UNIVERSITY OF BIRMINGHAM

Combustion and Emissions of Dieseline in a Direct Injection HCCI Engine

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Presentation outline

- Background and objective
- Experimental systems
- Results and discussion
- Summary

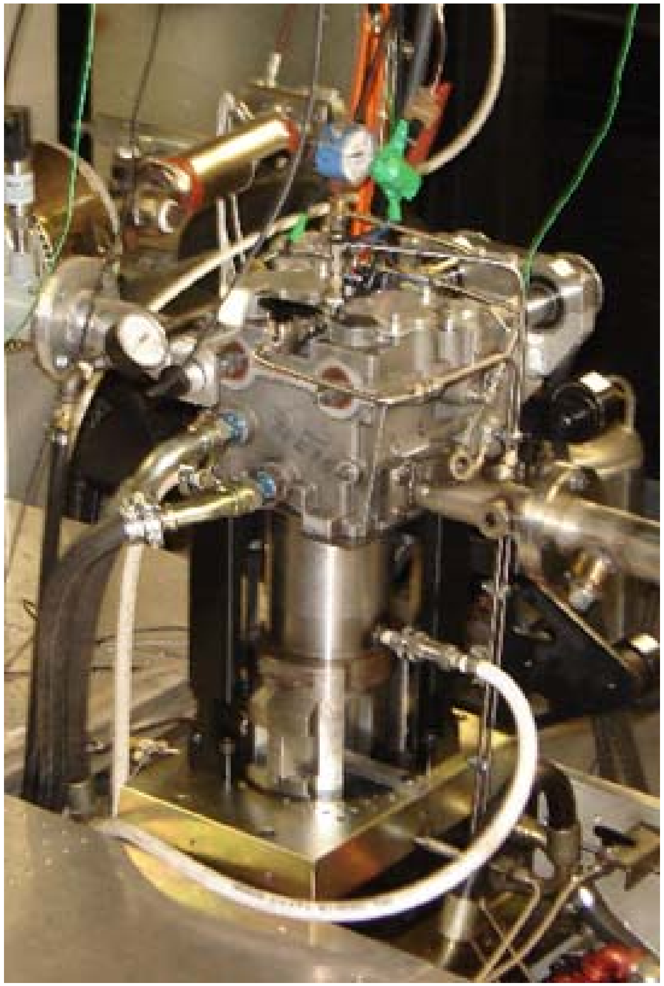
What is dieseline and why?

- Gasoline, which has high volatility but low self-ignitability, is generally produced as a high octane number fuel. It is associated with the main problem in the HCCI engine of over-rapid combustion rate at upper loads and misfire at low loads.

- The Diesel fuel, on the other hand, has a high cetane number with larger carbon content and heavier molecular weight with low volatility, is better suited to auto-ignition but often requires a lower compression ratio than the conventional Diesel if the HCCI mode is adopted.

- A mixture of Diesel and Gasoline (dieseline), mixed either online and off line, avoids any compromise and makes it possible to use the complimentary properties of the 2 different fuels.

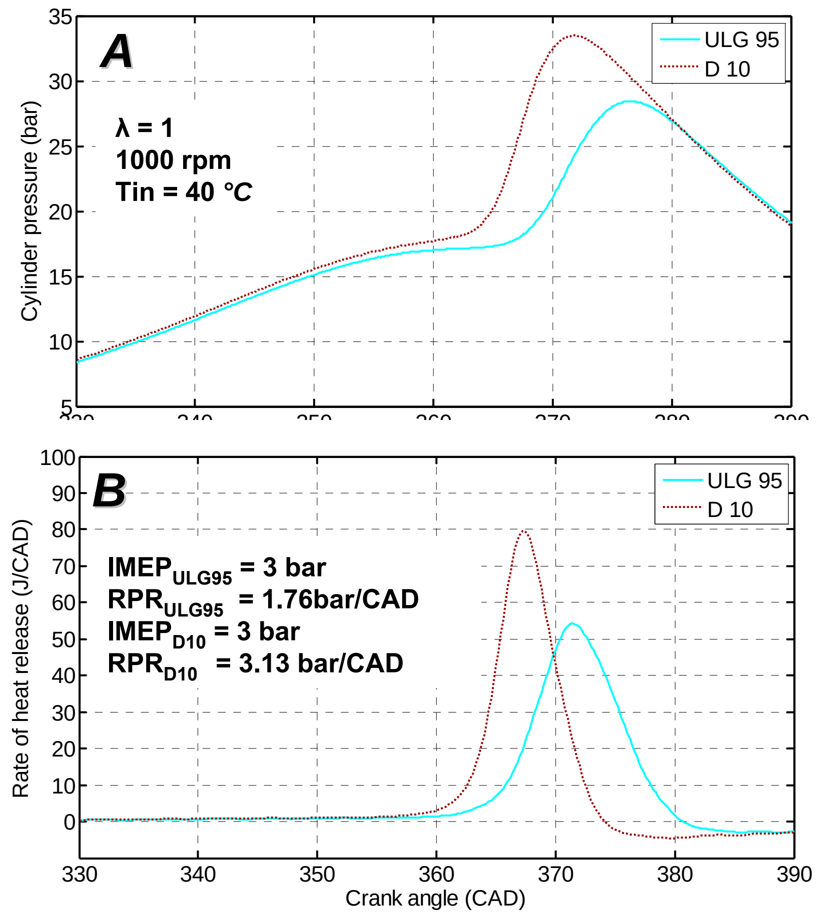
Dieseline combustion in an optical HCCI engine



Bore x Stroke (mm)	89.0 x 90.3	
Swept. Volume (cm^3)	561.5	
Compression Ratio (Geometric)	11.1:1	
Fuel Delivery	Direct Injection (150bar)	
Valves	**Intake**	**Exhaust**
Lift (mm)	2. 5	2.10
Duration (CAD)	150	110

