



Fuel Formulation Effects on Diesel Fuel Injection, Combustion, Emissions and Emission Control

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Pennsylvania Department of Environmental Protection
Cummins Engine Company**



Background

- In the case of biodiesel fueling (e.g., “B20”, a blend of 20vol.% methyl soyate in diesel fuel), there is a well documented increase of 2-4% in NOx emissions [Graboski, M.S. and R.L. McCormick, “Combustion of fat and vegetable oil derived fuels in diesel engines.” *Progress in Energy and Combustion Science*, 1998, 24(2): p. 125-164.]
- As shown by Van Gerpen and co-workers, the NOx increase with biodiesel fueling is attributable to an inadvertent advance of fuel injection timing due to the higher bulk modulus of compressibility, or speed of sound, in the fuel blend, which leads to a more rapid transfer of the pressure wave from the fuel pump to the injector needle and an earlier needle lift [Monyem, A., J.H. Van Gerpen, and M. Canakci, “The effect of timing and oxidation on emissions from biodiesel- fueled engines”. *Transactions of the ASAE*, 2001, 44(1): p. 35-42.]

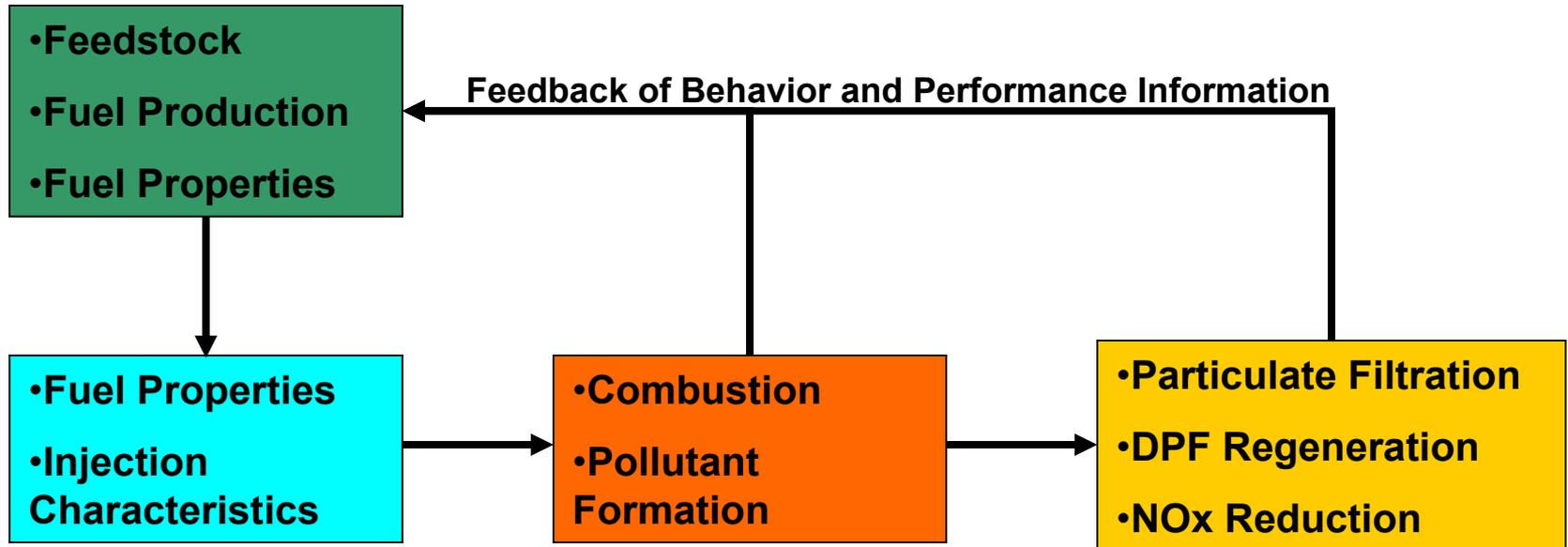


Objectives

- **Determine the Interaction between Formulation of Conventional, Renewable and Synthetic Diesel Fuels and their Injection Characteristics**
- **Measure Physical Properties of Fuels that Can Provide Support for Understanding Injection, Combustion and Emissions Performance of Diesel Fuels**
- **Use Injection Studies, Physical Properties, Emissions Measurements and In-Cylinder Visualization to Determine Optimal Fuel Formulations**
- **Link Feedstock and Fuel Production Process to Physical Properties and, Thereby, Injection, Combustion and Emissions Performance**



Research Strategy



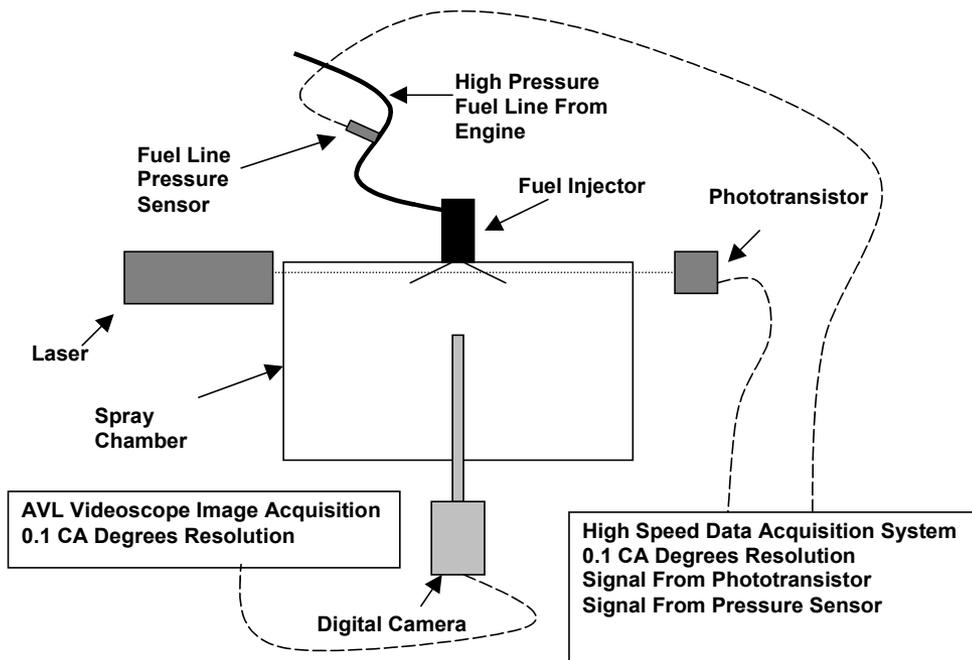
- Spray Visualization Chamber
- Bulk Modulus of Compressibility

- AVL 513D Engine Videoscope
- Particulate and Gaseous Emissions

- Various Aftertreatment Strategies



Experimental



Spray Visualization System

- SAE 2003-01-1039
- ACS Nat'l Mtg. New Orleans, 2003
Fuel Chemistry Div.

