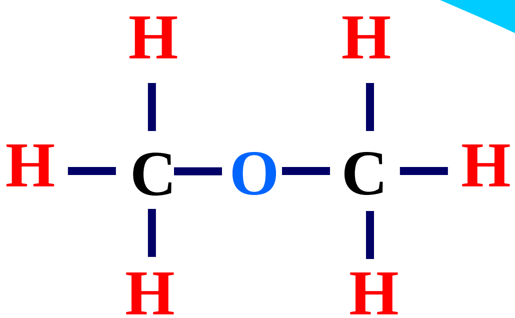
Low Engine-Out NOx Emissions with DME Using High Pressure Injection

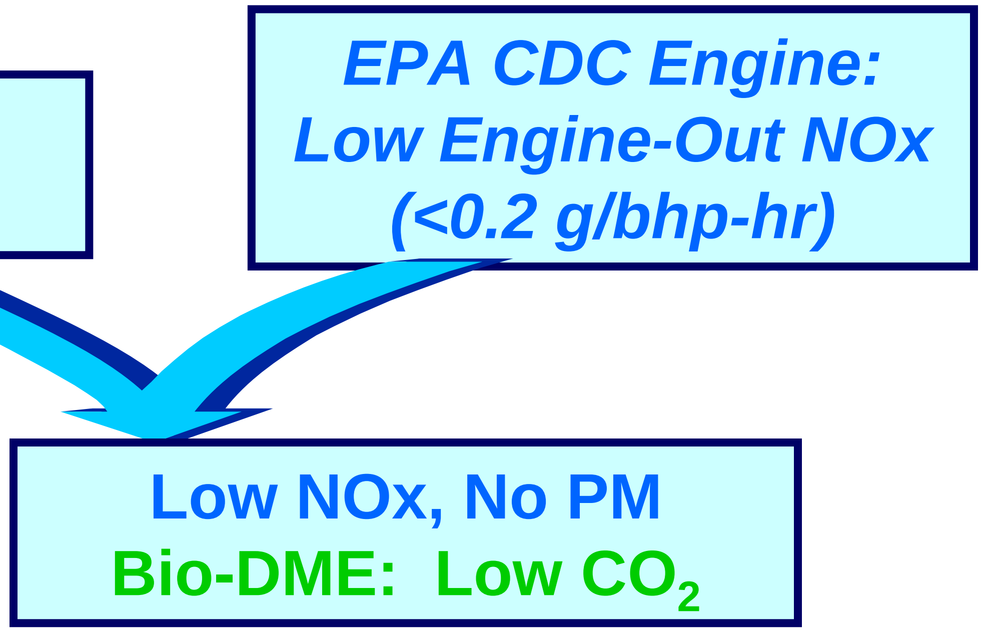
Matthew J. Brusstar, Fakhri J. Hamady
and Ronald M. Schaefer

U. S. EPA

October 30, 2007

Clean Diesel Combustion with DME





- Low NOx, low PM
  - Aftertreatment potentially reduced to oxidation catalyst only
- DME from cellulosic biomass: low greenhouse gases

DME Test Program

- DME Injector development
  - Modified stock (Siemens) injector
  - Flow visualization (comparison with diesel)
  - Nozzle pressure characterization

- Combustion chamber development
  - Single-cylinder engine
  - Characterize indicated efficiency, emissions

Properties of DME vs. Diesel

	NO. 2 DIESEL	DME
Lower Heating Value (kJ/g)	43.1	28.9
Liquid Density at 20ºC (g/Liter)	840	660
Cetane Number	40-45	65-68
Heat of Vaporization (kJ/MJ)	5.9	14.0
Bulk Modulus at 20ºC (MPa)	1400	350
Kinematic Viscosity at 40ºC (cSt)	1.9-4.1	0.21
CO2 emissions (g/MJ)	74.3	67.3