Gasoline and Dieseline combustion

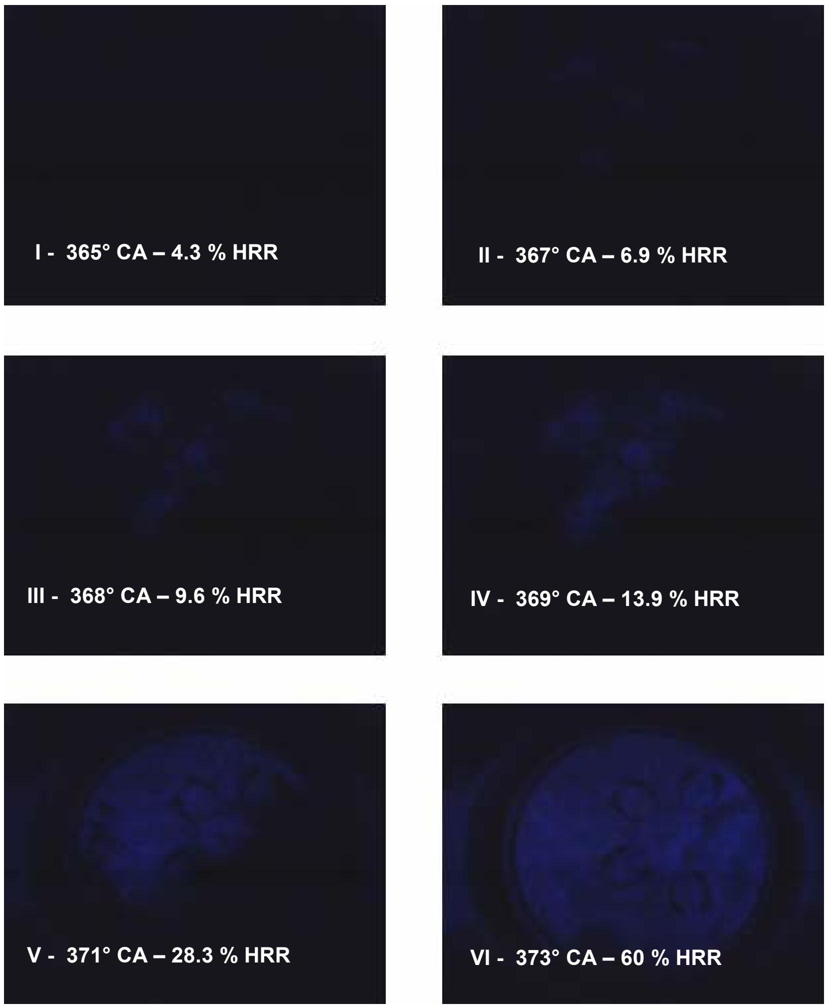
Fuel Property	Unleaded Gasoline ULG 95	Ultralow sulfur Diesel ULSD
Cetane number	unknown	53.9
Research Octane Number	95.8	unknown
Motor Octane Number	84.9	unknown
Density @15° C	738.7	827.1
10% Distillation (°C)	37.9	202.1
50% Distillation (°C)	93.4	264
90% Distillation (°C)	160.1	329
Paraffins	48.26	unknown
Olefins	16.2	unknown
Naphthenes	3.66	unknown
Aromatics	30.2	unknown