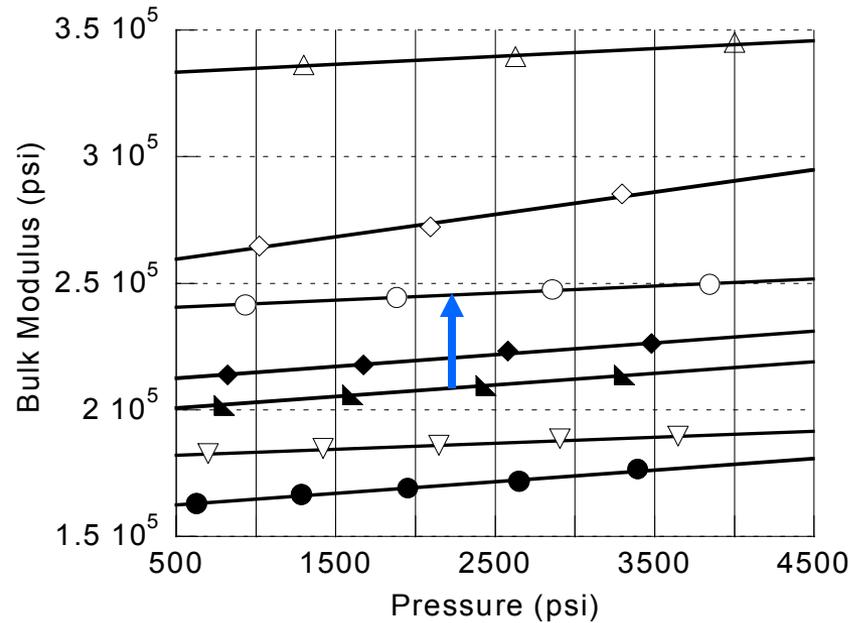
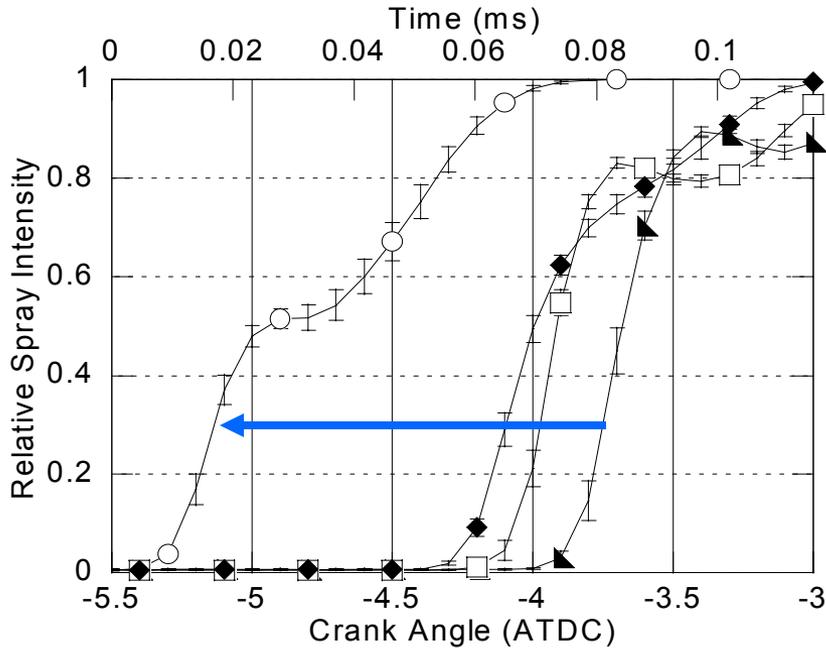


High Pressure Housing for Pycnometer



Fuel Injection and Bulk Modulus

Biodiesel and Soybean Oil



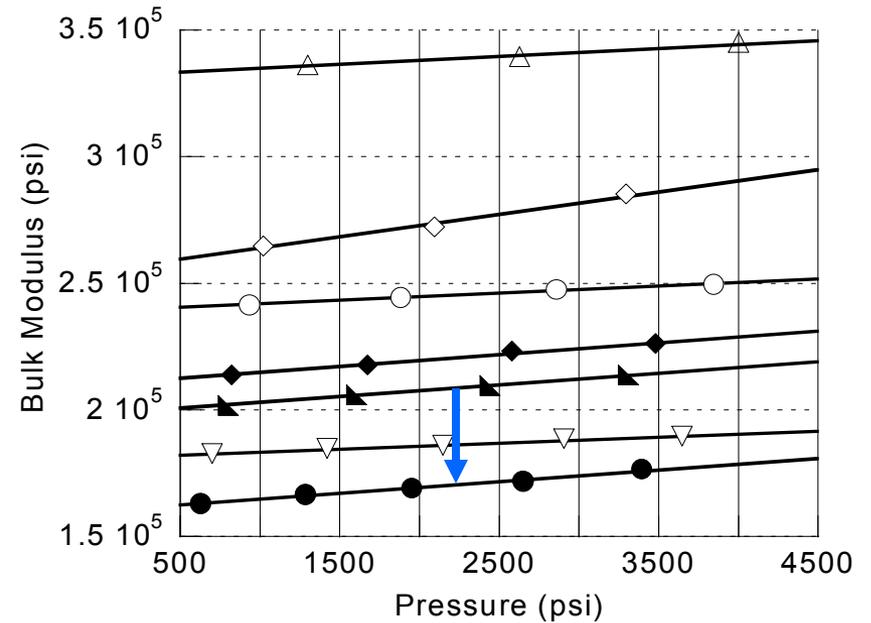
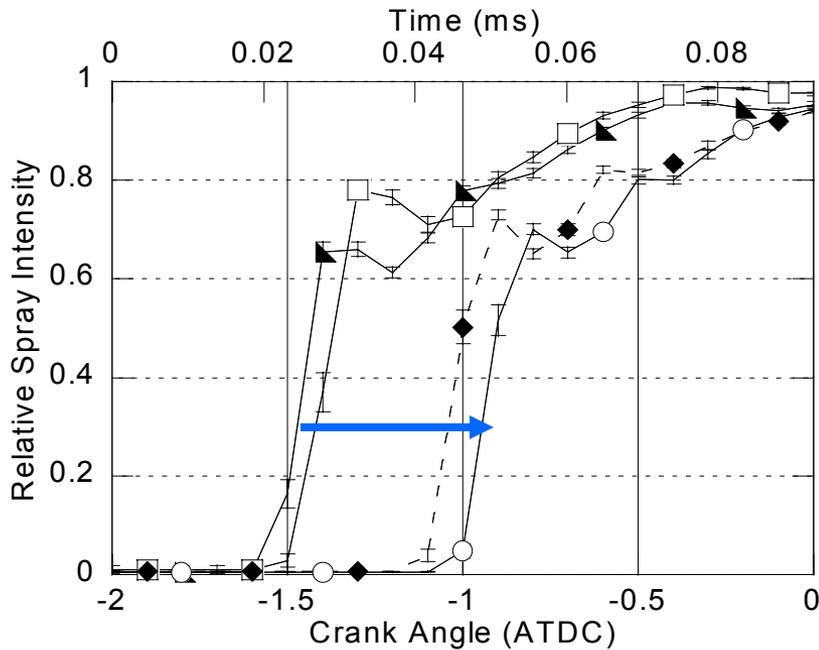
Fuel injection timing for biodiesel blends in conventional diesel fuel (▲) Baseline diesel fuel, (□) B20, (○) B100, (◆) 16vol.% Soy oil in diesel fuel.

Bulk modulus of (△) Water, conventional and ultra low sulfur fuels, (◇) Soy oil, (○) Biodiesel, B100, (◆) 20% Soy oil blend in conventional diesel fuel, (▲) diesel fuel and (▽) paraffinic distillate and (●) Norpar-13.



Fuel Injection and Bulk Modulus

Paraffinic Fuels



Fuel injection timing for paraffinic fuels versus conventional diesel fuel., (▲) 15 ppm sulfur diesel fuel (BP15), (□) 325 ppm sulfur diesel fuel, (○) Norpar-13, (◆) paraffinic distillate.

Bulk modulus of (△) Water, conventional and ultra low sulfur fuels, (◇) Soy oil, (○) Biodiesel, B100, (◆) 20% Soy oil blend in conventional diesel fuel, (▲) diesel fuel and (▽) paraffinic distillate and (●) Norpar-13.



