Impact of Variable Valve Timing on Low Temperature Combustion

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Navistar

Advanced Combustion

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Acknowledgements: DOE LTC consortium project, Low Temperature Combustion Demonstrator for High Efficiency Clean Combustion (DE-FC26-05NT42413) .

Industrial Partners: UCB, LLNL, Ricardo, Siemens, ConocoPhillips, BorgWarner, Mahle.

Outline

Low Temperature Combustion Roadmap

Clean and Efficient Combustion

Review of Variable Valve Actuation in LD and HD SCTE engines

Navistar MAXXFORCE V8 6.4L

Levering technologies

An Effective Electro-Hydraulic VVA Device

Thermodynamic Effects of VVA

Performance and Combustion Effects of VVA

Ignition Temperature and Ignition Delay

Soot Chemistry

Combine effects with PCCI

Extension of LTC Operation

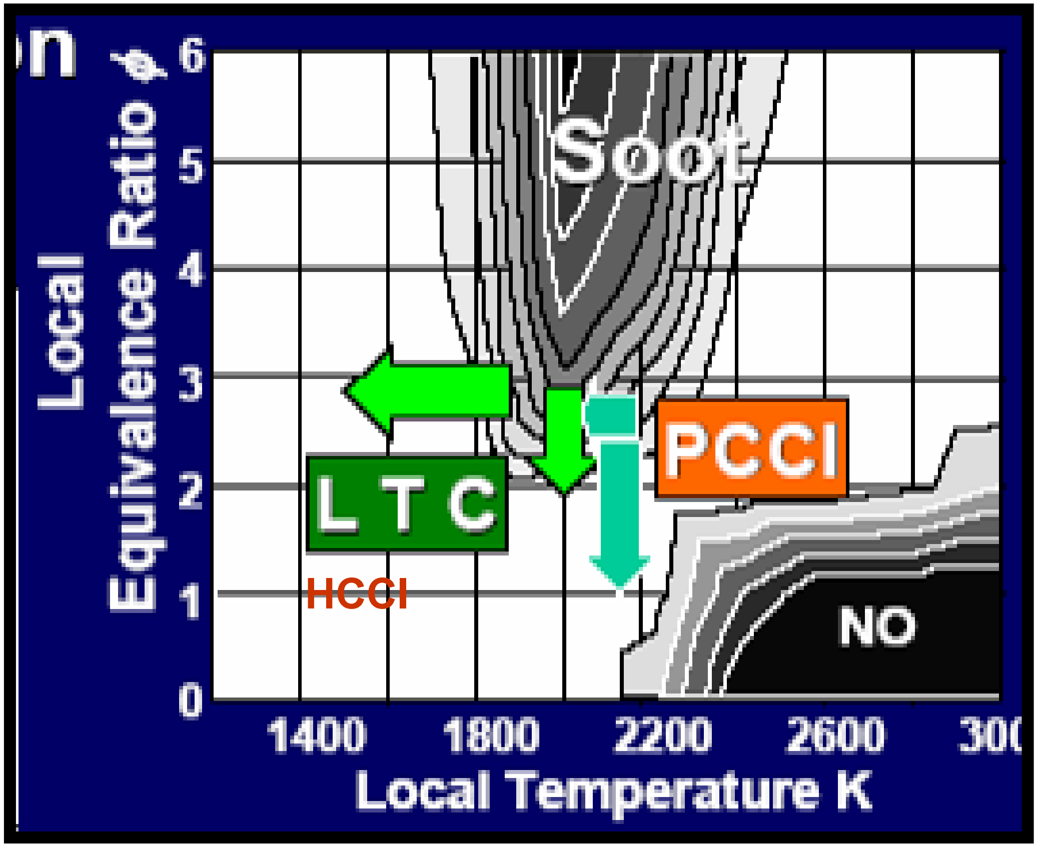
Summary

Acknowledgements and Project Partners

LTC Road Map

NOx suppression: Low flame temps
T < 2200K

Soot formation: ϕ > 2
1500 < T< 2200



[Herzog et. al 1992]
[Akihama et. al 2001]

Efficiency: Combustion phasing
Combustion efficiency
Reduce pumping losses
Reduce parasitic

→ Turbocharger design
EGR / Charge Air system

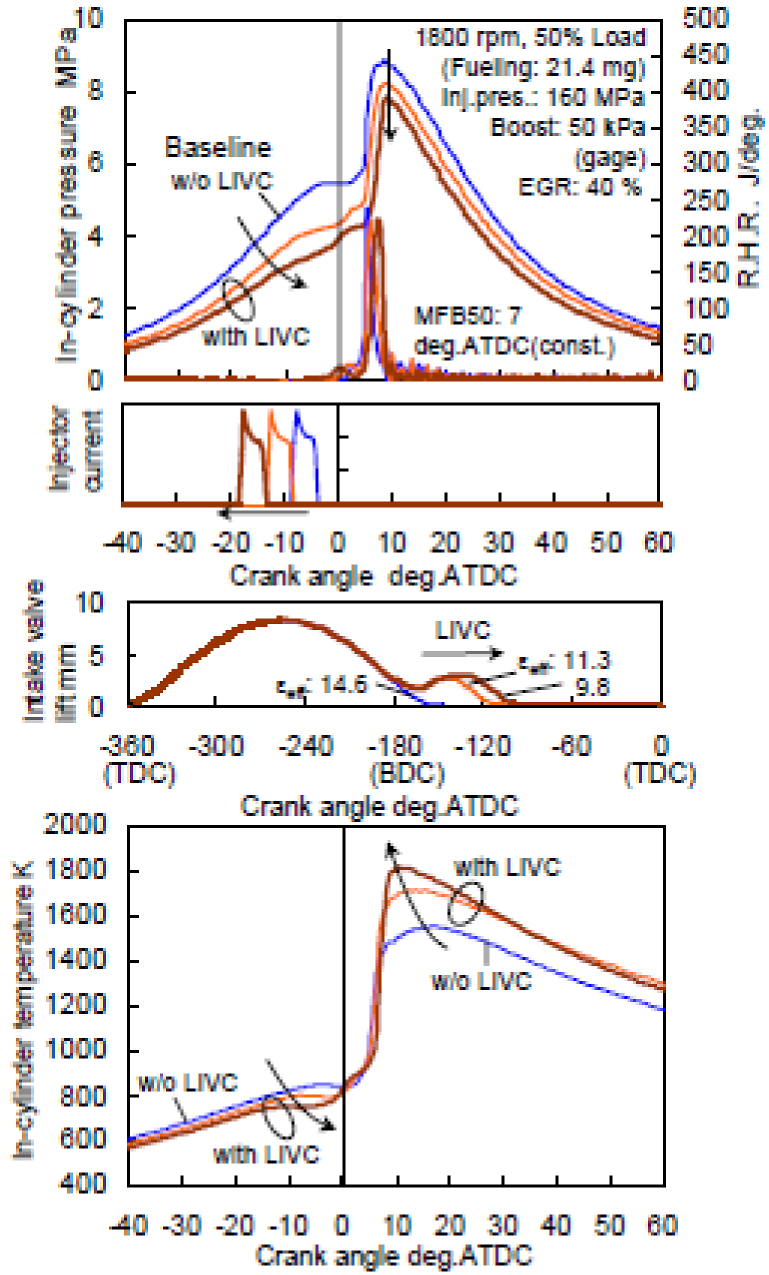
Review of VVA in SCTE (Light Duty)