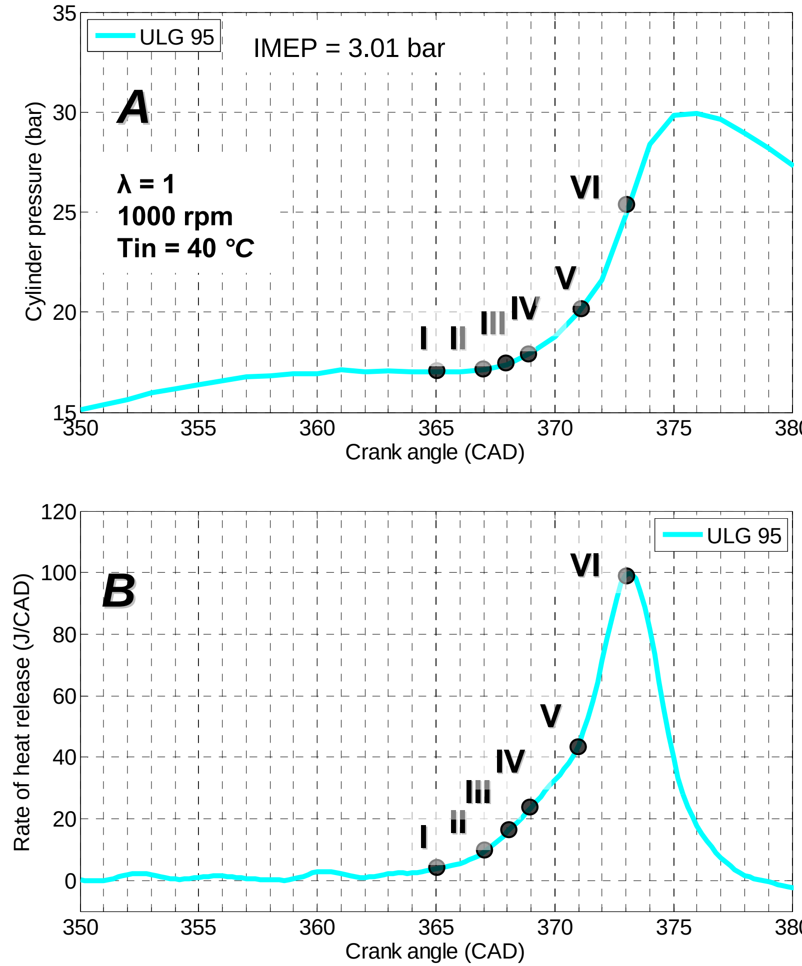


A – In-cylinder pressure as a function of crank angle,

B – Heat Release Profiles

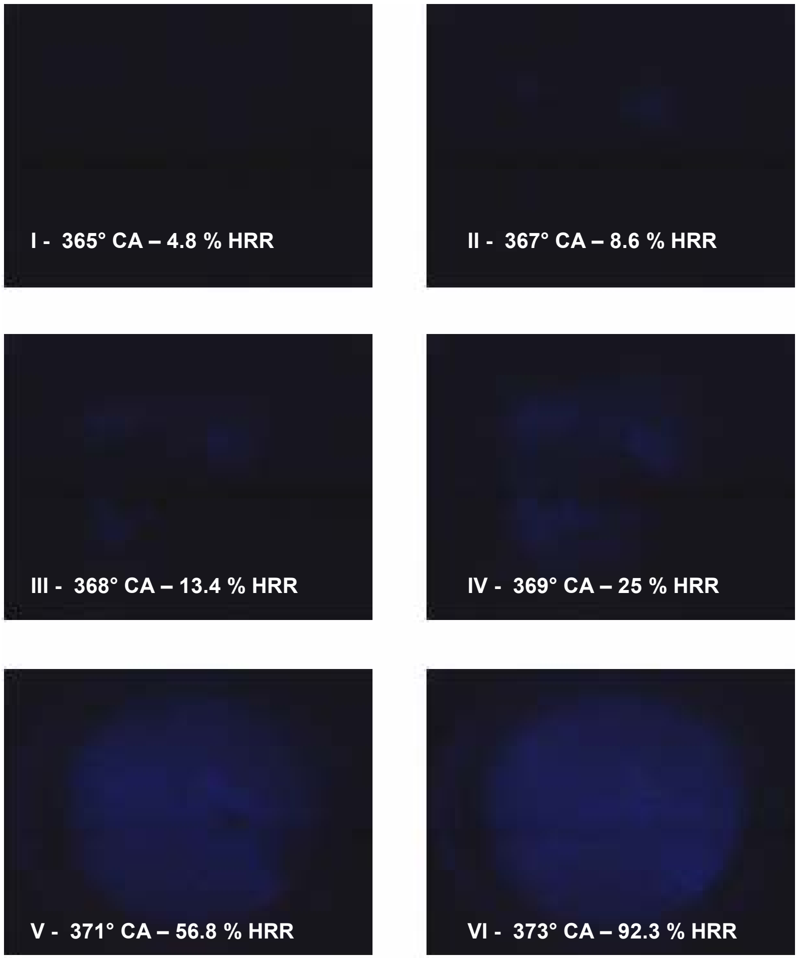
ULG95 - Cycle Hi-Speed Imaging and Burn Analysis