High Flow Requirement

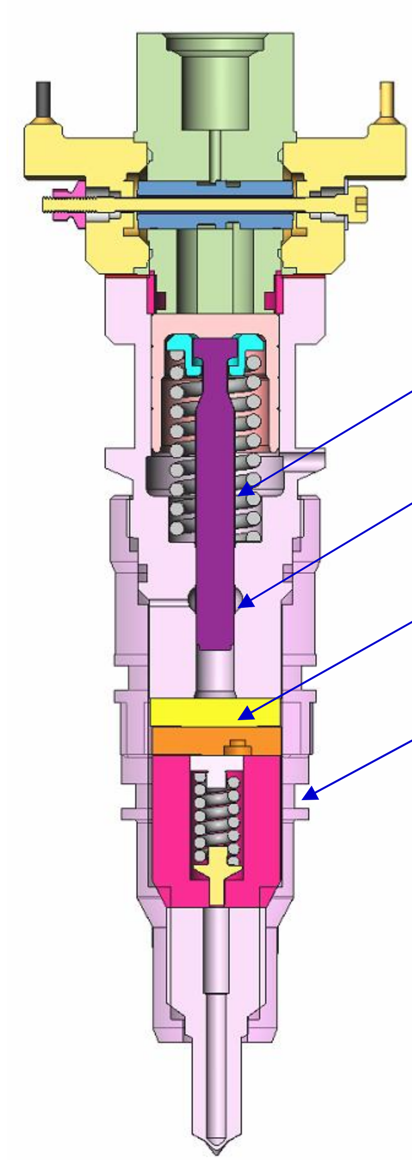
Short Ignition Delay

Slightly cooler charge

Challenge for HP injection systems

Lower exhaust CO_2

Injector Changes: Phase I



Base: Siemens Hydraulically-Intensified Injector (7:1)

Anti-wear DLC coating

Plunger lip seal

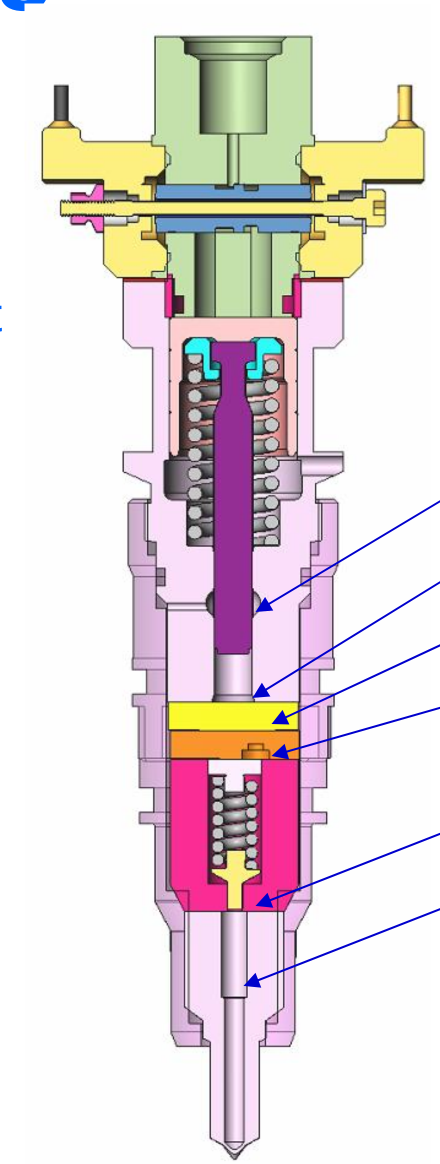
Ceramic check valve

Teflon external seals

2007-01-4093

Injector Changes: Phase II

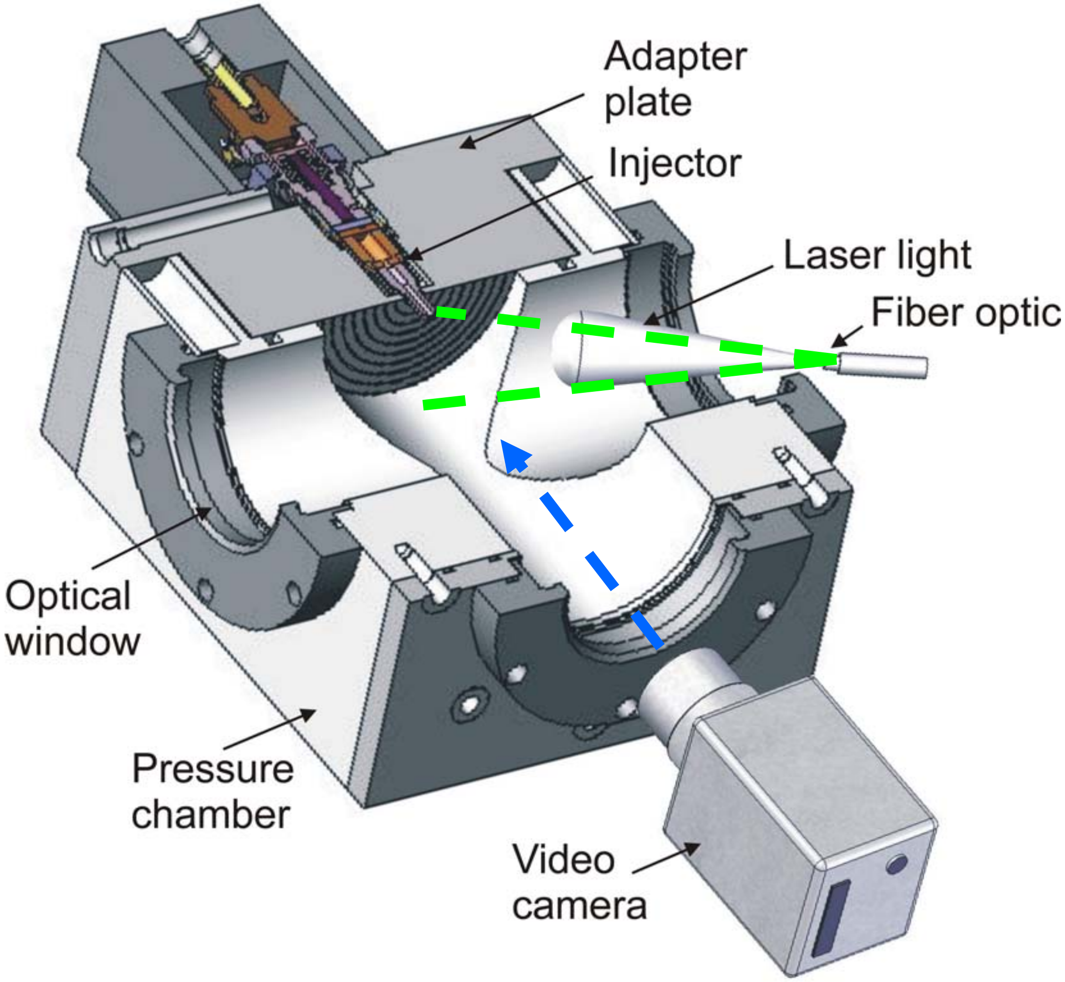
- Additional anti-wear coatings
  - Injector body: impact wear from check ball
  - Hardened check ball seat
  - Gas backflow preventer: impact wear
  - Spring cage: impact wear
  - Pintle: sliding and impact wear
- Seal changes
  - Plunger seal placed in injector body
- Evaluation/improvements ongoing