Light Duty SCTE (0.5L)

Effects of Late Intake Valve Closing (LIVC) at 25 and 50% loads

- Lowers effective compression ratio
- Lowers in-cylinder temperatures
- Increases ignition delay

- **Reduced smoke** despite lower excess air ratios.
- LIVC, EGR, supercharging and high-pressure fuel injection **simultaneously reduces NOx and smoke**.
- High CO and THC competes with fuel economy.



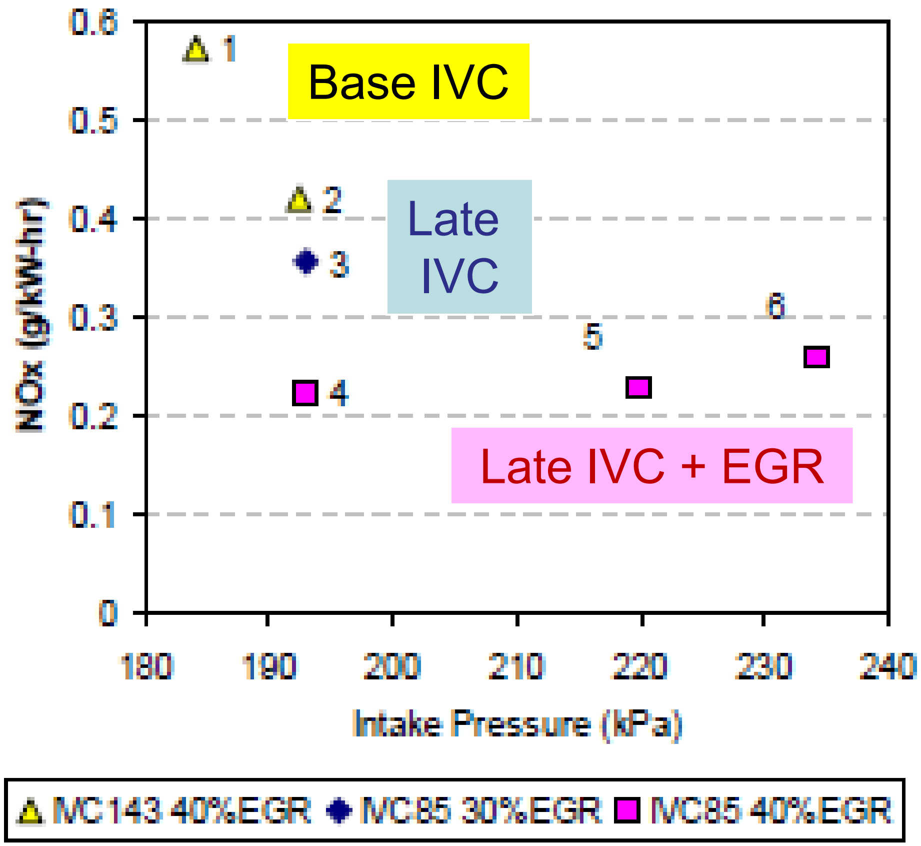
Murata, Y., Kusaka, J., Odaka, M., Daisho, Y., Kawano, D., Suzuki, H., Ishii, H., and Goto, "Achievement of Medium Engine Speed and Load Premixed Diesel Combustion with Variable Valve Timing" **SAE Paper 2006-01-0203**.

Review of VVA in SCTE (Heavy Duty)

Heavy Duty SCTE (2.4L)

Effects of LIVC at 50% load

- Effective to **reduce NOX**
- Boost compensated to keep **soot at ~ 0.01g/kW-hr**



Nevin R.M., Sun Y., Gonzalez M.A. and Reitz R.D.

"PCCI Investigation Using Variable Intake Valve Closing in a Heavy Duty Diesel Engine"

SAE Paper 2007-01-0903

Navistar MCTE V8 Engine

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Engine Configuration

<u>Multi-Cylinder Test Engine</u>

1. Upgraded turbo
2. Improved HP EGR loop
3. Variable valve actuation (early intake valve closing)
4. Combustion feedback

	Base Engine	Test Engine	
Displacement	6.4L	6.4L	
Bore	98.2mm	98.2mm	
Stroke	105mm	105mm	
FIE	DI Common Rail	DI Common Rail	
CR	16.5	16.2	
Turbo Charger	Dual Stage Waste Gate	**Dual Stage VNT**	1
EGR system	HP loop Single Cooler	**HP loop Dual Cooler**	2
IVC	-130 ATDC	**-230 to -130 ATDC**	3
Bowl Geometry	Re-entrant	Re-entrant	

Data reported here

N	**2050**
BMEP(bar) tested	**5** 2 - 7
Combustion phasing CA50	**2 , 7.5 , 12.5**