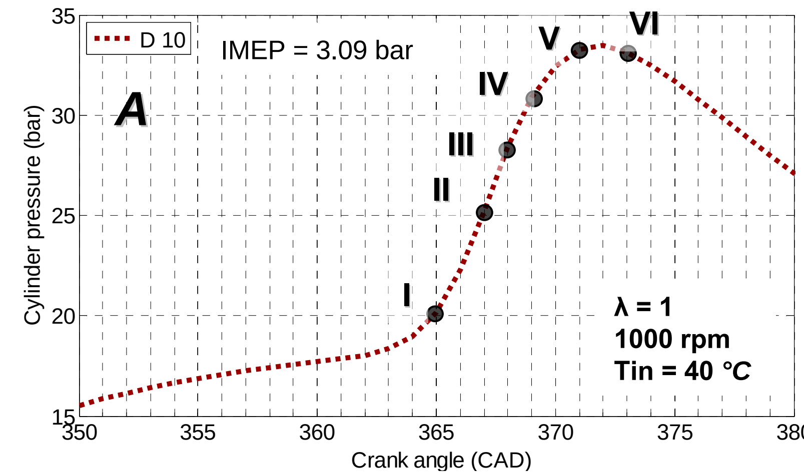


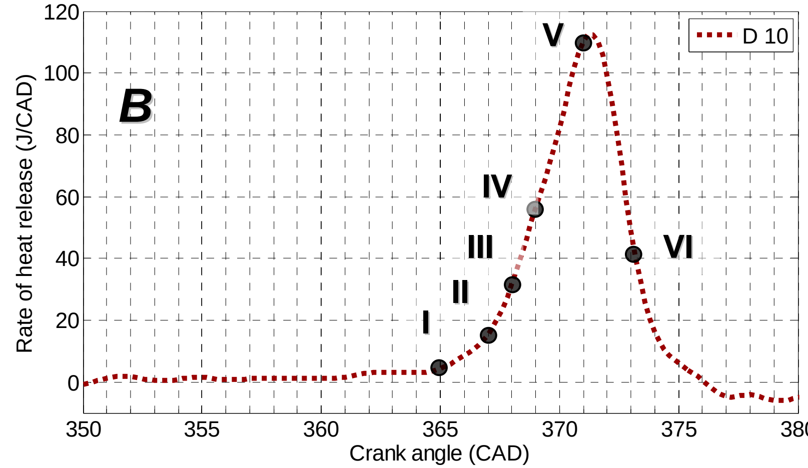


A – In-cylinder pressure profile
B – Heat release profile

D10 - Cycle Hi-Speed Imaging and Burn Analysis

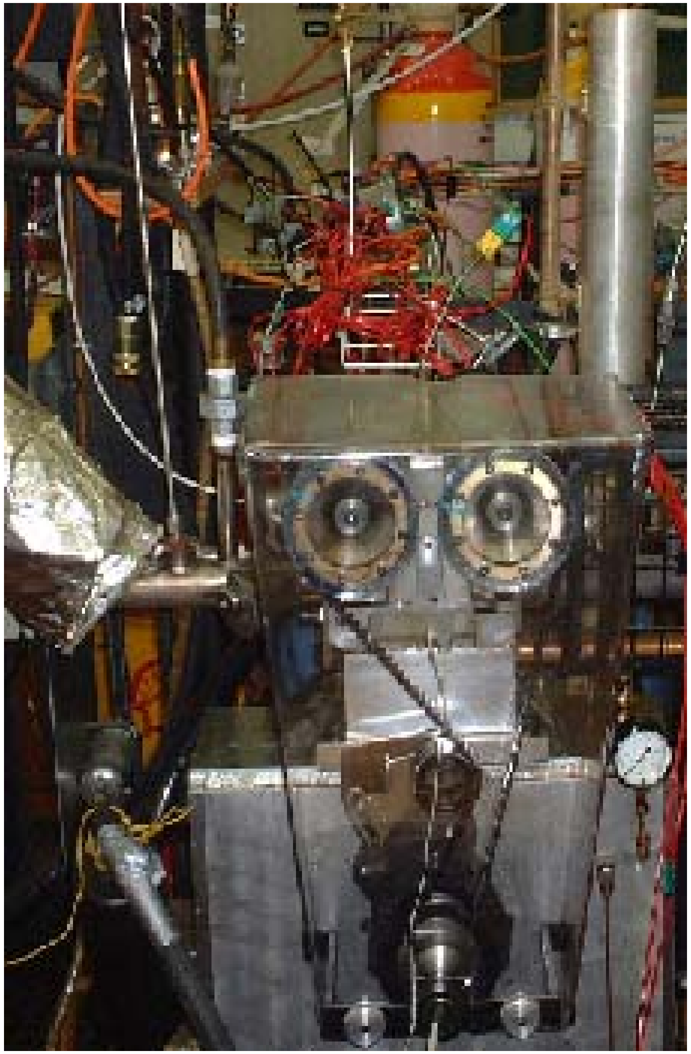






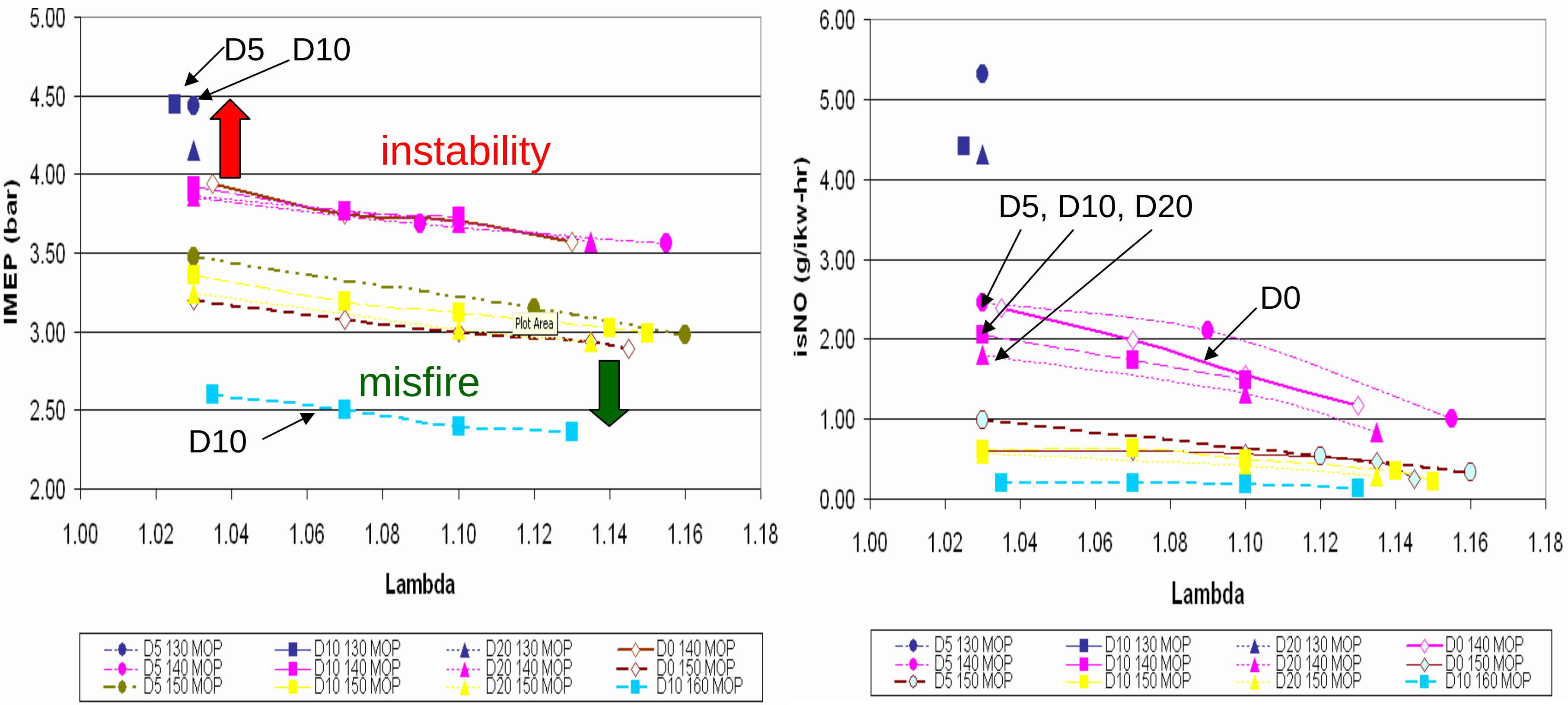
A – In-cylinder pressure profile
B – Heat release profile

Dieseline test in a port-injection engine



Engine type	Medusa single cylinder 4-V engine
Displaced Volume	447 cm^3
Bore	80 mm
Stroke	88.9 mm
Inlet Valve Diameter	50 mm
Exhaust Valve Diameter	46 mm
Valve Lift Exhaust	3 mm
Valve Lift Inlet	3 mm
Nominal compression ratio	10.4
Fuelling type	liquid port-injected injection at 3 bar (gauge)