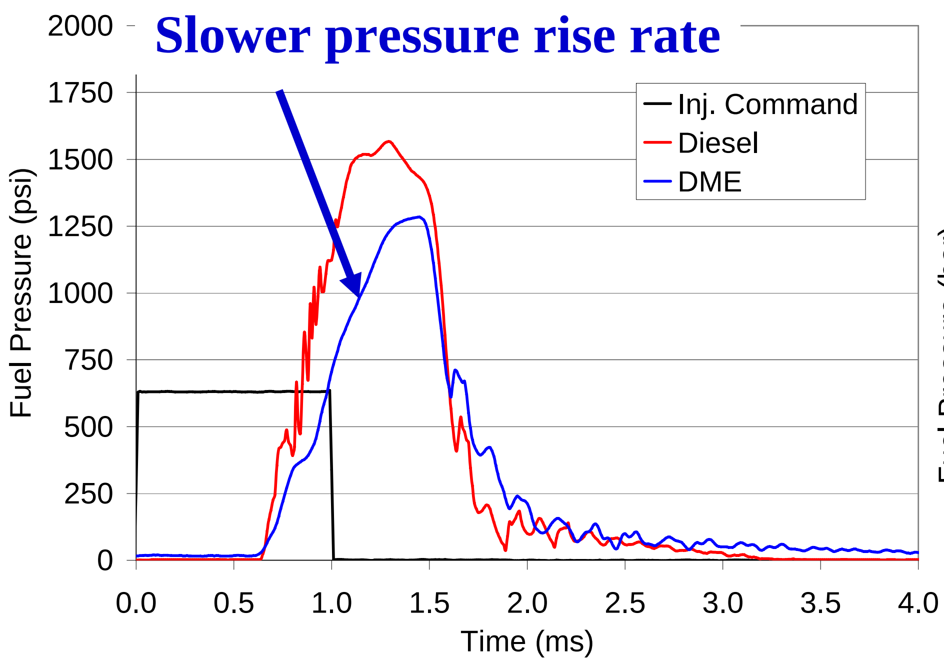
2007-01-4093

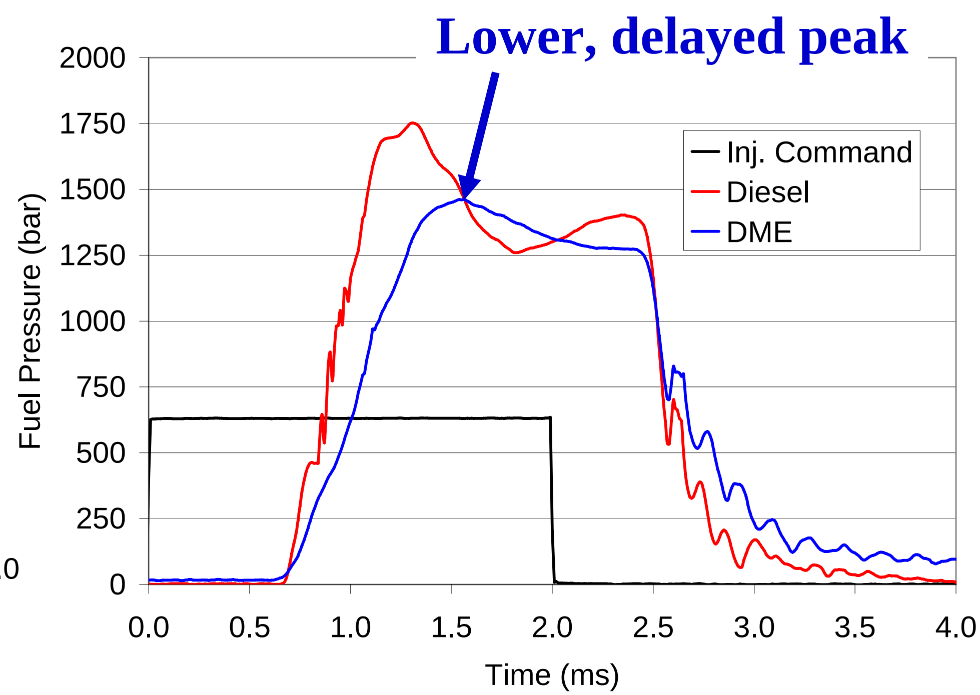
Spray Imaging Chamber

- Mie scattering with pulsed (20 ns) Cu vapor laser
- 10,000 fps video
- 512 x 512 resolution
- Pressurized (35 bar)



Pressure at Injector Nozzle Tip



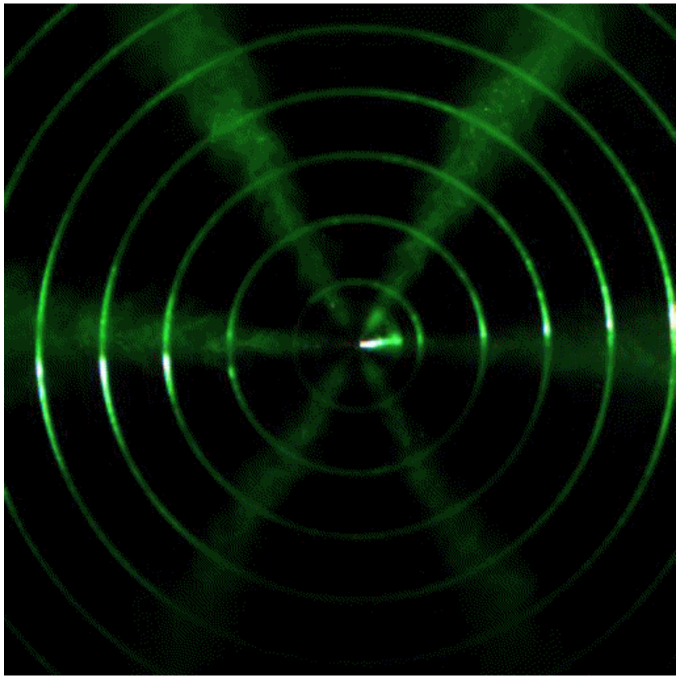