Leveraging Technologies

Base engine development

Combustion Efficiency

Combustion Phasing
Combustion Duration

Cylinder Heat Rejection

High Boost / Lean

Optimum CR

Enablers

Injection strategy (PCCI)
High Injection Pressure
Controls

Efficient Turbocharging

VVA

Parasitic Losses

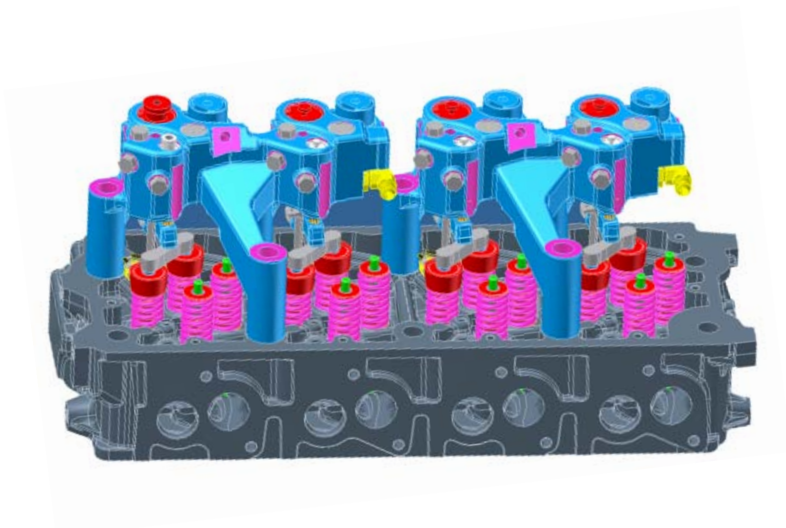
Bottoming Cycles

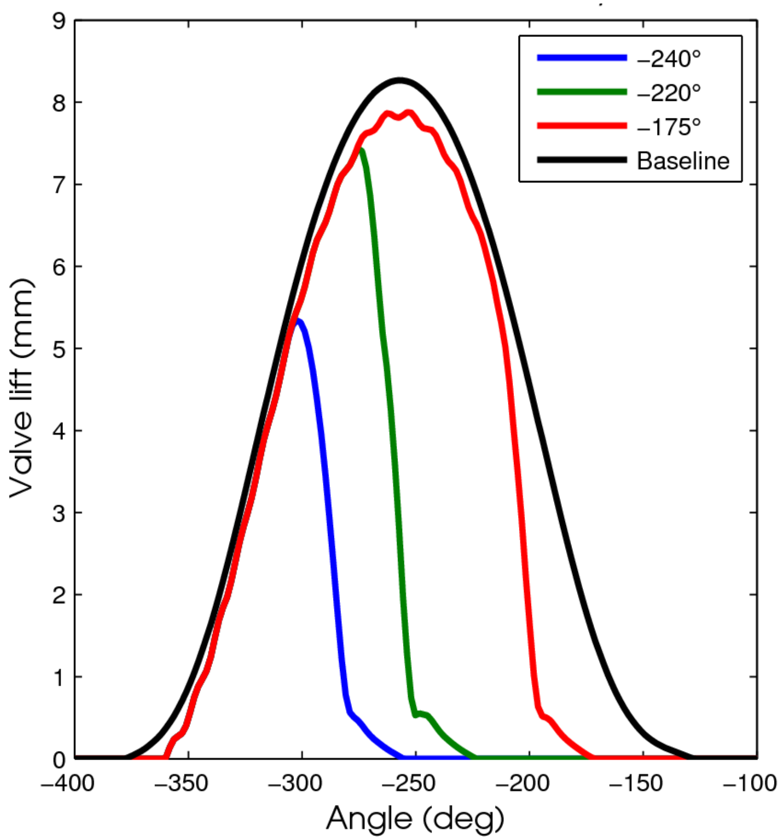
Aftertreatment Management

An Effective VVA Device

Advantages of Electro-Hydraulic System:

- Simple and Robust
- Fine resolution for IVC
- Cylinder to cylinder adjustment
- Cycle to cycle adjustments
- Simple package over baseline valve train





Other Advantages

- Real world soot and BSFC reductions

Thermodynamic Effects of VVA

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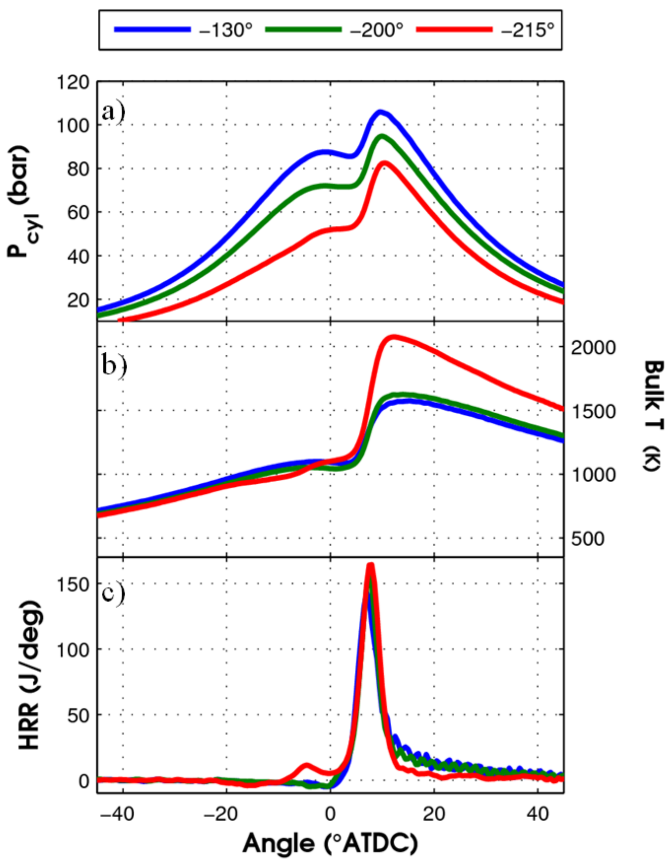
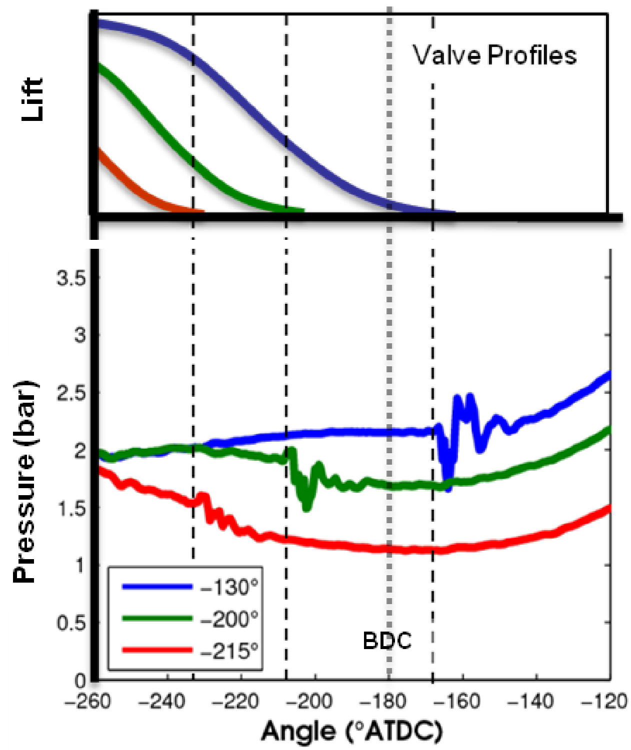
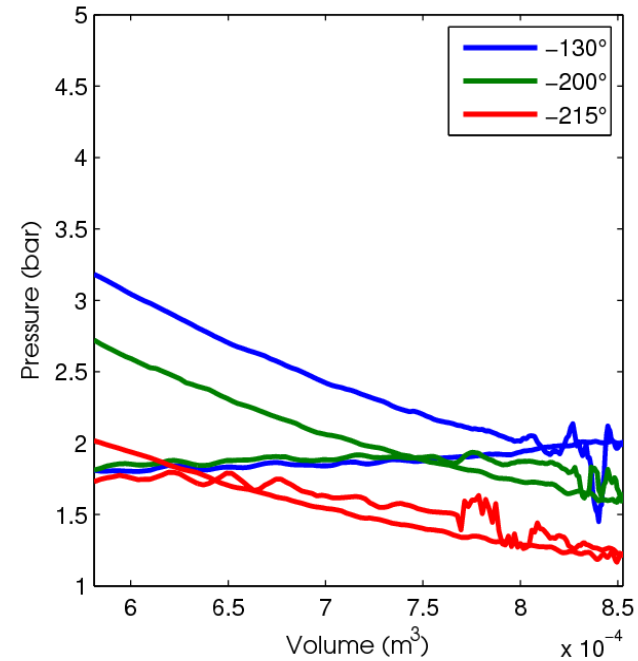
1	2	3
lowered effective CR	Early intake valve closing (EIVC) lowered in-cylinder pressure	EIVC produces a nearly isentropic expansion (reduced losses)