AVL 513D Videoscope and Accessories

Console



Endoscopes



0, 30 and 60 degrees

Illumination Tips



0, 30 and 70 degrees

Glass Windows



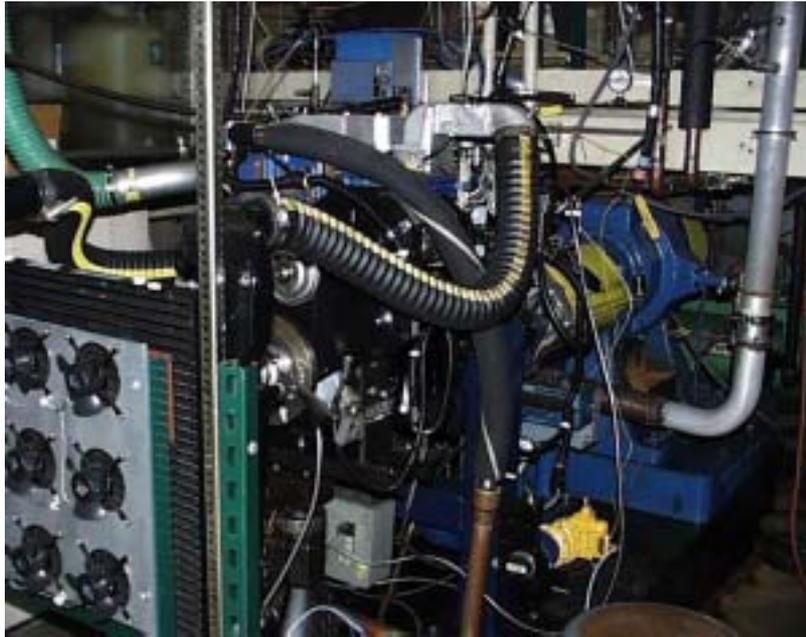
0, 30 and 70 degrees

Main Processing Unit

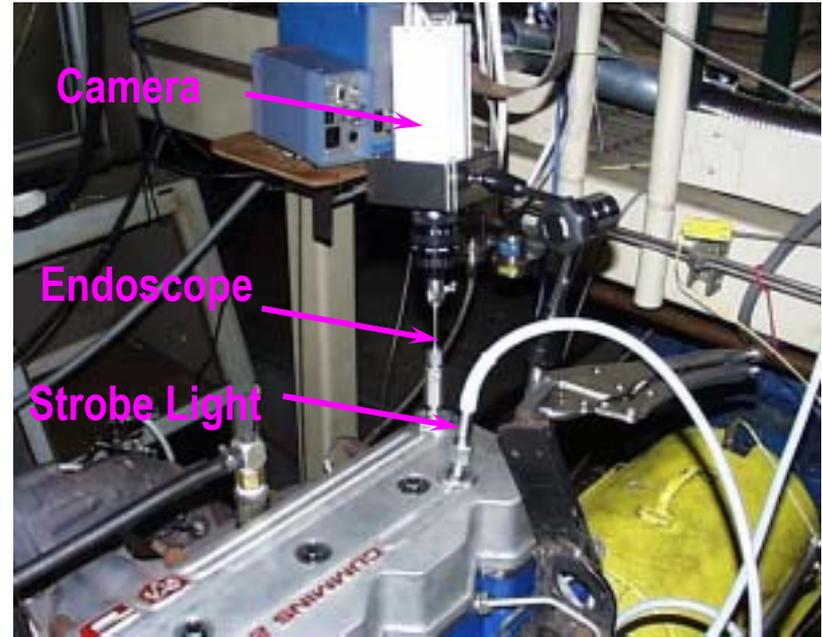




Cummins ISB 5.9L 6-Cylinder Test Engine



Test Engine

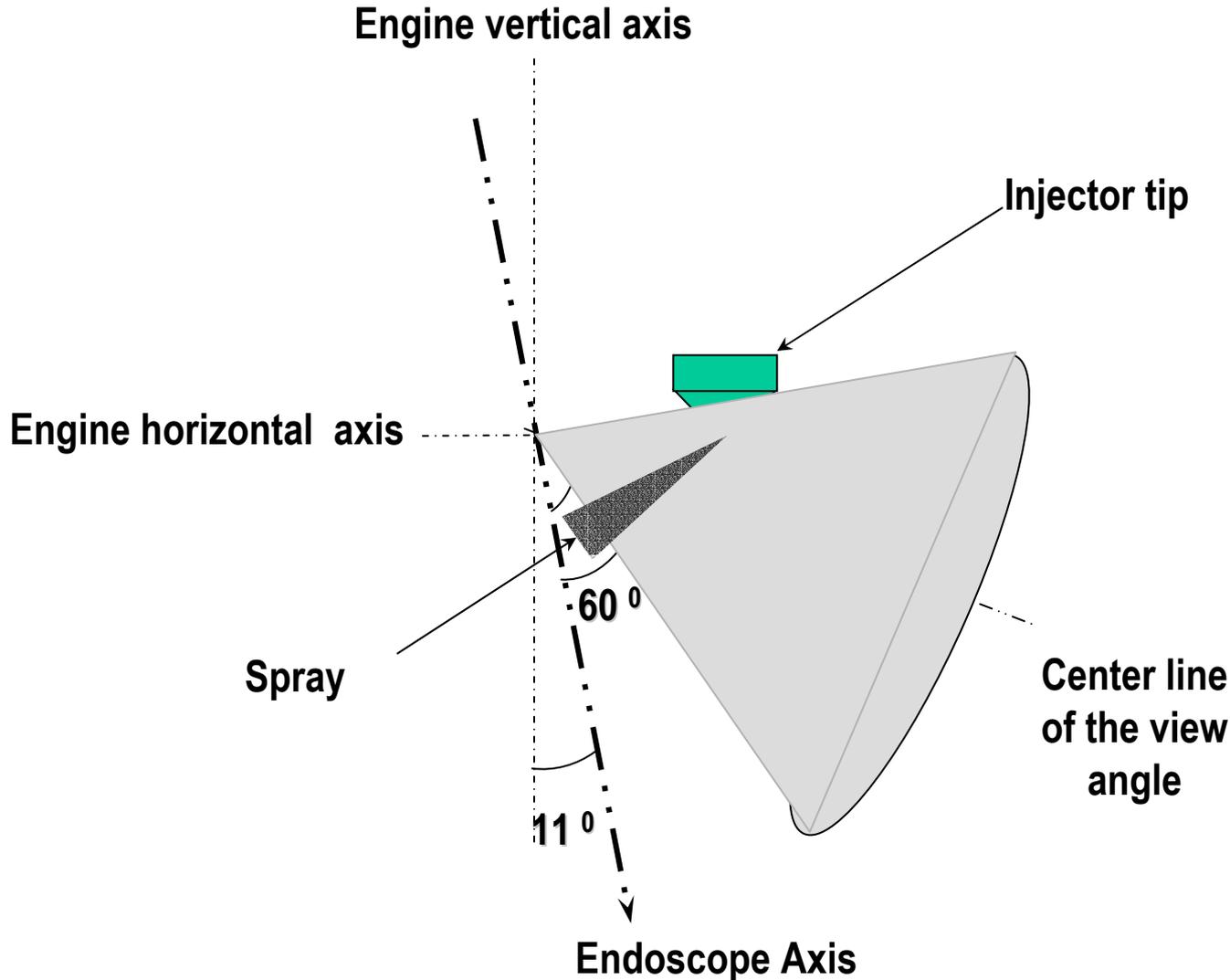


Videoscope Instrumentation





Viewing Window of Endoscope



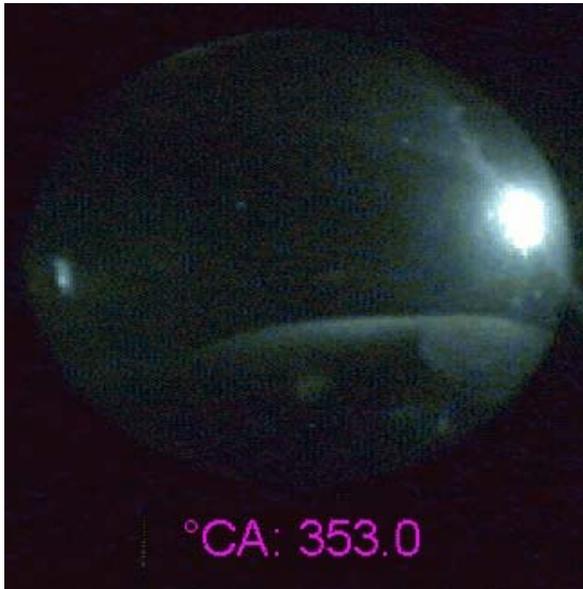
- Endoscopes 0, 30 and 60 deg
- Strobe lights 0, 30 and 70 deg
- Viewing window of endoscope is 80 deg