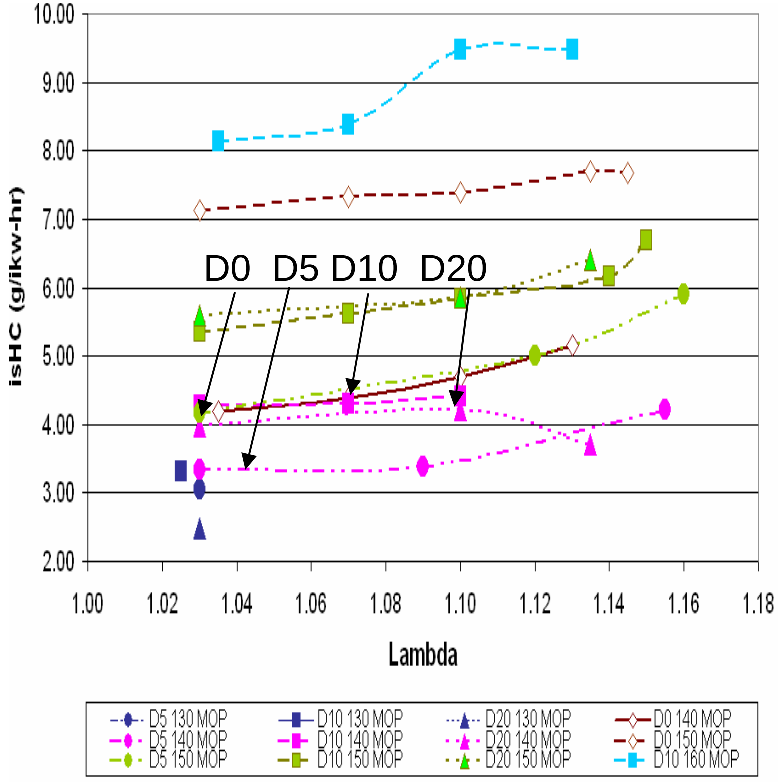
Effect of dieseline on load boundary and NO

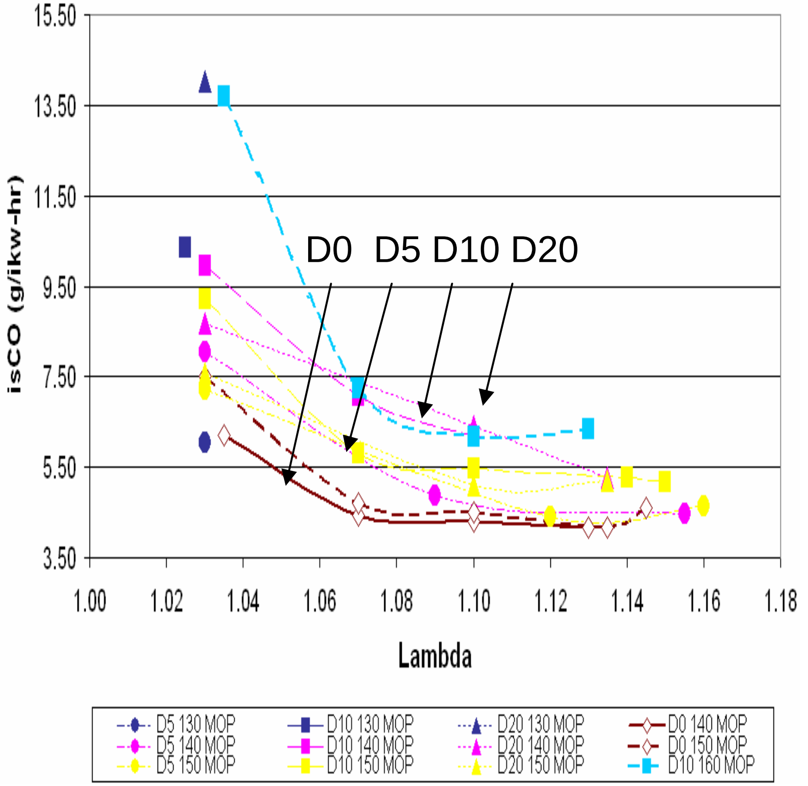


- Dieseline extends the upper and lower load boundaries
- At the same load level, NO for D10 and D20 appears lower than gasoline?