Pulse Width = 1.0ms
Nozzle: 6x0.16mm
Oil Pressure = 220 bar

Pulse Width = 2.0ms
Nozzle: 6x0.16mm
Oil Pressure = 220 bar

DME vs. No. 2 Diesel: 1 millisecond pulsewidth

Scale: each ring = + 0.5 cm radius

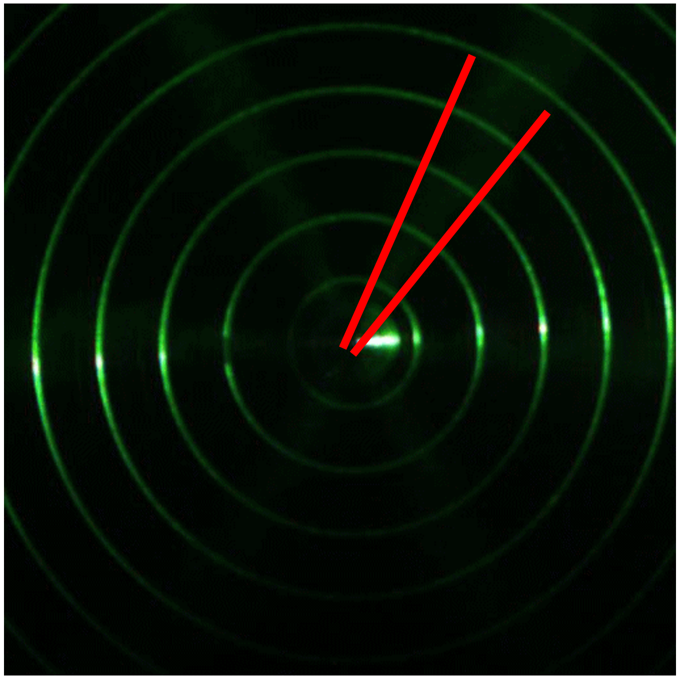


Nozzle: 6 x 0.16mm
Pulse Width = 1.0ms
Oil Pressure = 220 bar
Pressure Chamber= 35 bar