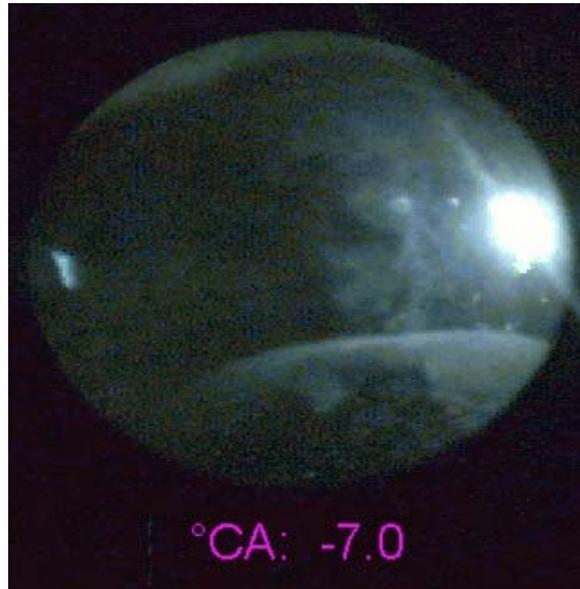
Spray and Combustion

10% Load and 1800 RPM in Cummins 5.9L ISB

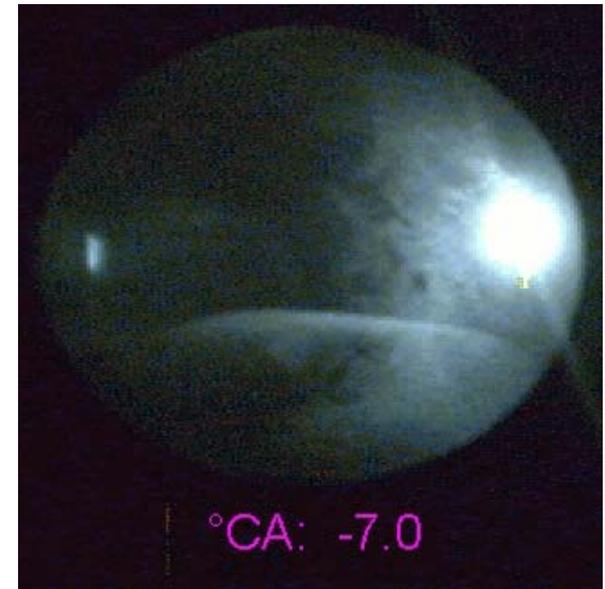
BP 15



BP 15 + 40 % Biodiesel



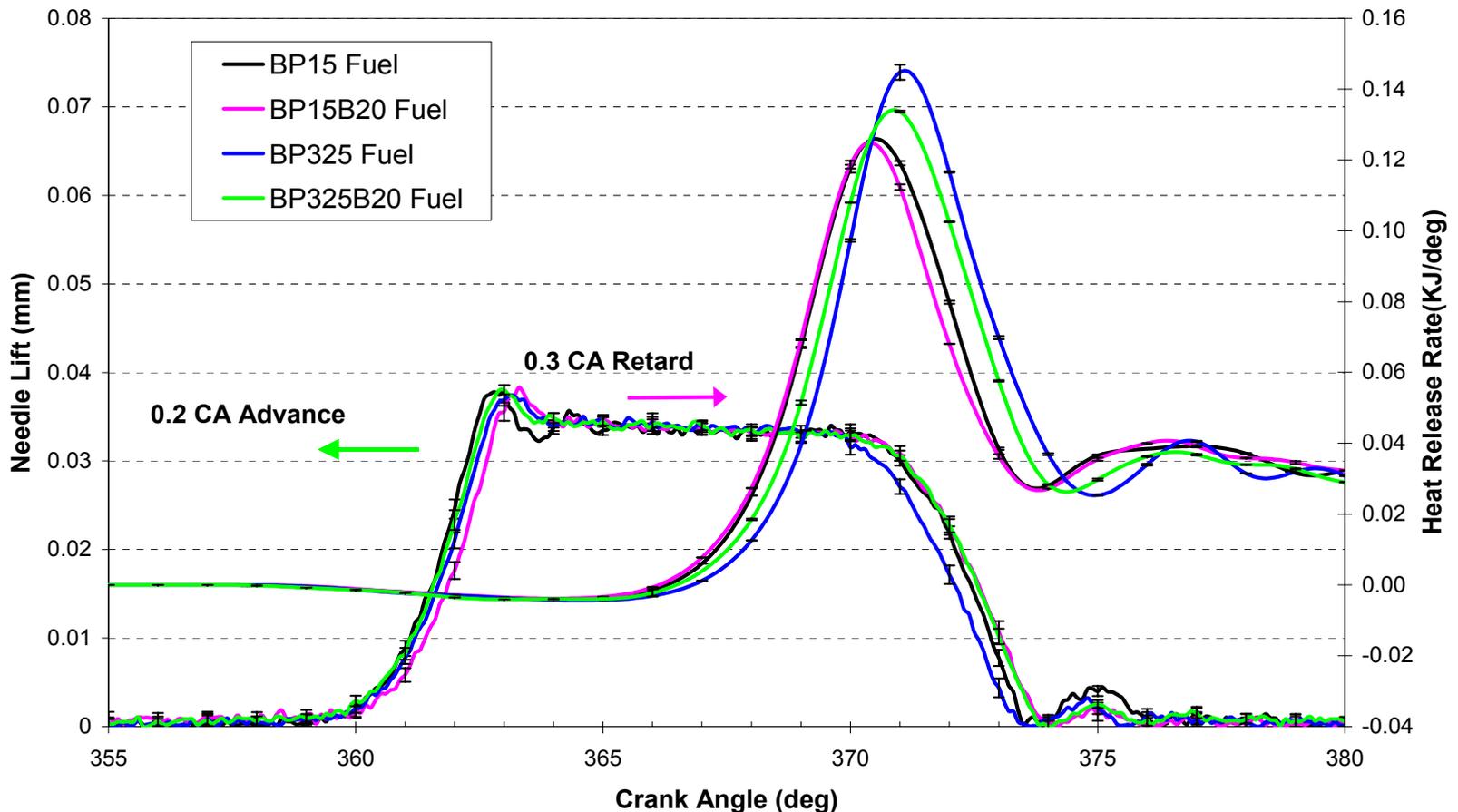
B100





Injection and Rate of Heat Release Analyses

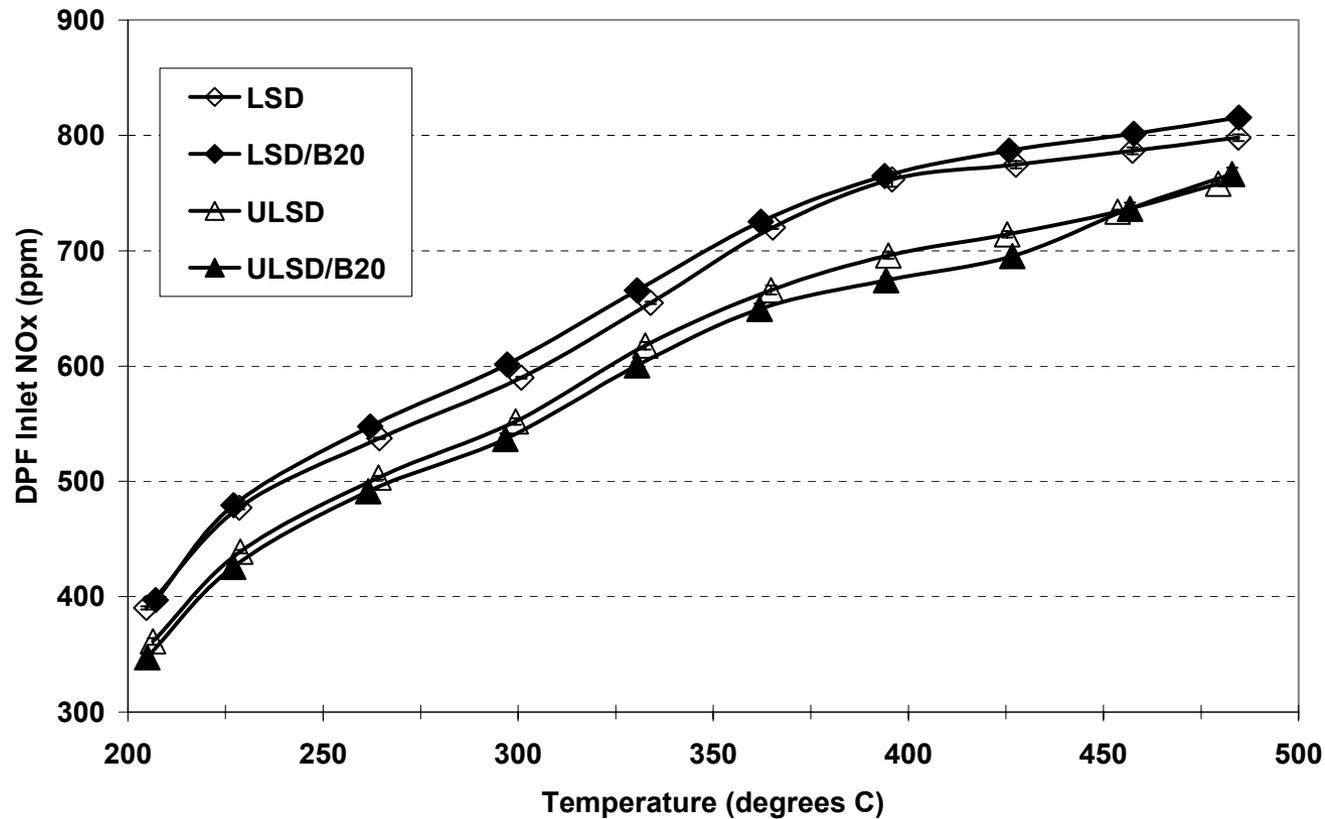