Combustion Effects of VVA

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Advancing Intake Valve Closing

1 Testing is carried out at a constant NOx (0.18g/bhp-hr) and constant phasing

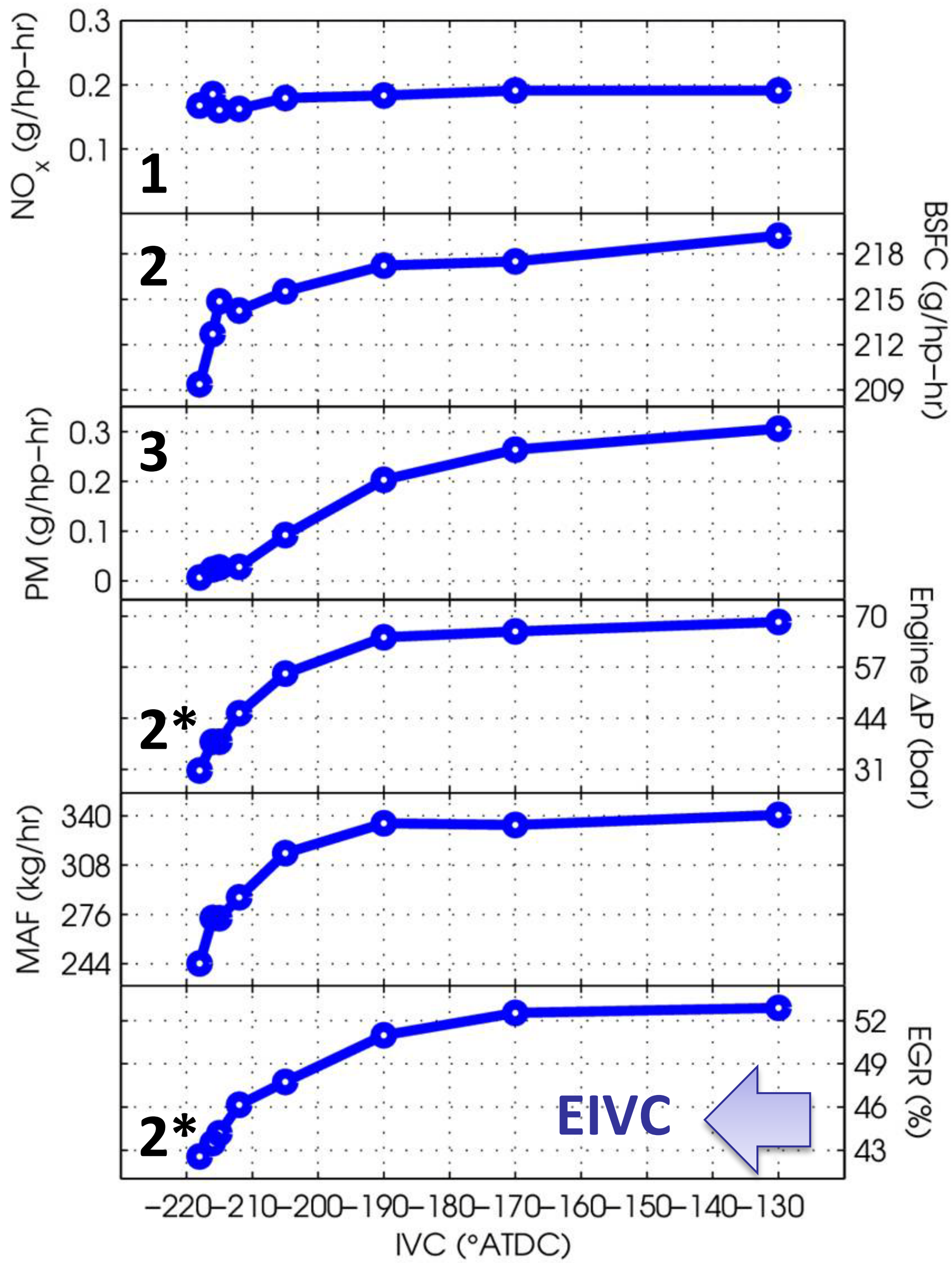
2 BSFC is reduced ~ 5%

3 Soot is reduced ~95%

2* {
MAP ~ constant
Boost-Back ~ reduced by 50%
MAF ~ reduced by 30%
EGR ~ reduced by 10 percent points