Xu et al, 2007 SAE HCCI Symposium

Effect of dieseline on HC and CO



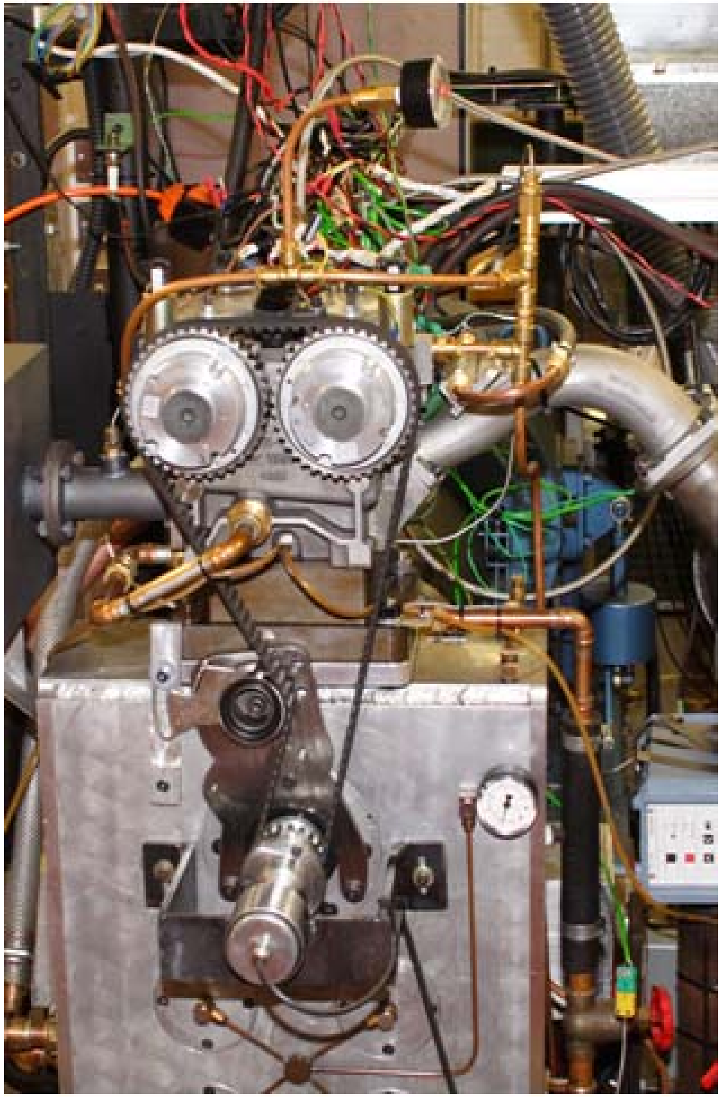


At the same load level

- HC for D10 and D20 appears lower than gasoline?
- Higher CO indicates reduced combustion efficiency with Dieseline because of poor mixing for the PFI system