Diesel and B20 Test Fuels in the Cummins 5.9L ISB





Fuel Composition Effects on Emissions

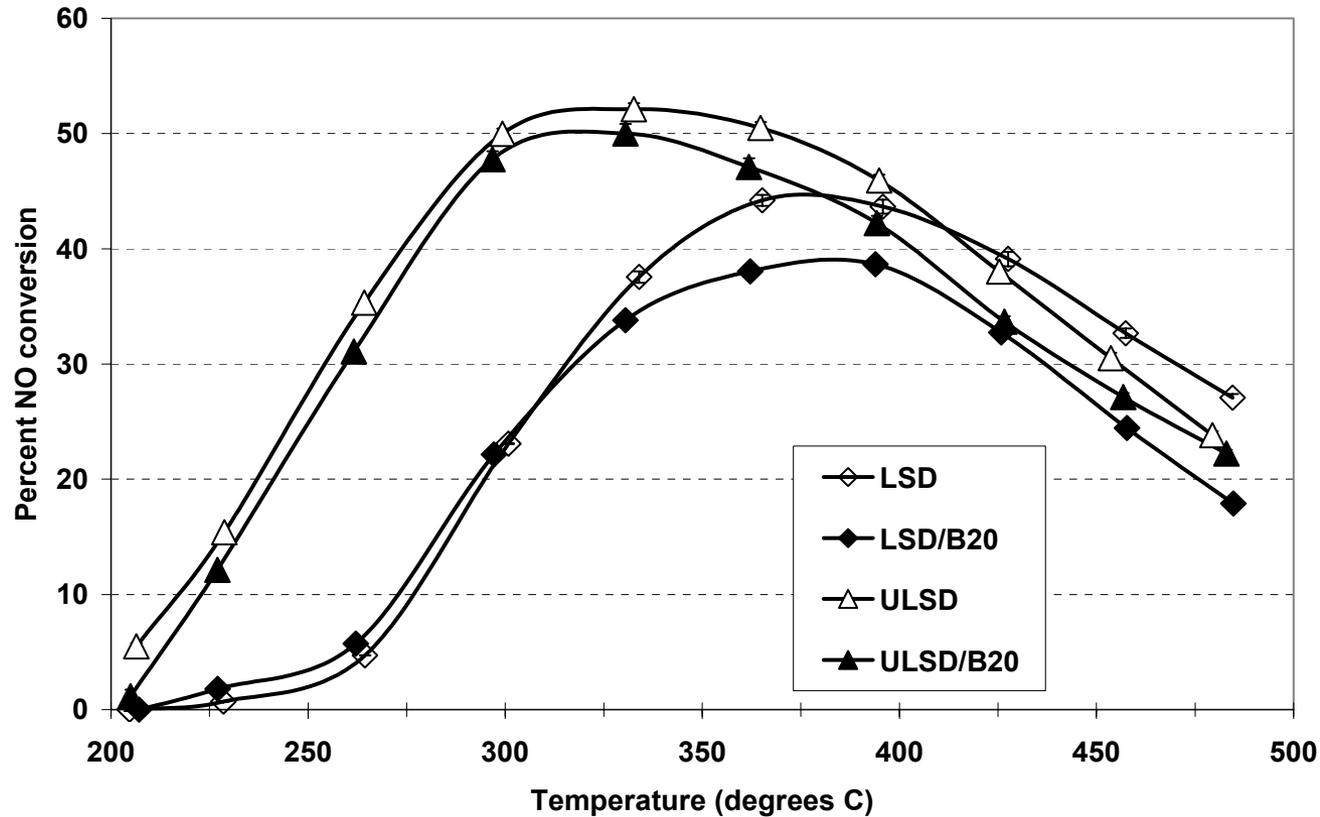
BP-325 and BP-15 Test Fuels in the Cummins 5.9L ISB





Fuel Composition Effects on Emissions

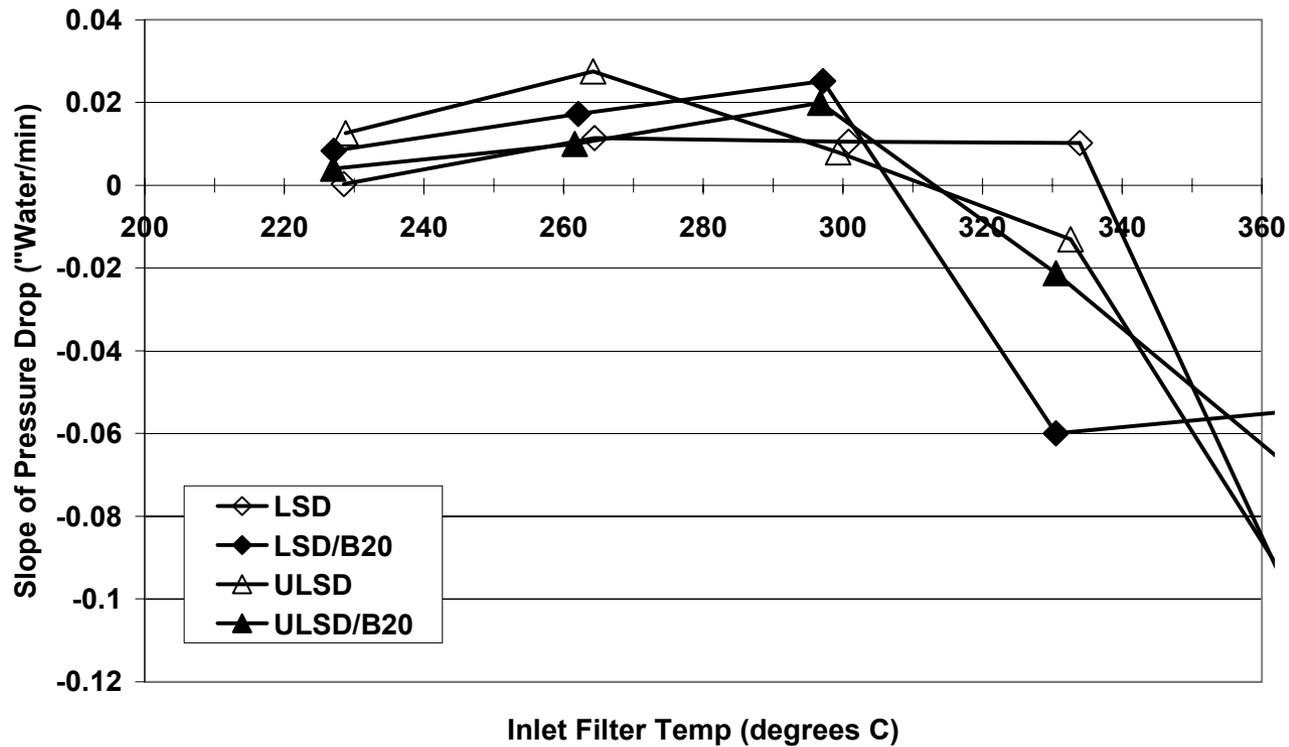
BP-325 and BP-15 Test Fuels in the Cummins 5.9L ISB