3* { Increased ignition delay

Ref **SAE 2010-01-1124**
trend holds for CA50 = 2, 7.5, 12 deg



Ignition temperatures

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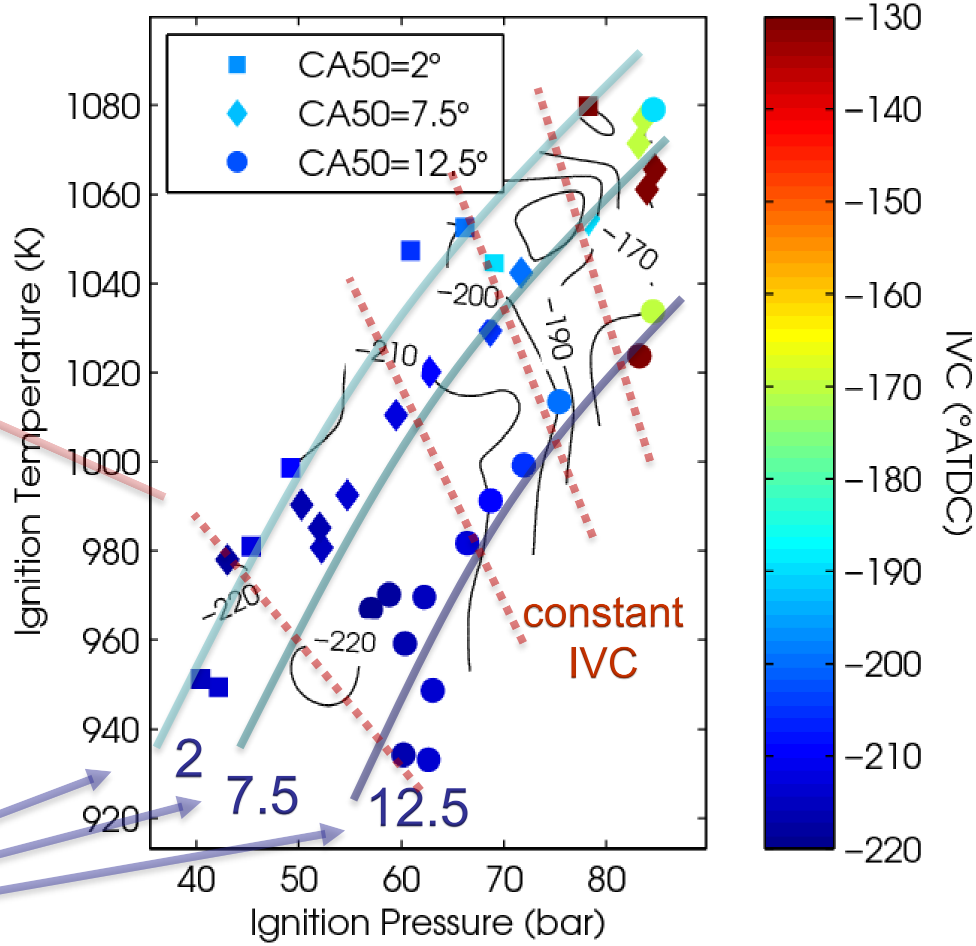
Advancing Intake Valve Closing

Ignition temperatures drop as IVC lines are advanced



IVC sweeps baseline -130 ° to -220°

EIVC

Data at three combustion phasing (2 , 7.5 , 12)

Ignition delay

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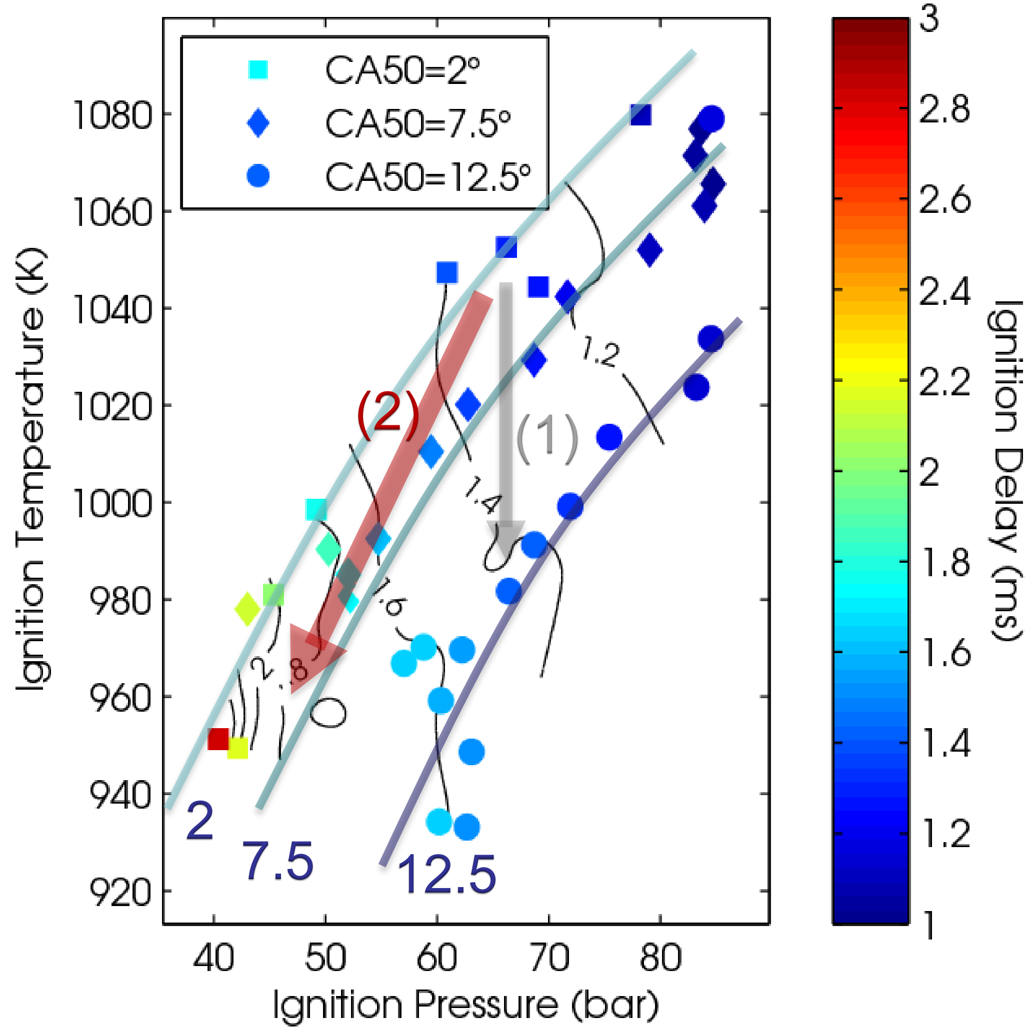
Ignition Delay