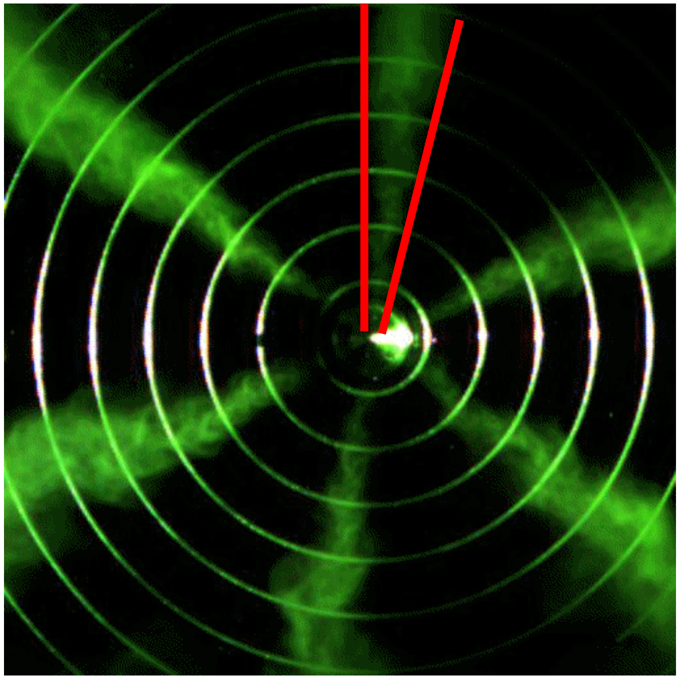
Nozzle: 6 x 0.16mm
Pulse Width = 2.0ms
Oil Pressure = 220 bar
Pressure Chamber= 35 bar

DME vs. No. 2 Diesel: 2 millisecond pulsewidth

Scale: each ring = + 0.5 cm radius



Nozzle: 6x0.16mm
Pulse Width = 1.0ms
Oil Pressure = 220 bar
Pressure Chamber = 35 bar