Fuel Composition Effects on Emissions

BP-325 and BP-15 Test Fuels in the Cummins 5.9L ISB





Injection Timing Study with COP FT Diesel

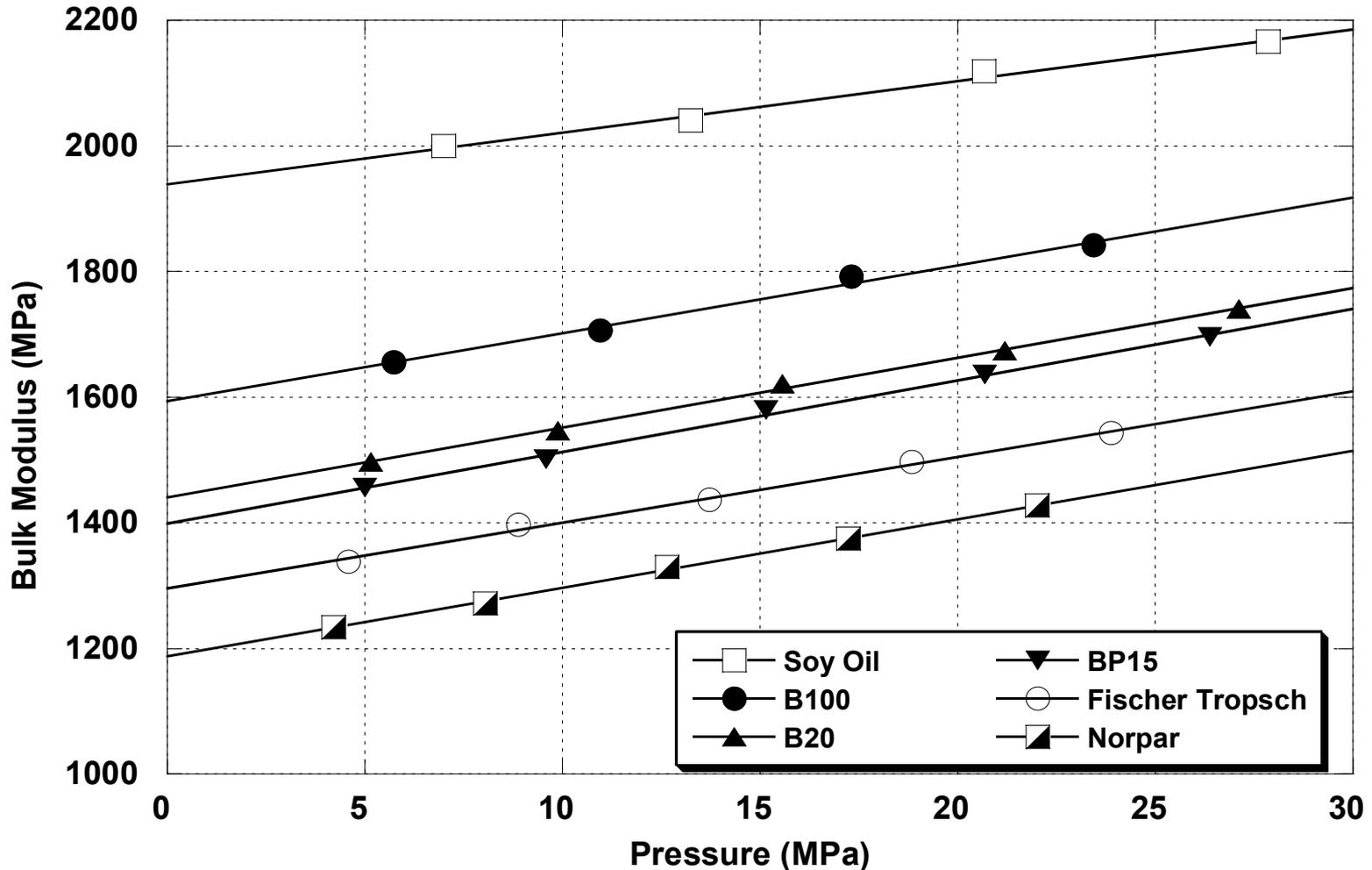
Properties of Test Fuels

Fuel	Cetane Number	Viscosity @40 C, cSt	Flash Point, F
BP-15 ULSD	49.7	2.5	147
BP-325 LSD	46.8	2.5	146
BP-15 /B20	52.5	2.7	151
BP-325 /B20	49.2	2.7	154
COP FT Diesel	83	2.5	166