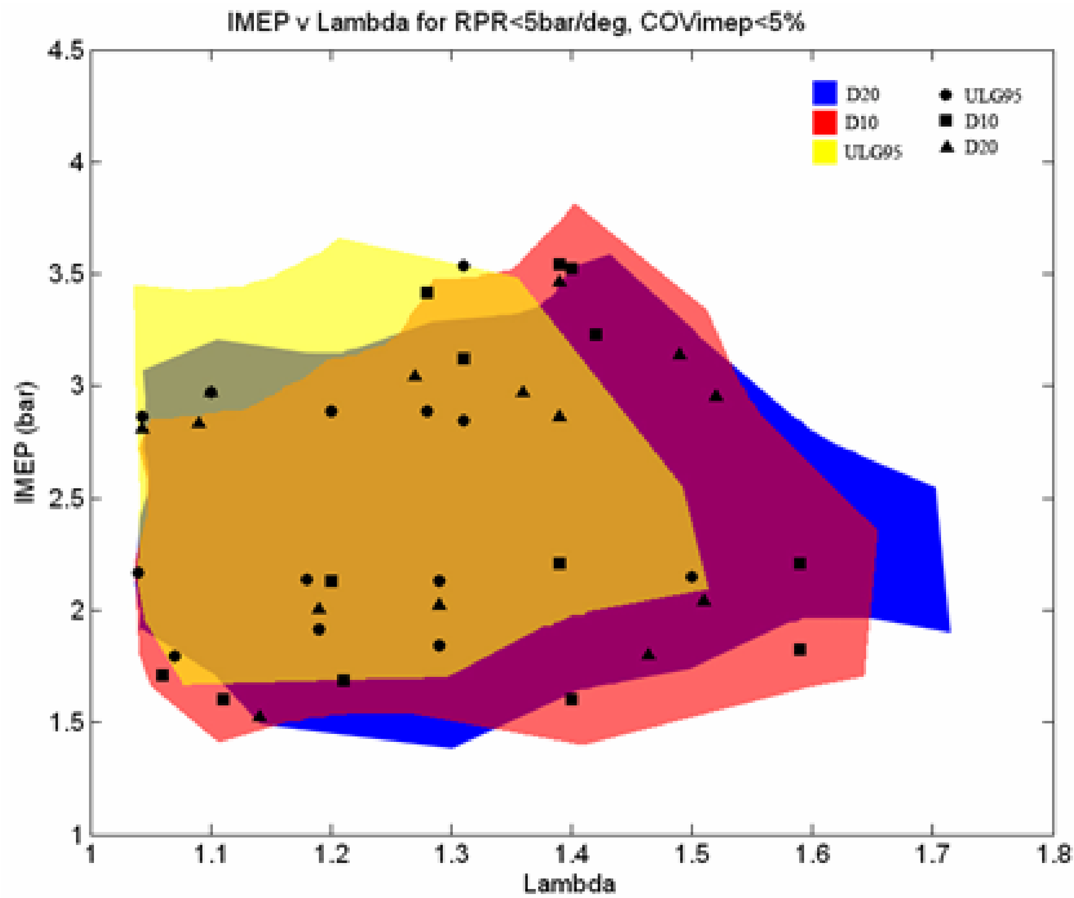
Xu et al, 2007 SAE HCCI Symposium

Dieseline test in a single-cylinder thermal engine



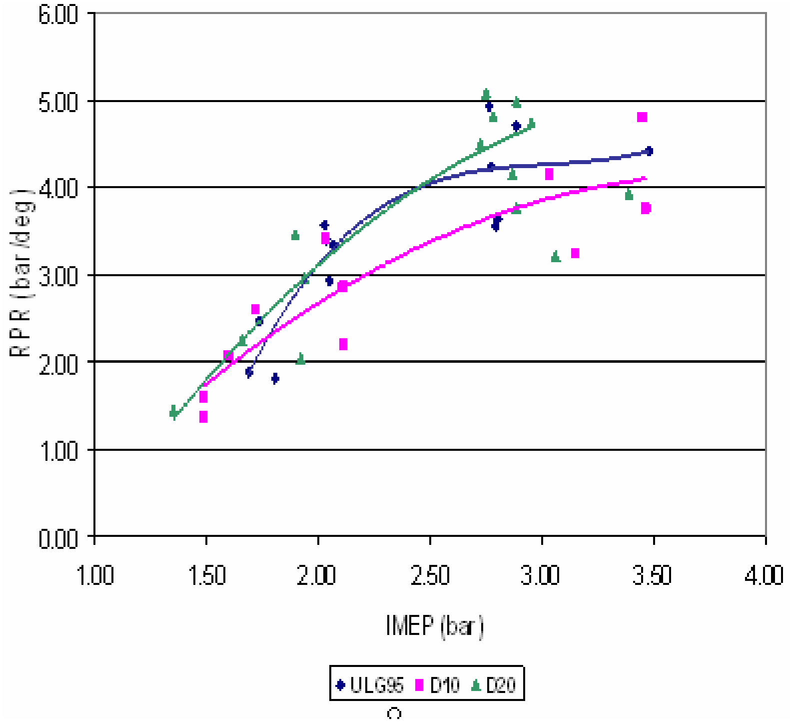
Bore x Stroke (mm)	90.0 x 88.9	
Swept. Volume (cm^3)	565.6	
Compression Ratio (Geometric)	11.5:1	
Fuel Delivery	Spray Guided Direct Injection (150bar)	
Valves	**Intake**	**Exhaust**
Lift (mm)	2.65	2.10
Duration (CAD)	130	110

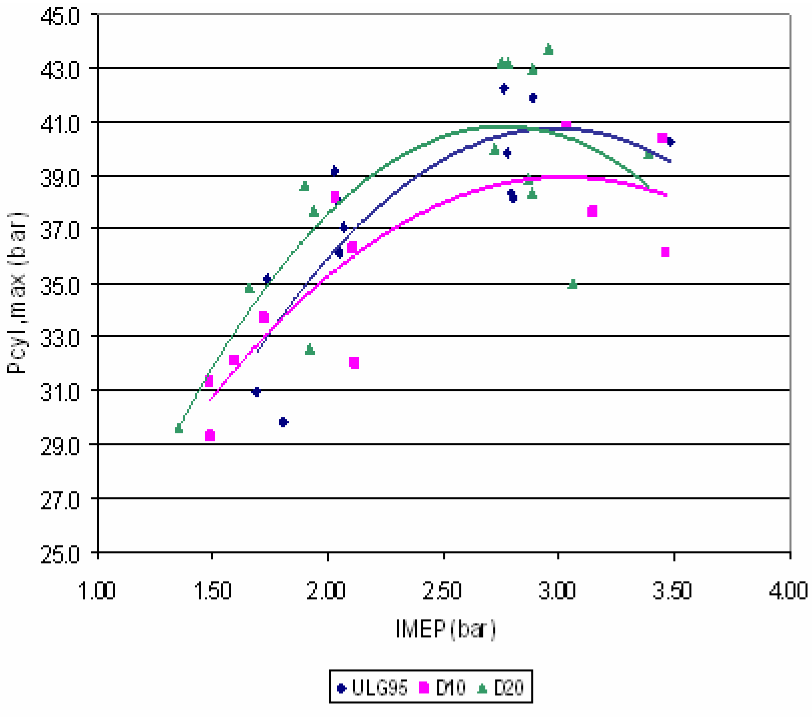
Operating boundary of Dieseline in the DI engine



- Upper boundary is limited by the pressure rise rate of 5bar/CAD
- Lower boundary is limited by 5% cyclic variability
- Dieseline allows to burn leaner mixtures
- 10% of diesel addition is sufficient to modify the auto-ignition property
- symbols represent the engine conditions for data repeatability checking

