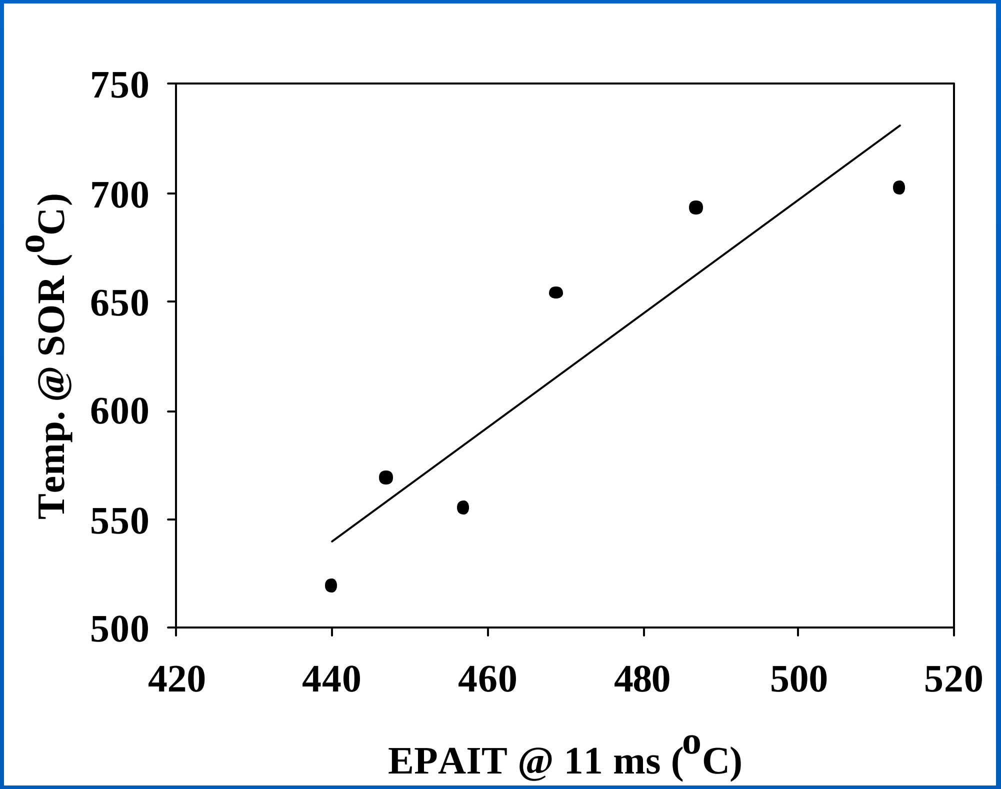
EPAIT vs ON

- The ON Relationship is not as Good as the CN Relationship
  - Negative ON is Possibly Meaningless
  - More Deviation with the Additized Fuel
  - Shape Inflection Makes Definition of EPAIT Difficult



Correlation
IQT-EPAIT Data and Engine Data

- SOR in the Engine is Based on the Pre-Reaction
- SOR Predicted using an Arrhenius Type Rate Expression
  - Verified by Engine HRR Measurements
- Correlation is Fair



Future of HCCI Method

- Need to Test More Fuels in both the IQT and the HCCI VCR Engine
  - Follow the IQT Test Method Described
  - Engine Tests in SwRI VCR Test Engine
  - Test Fuels:
    - More GTL Products
    - Petroleum Naphtha Fractions
    - Additized ON Reference Fuel Blends
    - Additized Gasolines
    - Alternative Fuels
  - Relate to SOR In the Engine