Injection Timing Study with COP FT Diesel

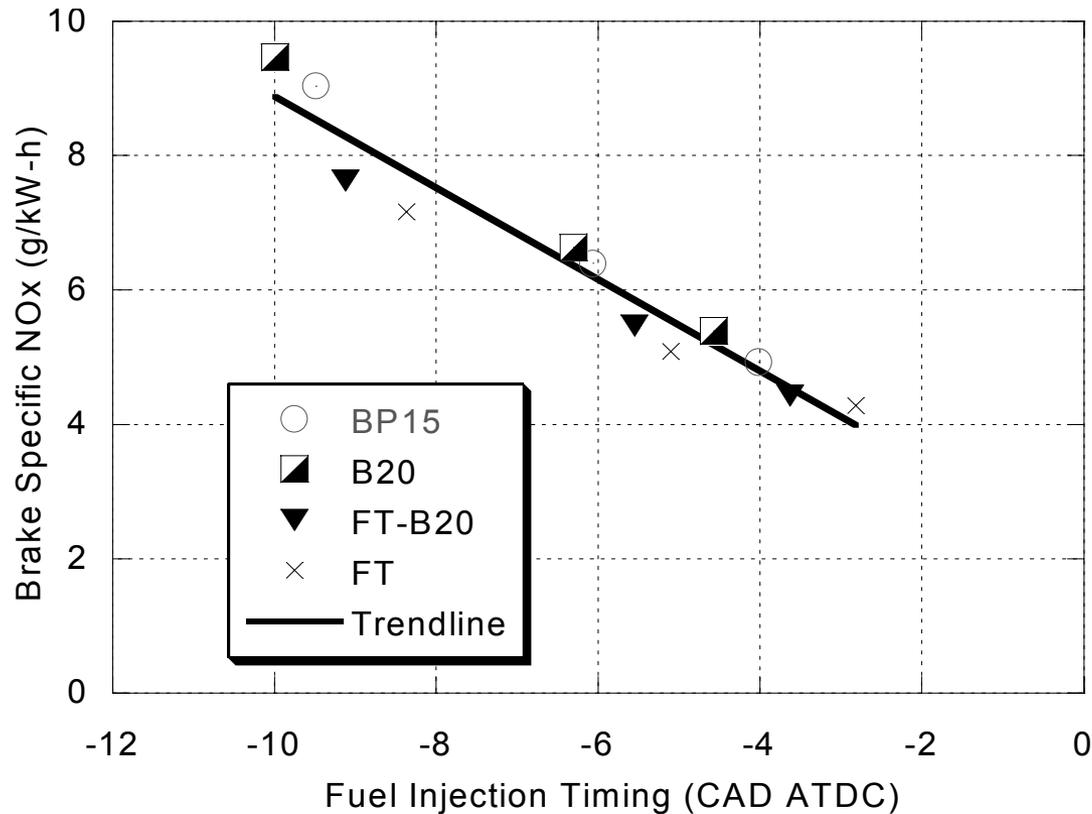
Bulk Modulus of Test Fuels





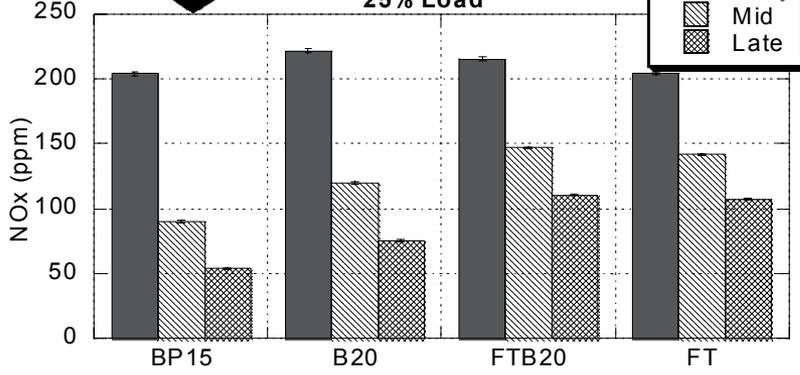
Injection Timing Study with COP FT Diesel

Yanmar L70EE 7 hp Air-Cooled Single-Cylinder DI Diesel Engine

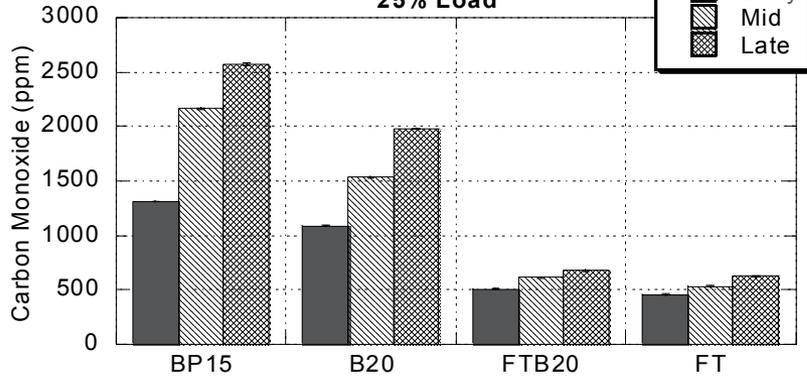




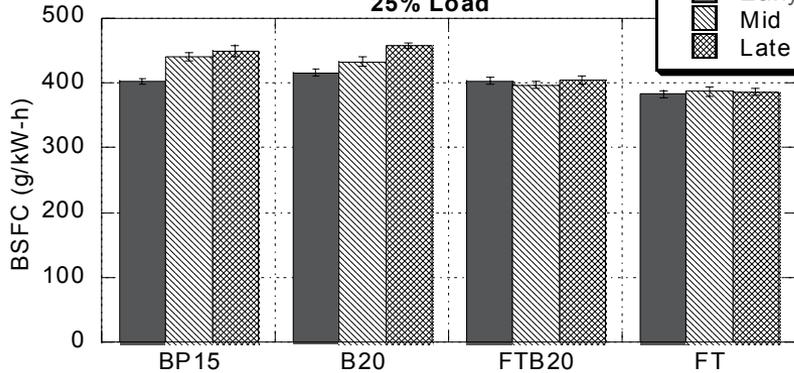
NOx Emissions 25% Load



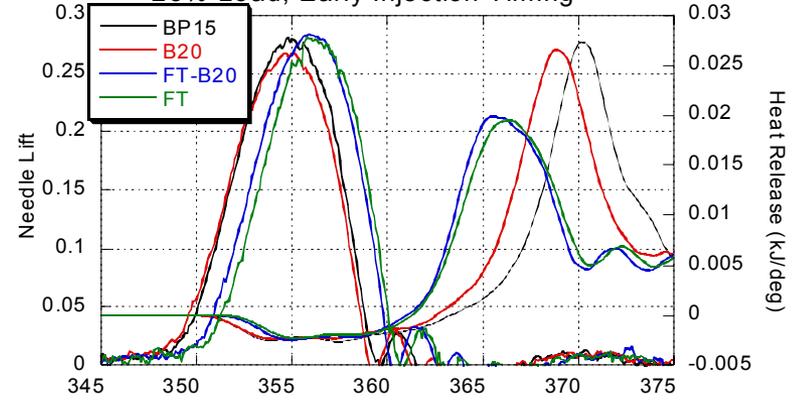
Carbon Monoxide Emissions 25% Load



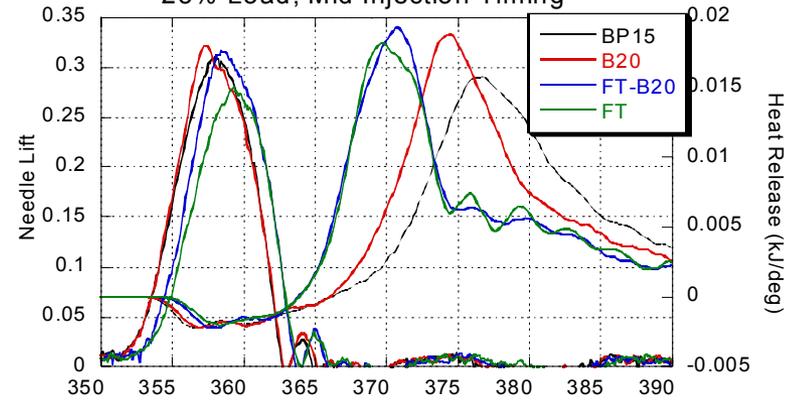
Brake Specific Fuel Consumption 25% Load