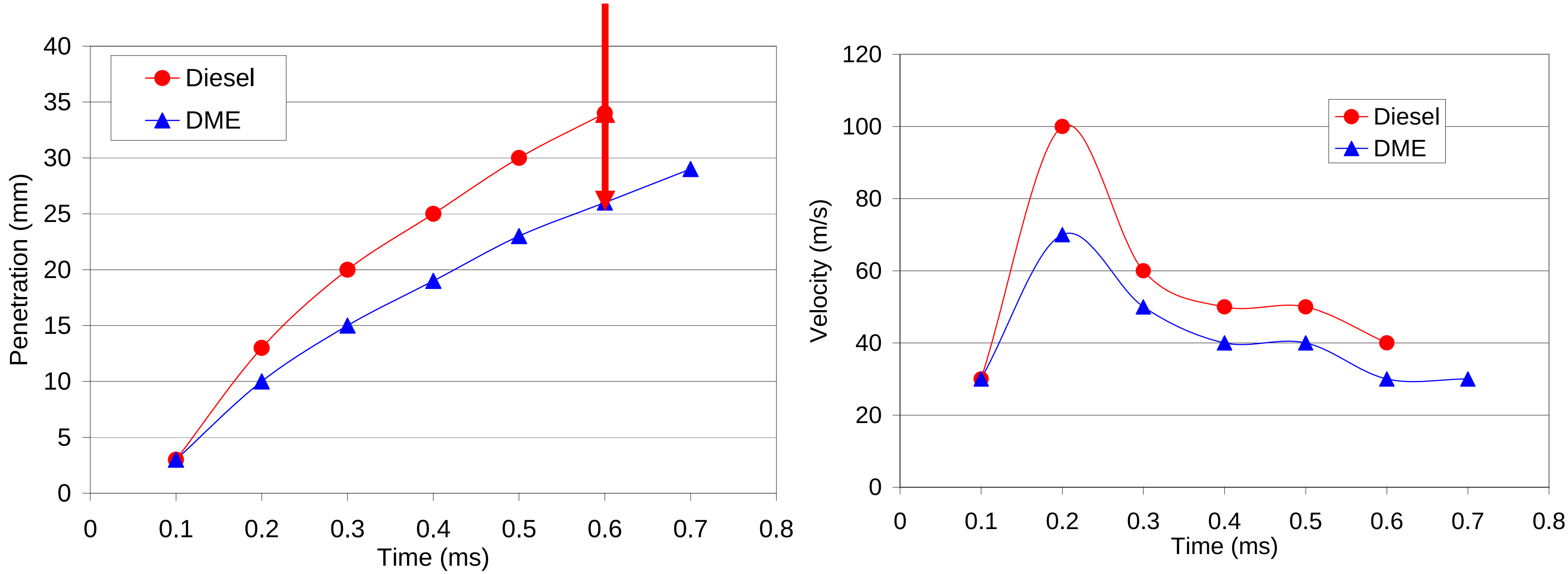


Nozzle: 6x0.16mm
Pulse Width = 2.0ms
Oil Pressure = 220 bar
Pressure Chamber = 35 bar

2007-01-4093

Fuel Penetration Rate

$L_{DME}/L_{Diesel} = 0.75$



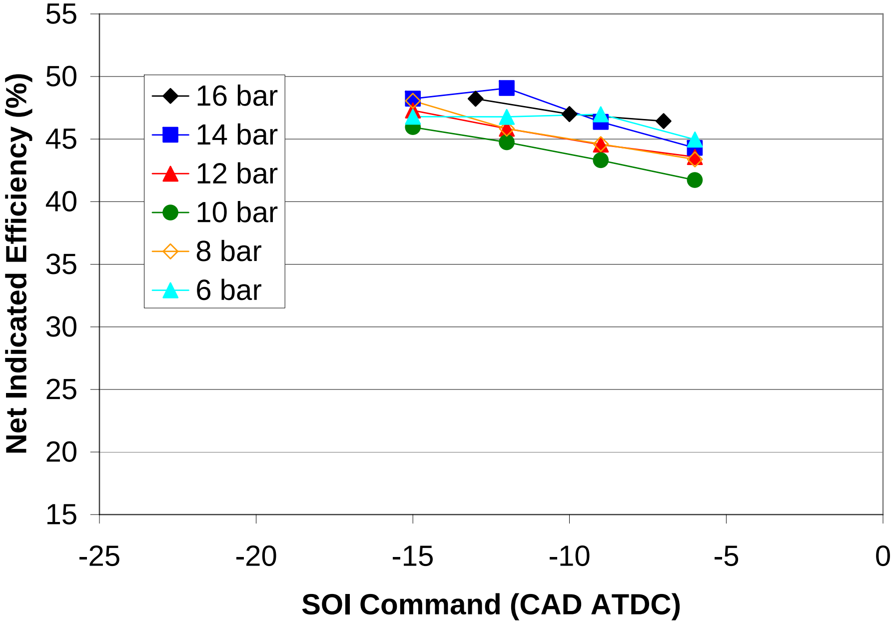
Nozzle: 6x0.16mm
Oil Pressure = 220 bar
Pressure Chamber= 35 bar

2007-01-4093

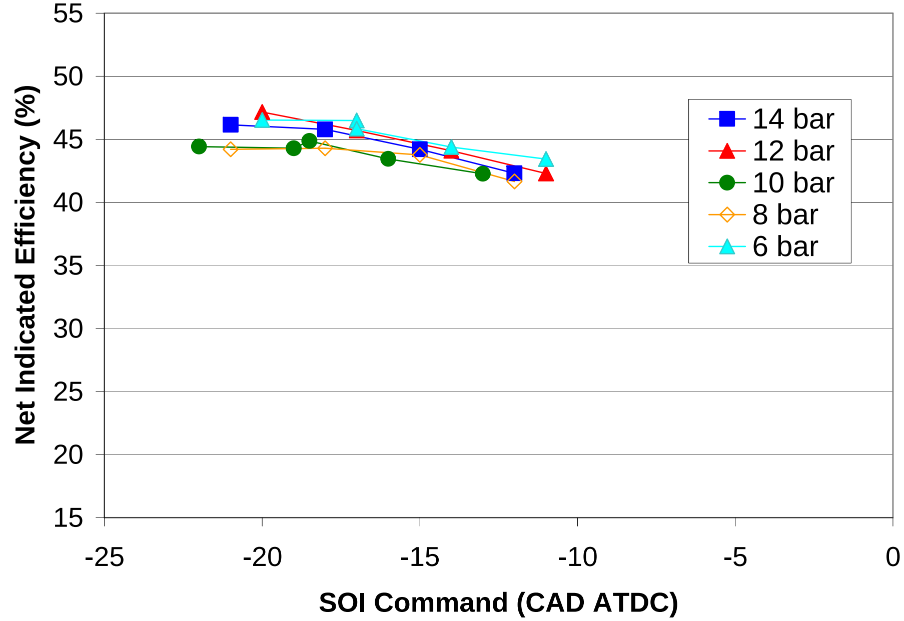
Single-Cylinder Engine Characteristics

Displacement (liters)	0.746
Bore Diameter (mm)	95.0
Stroke (mm)	105.0
Valves per Cylinder	4
Swirl Ratio	~2.0
Compression Ratio	18.0
Fuel Type	99.5% DME