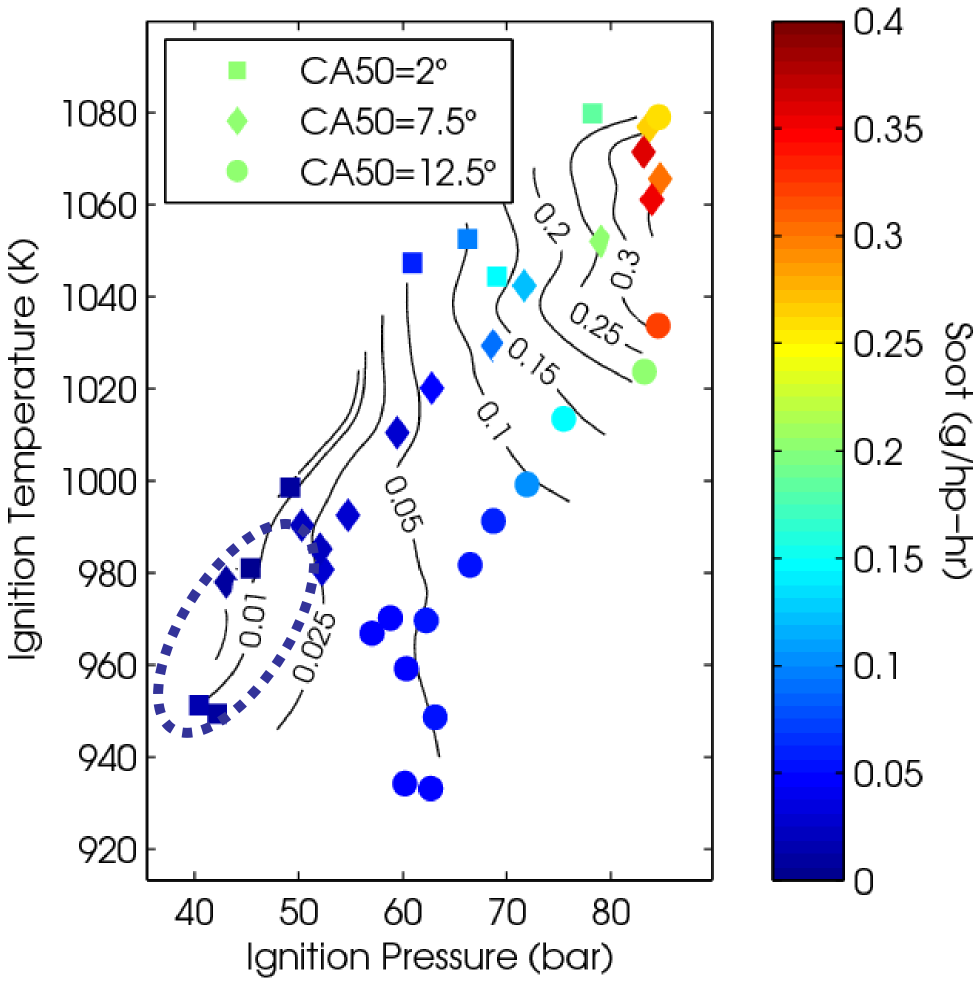
(1) Small effect of combustion phasing
τ_{id} ~ 0.1ms
per 10° CA50