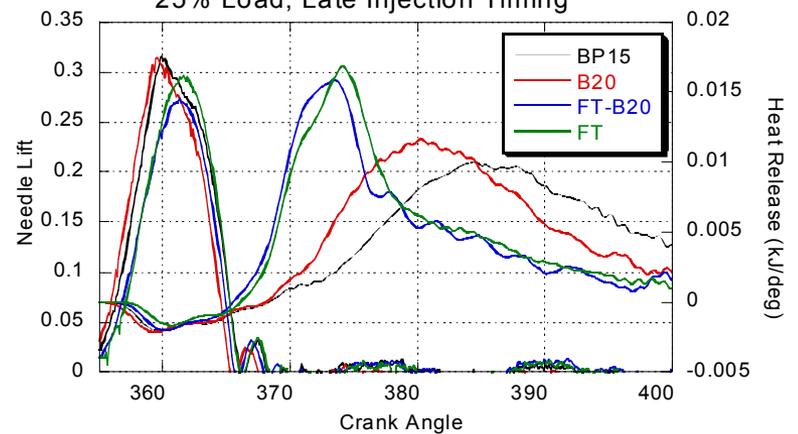
25% Load, Early Injection Timing



25% Load, Mid Injection Timing

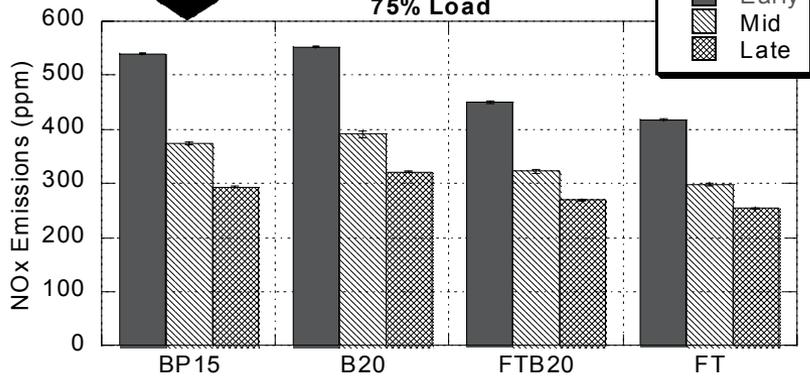


25% Load, Late Injection Timing

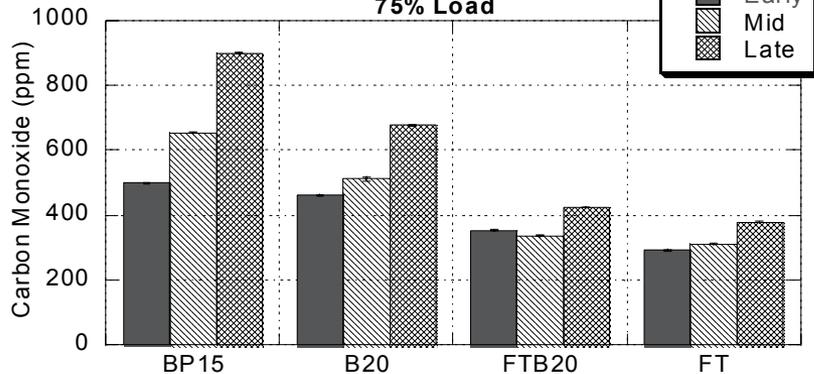




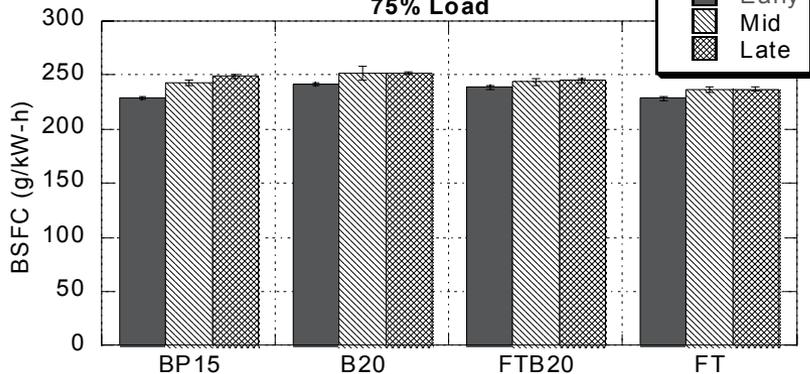
NOx Emissions 75% Load



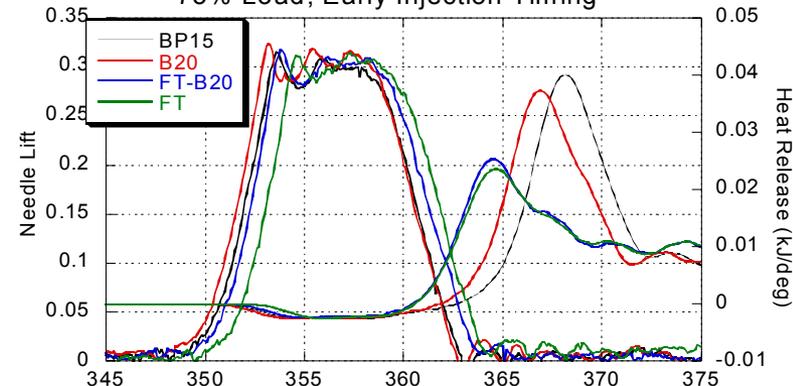
Carbon Monoxide Emissions 75% Load



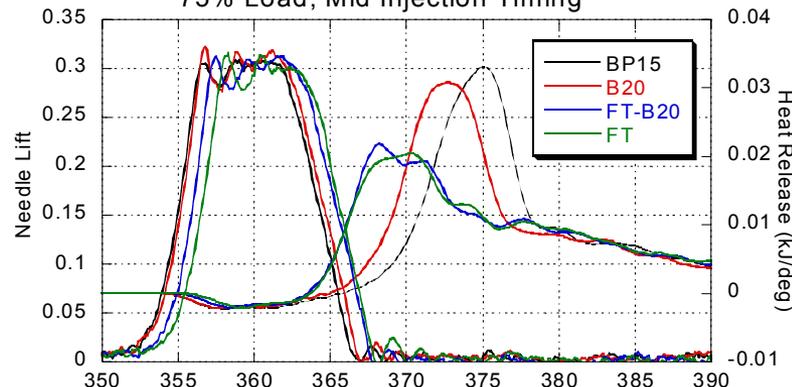
Brake Specific Fuel Consumption 75% Load



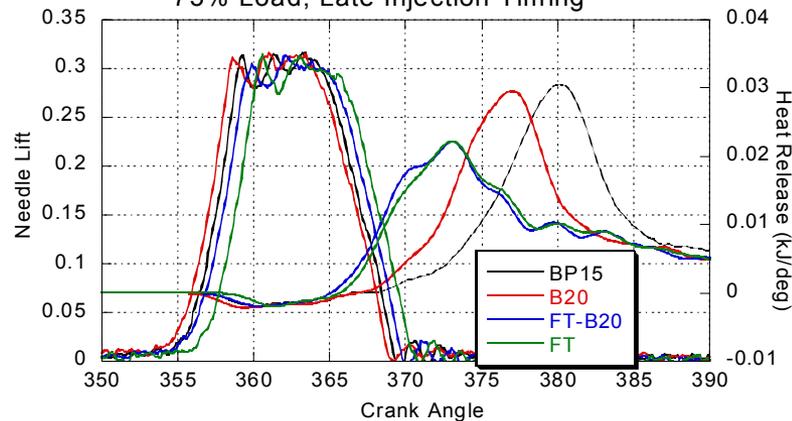
75% Load, Early Injection Timing



75% Load, Mid Injection Timing



75% Load, Late Injection Timing





Conclusions

- **Biodiesel and Soybean Oil Fuels**
 - ➔ The higher bulk modulus of compressibility of vegetable oils and their methyl esters leads to advanced injection timing
 - ➔ The advanced injection timing results in the increased NO_x emissions associated with Biodiesel, the “NO_x effect”
- **Paraffinic and Fischer-Tropsch Fuels**
 - ➔ The lower bulk modulus of compressibility of paraffinic fuels lead to a retarding of injection timing
 - ➔ The retarded timing supports the observation that paraffinic fuels such as Fischer-Tropsch diesel fuels yield lower NO_x emissions
 - ➔ The high cetane number of the COP FT diesel permits retarded injection timing without degraded combustion
- **Aggregate Effects on Emissions Control**
 - ➔ Higher engine-out NO_x and higher PM-SOF can enhance DPF regeneration and lower the Break Even Temperature (BET)
 - ➔ NO_x/PM ratio and PM composition/reactivity are key issues in DPF regeneration



Future Work

- **Ultra Clean Fuels Program**

- **Examine COP Fischer-Tropsch Diesel Products Neat and in Blends, Including Blended with Biodiesel, in the Cummins ISB 5.9L Turbodiesel Engine**
- **Includes Property Evaluation, Combustion & Emissions Tests, Exhaust Aftertreatment and In-Cylinder Visualization**
- **Examine Optimization of Engine Control Parameters to Maximize the Benefits from the Unique Properties of the COP F-T Diesel**



Acknowledgment and Disclaimers

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