Net Indicated Efficiency



N = 1500 rpm

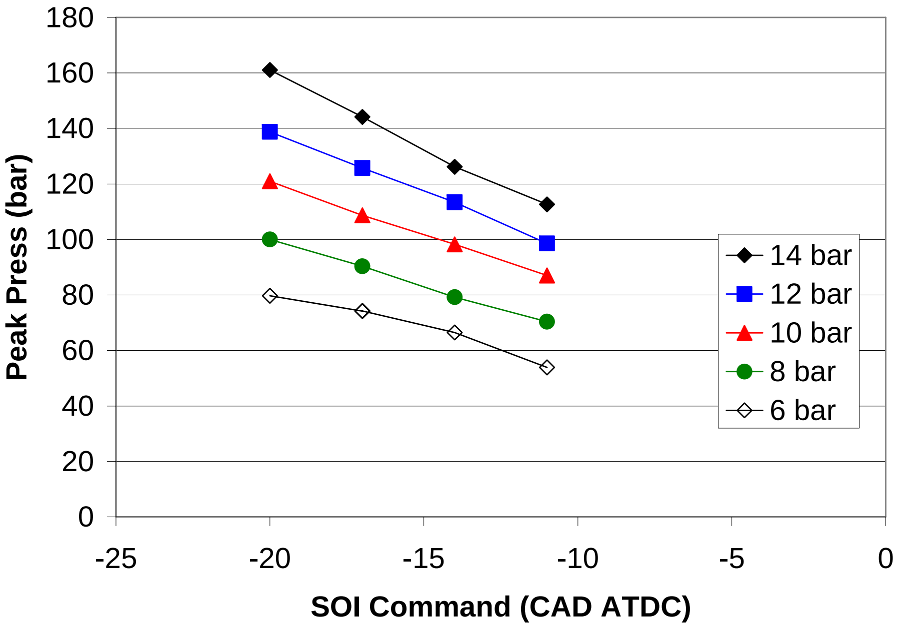


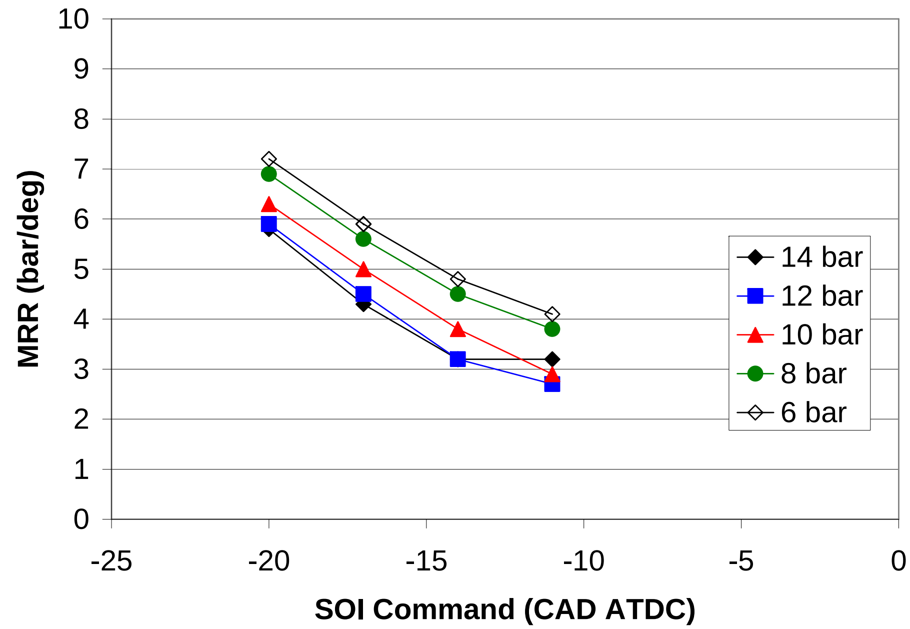
N = 2000 rpm

Test Conditions:
T_{intake} = 40 deg C
T_{oil} = 72-80 deg C
$BSNO_x$ < 0.21 g/kW-hr
Exhaust O2% = 4.0%

2007-01-4093

Peak Cylinder Pressure, Rate of Rise





Test Conditions:

N = 2000 rpm

T_{intake} = 40 deg C

T_{oil} = 72-80 deg C

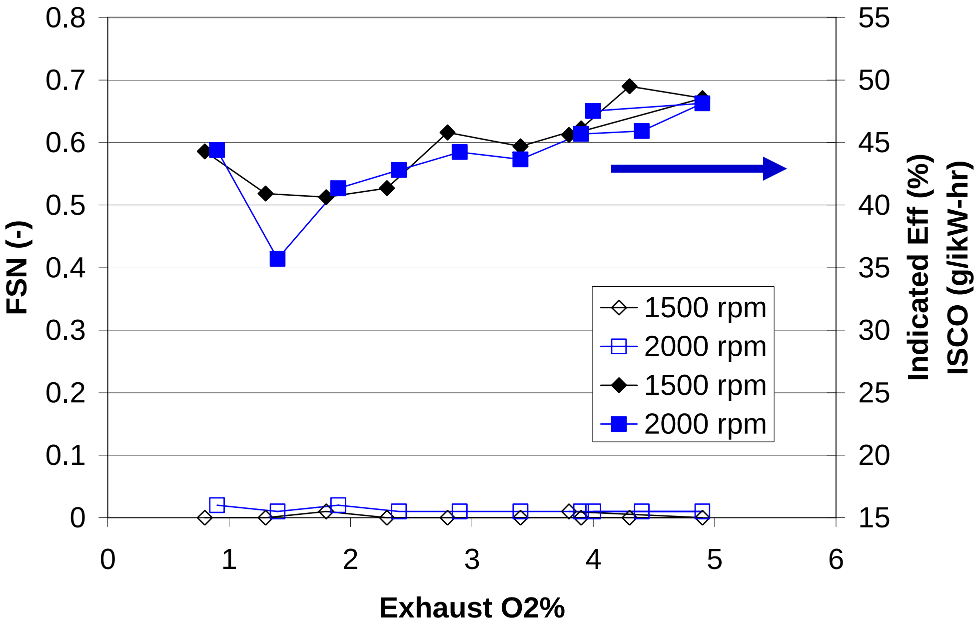
$BSNO_x$ < 0.21 g/kW-hr

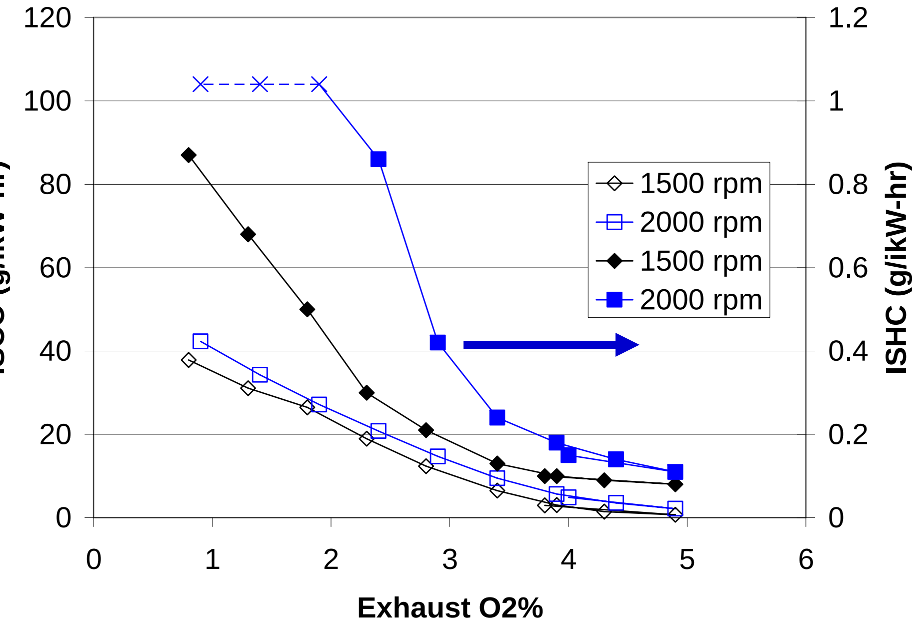
Exhaust O2% = 4.0%

SAE®

2007-01-4093

Boost / Exhaust O2 % Sensitivity





Test Conditions:

T_{intake} = 40 deg C

T_{oil} = 72-80 deg C

$BSNO_x$ < 0.21 g/kW-hr

2007-01-4093

Summary/Conclusions

- Low engine-out NOx is possible with DME
  - 80% of the level of the US Heavy-Duty Onroad NOx standard demonstrated,
- Small, Non-zero PM levels: lube oil contributions
- Engine efficiency with DME is equivalent to base diesel efficiency
- A high-pressure (>1500 bar) DME injection system has been developed
  - Key to low-NOx strategy
  - Injector wear is an ongoing concern
- In the future, DME from biomass may offer potentially attractive GHG reductions.

THANK YOU!!!

Contact: brusstar.matt@epa.gov