(2) Large effect of EIVC
τ_{id} ~ 1ms
per 20° IVC

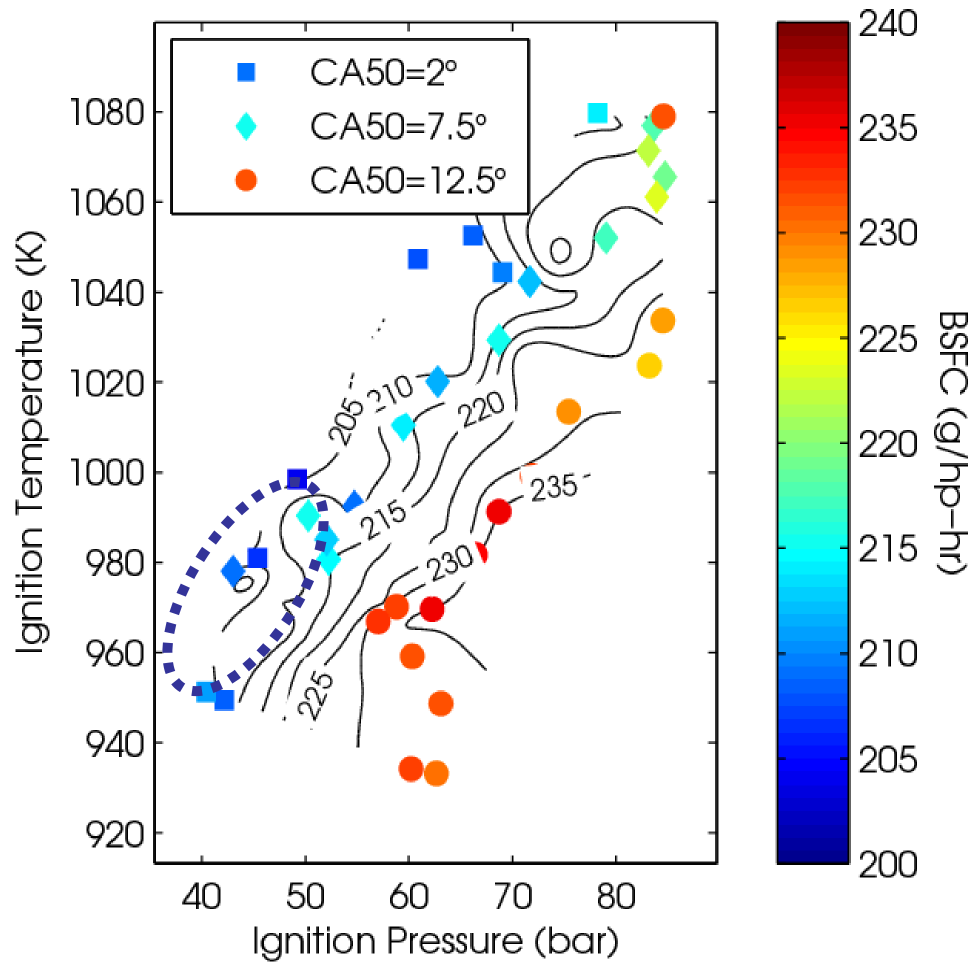


Soot and BSFC

Reduction in soot and impact on fuel consumption



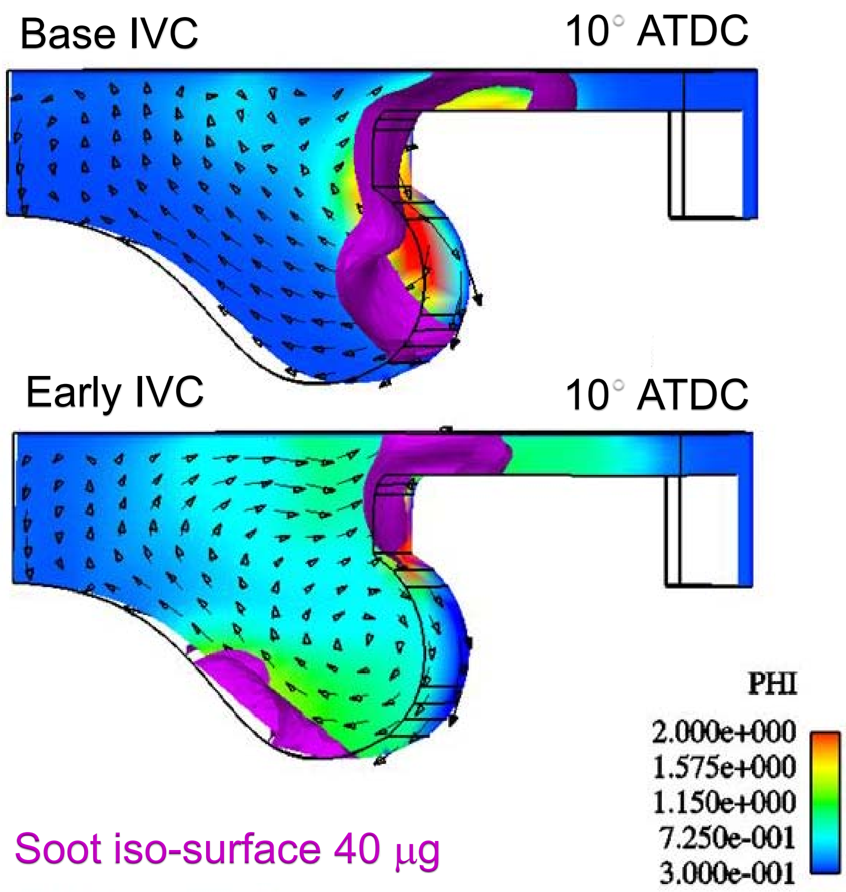
Very low soot

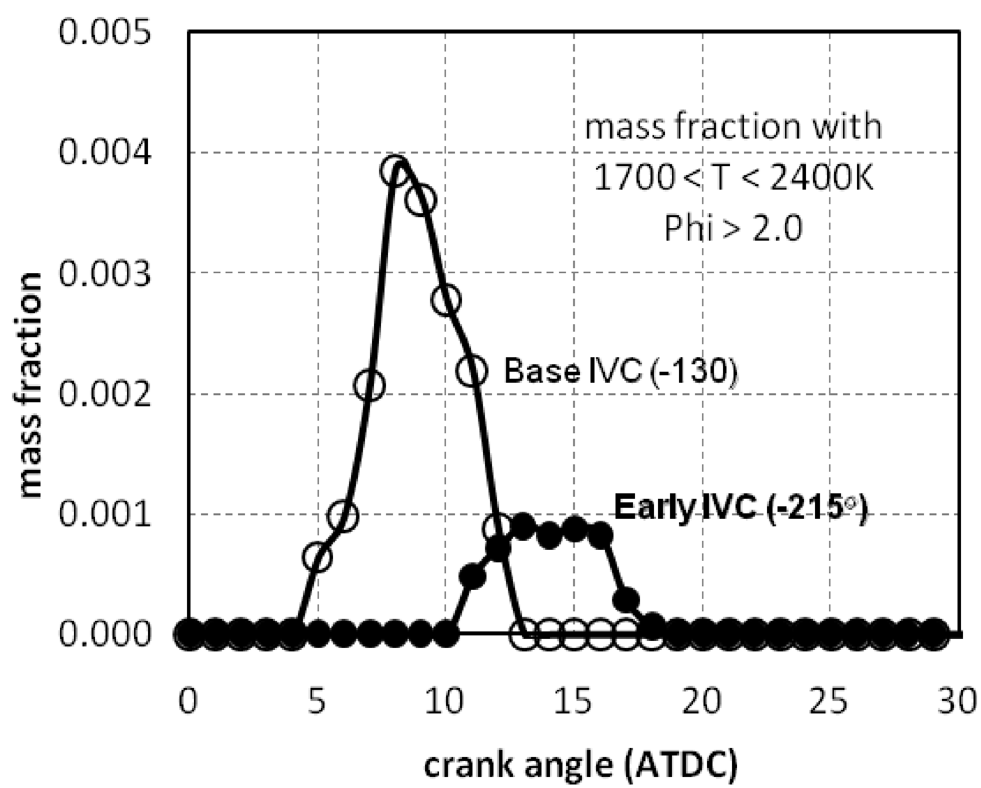


Simultaneous with reduction in BSFC

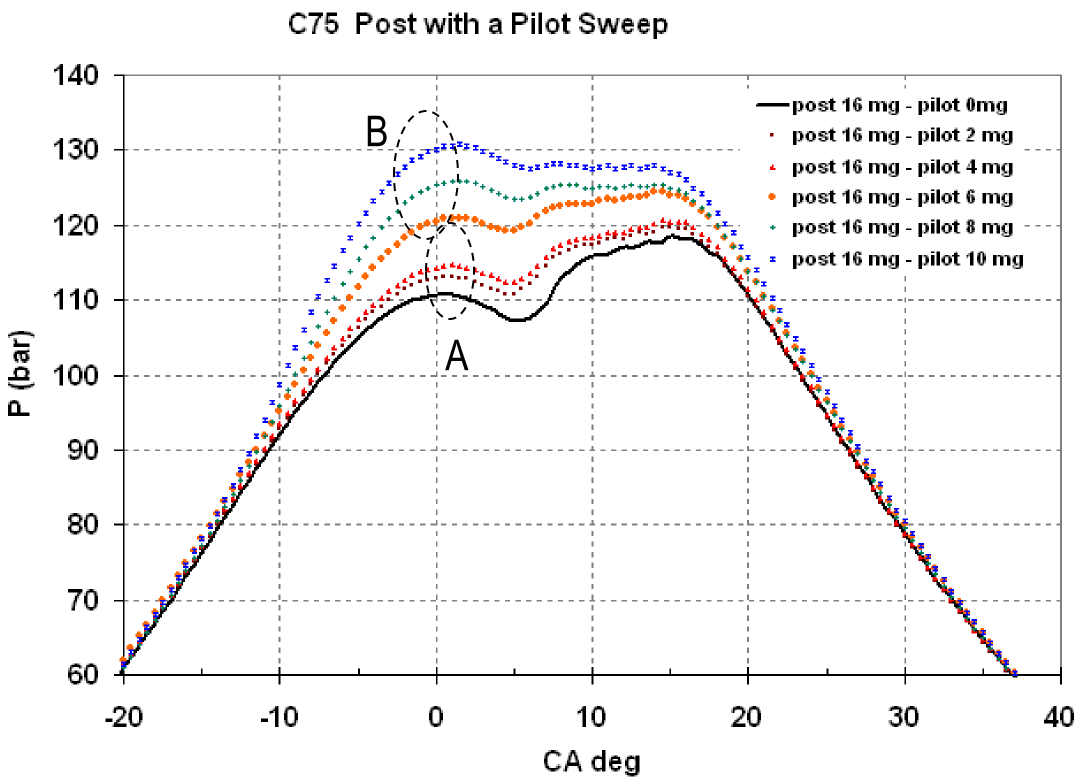
Soot Chemistry

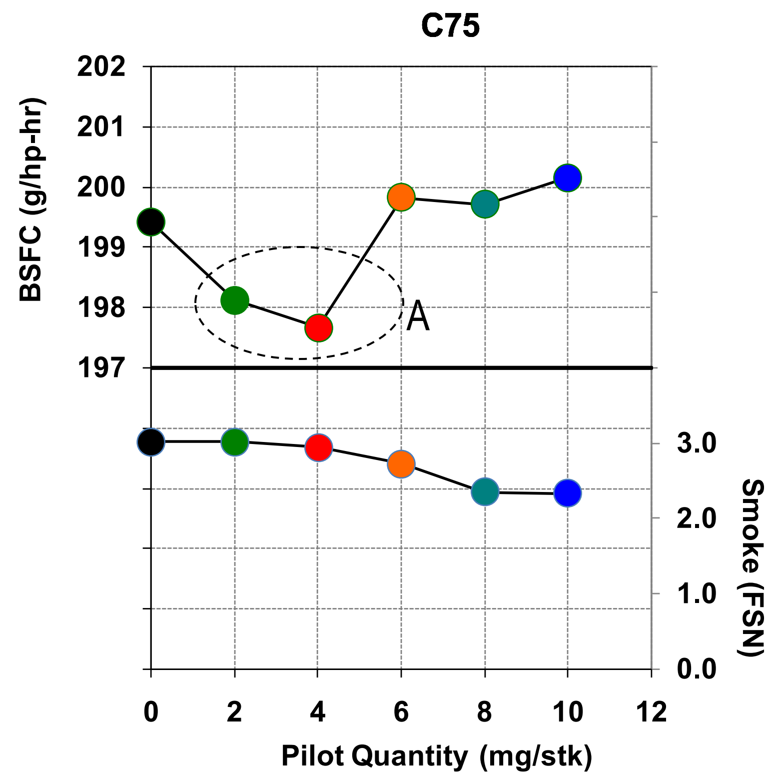
Soot reduction mechanisms with advanced IVC:
* better mixture characteristics
* Dependency on local equivalent ratio





PCCI Effects





A BSFC improvement of 1-2% can be identified by PCCI or fuel pilot and harvested with accurate cylinder pressure control.

B Excess pilot deteriorates performance due to premature combustion.

Ref 2009 DEER Conference (Dearborn, MI)

Extension of Efficient LTC operation

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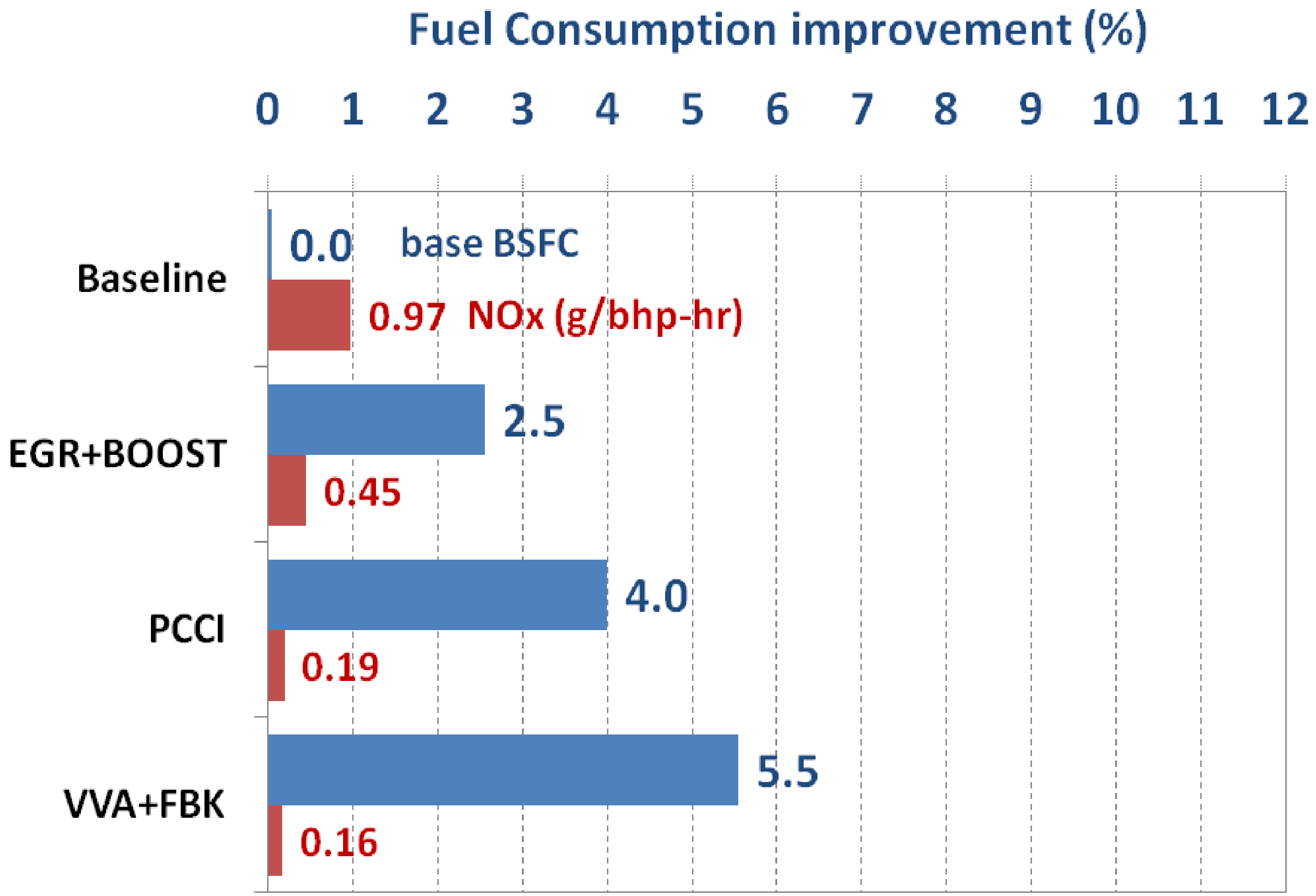
1. Boost-EGR Control: optimized combustion phasing
2. PCCI – premixed fuel injection strategies
3. Application of Variable Valve Actuation and Combustion Feedback



Summary

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A Variable Valve Actuation device was used on a Medium Duty V8 6.4L Diesel engine. The VVA adjusted:

- the intake valve closing individually on each cylinder ,
- demonstrated expansion process did not contribute to pumping losses,
- improved uniformity across cylinders provided better soot and efficiency.

Tests at a constant engine out 0.2 g/bhp-hr NOx showed:

- reduced soot emissions by 95% at loads up to 5 bar BMEP,
- lowered fuel consumption by 5%,
- reduced the amount of EGR required to dilute intake to a constant [O2].

Improved thermal efficiencies:

- lower ignition temperatures and pressures enabled long ignition delays,
- reduced the differential pressure across the engine.

Acknowledgements

Project Partners

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INTERNATIONAL

NETL

CFD
- Lawrence Livermore National Laboratory
- RICARDO

Fuels
- ConocoPhillips
- University of Windsor, thinking forward

Enabling Technologies
- BorgWarner Turbo & Emissions Systems
- MAHLE
- Continental
- Thomas, Driven by magnetics

Combustion Diagnostics
- Berkeley, University of California