Pressure rise rate and peak pressure

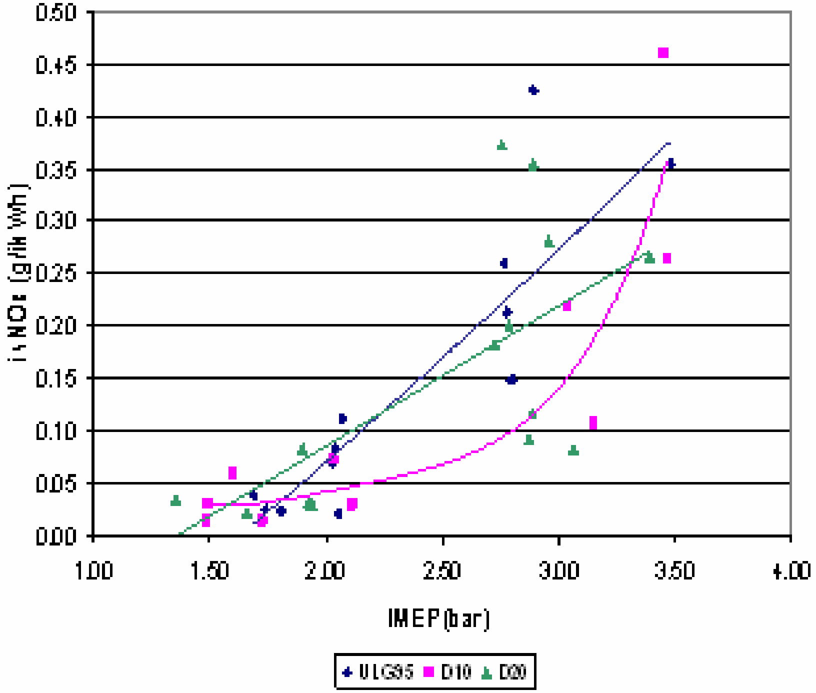


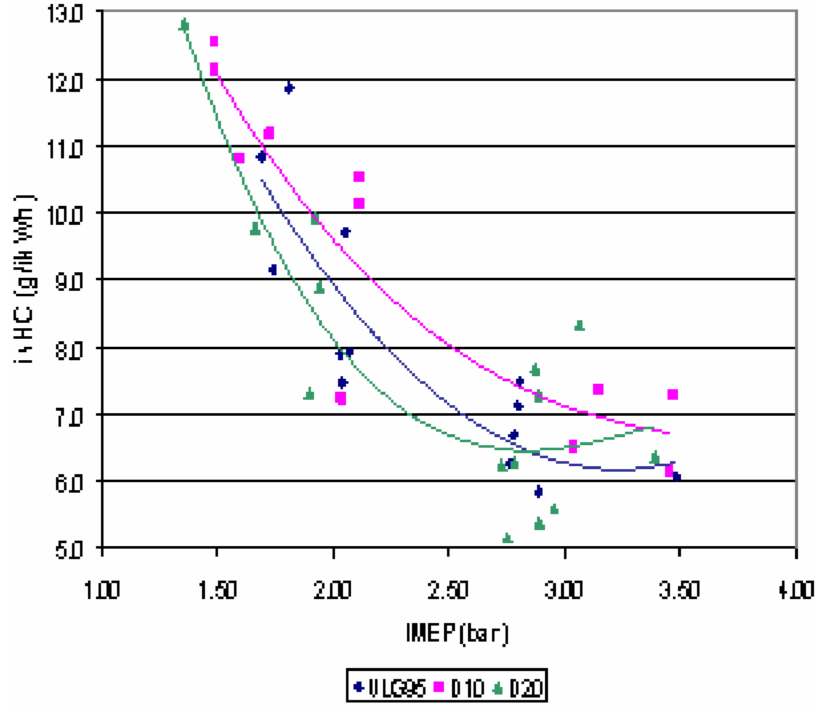


D10 reduces pressure rise rate compared with gasoline, perhaps mainly because of the leaner mixtures

Maximum pressure is reduced with D10. For the same load, diluted mixtures have retarded combustion

NOx and HC with dieseline

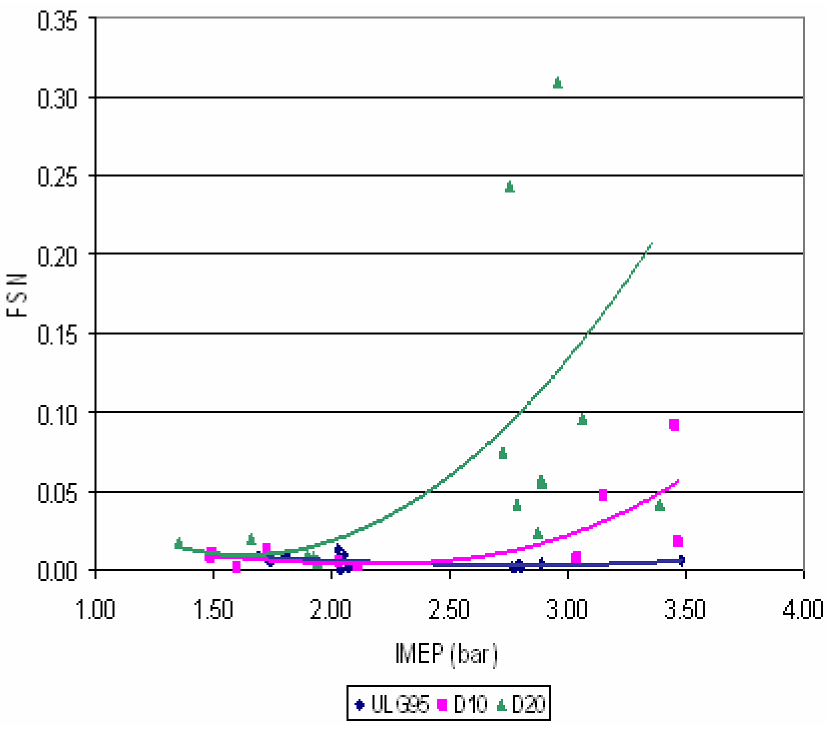


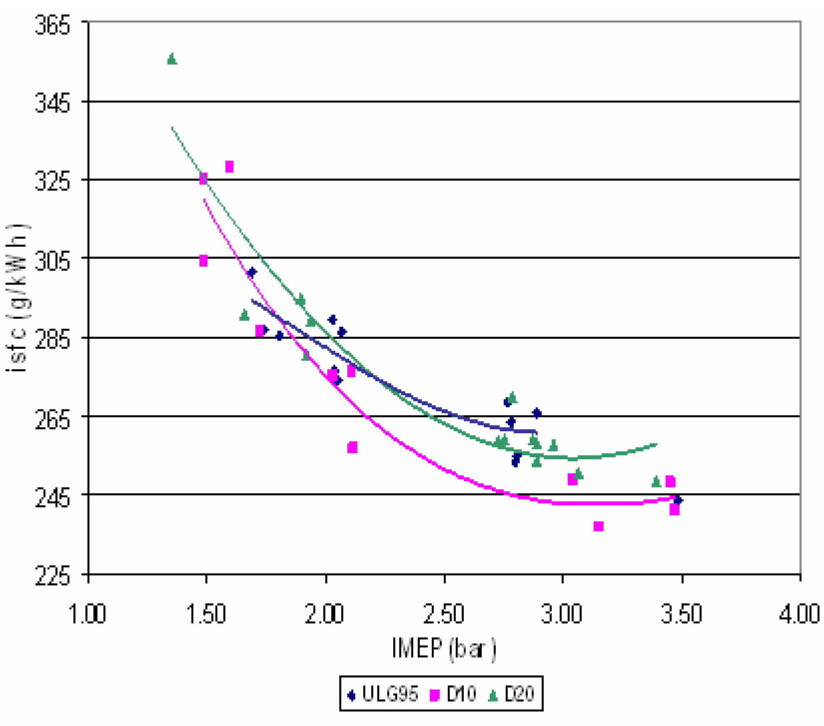


Addition of diesel allows a reduction of NOx near upper load boundary so an extension of the load limit.

There is a small increase of HC with D10, probably due to the relatively lower injection pressure of the current system and lower combustion temperature

PM and fuel consumptions with dieseline

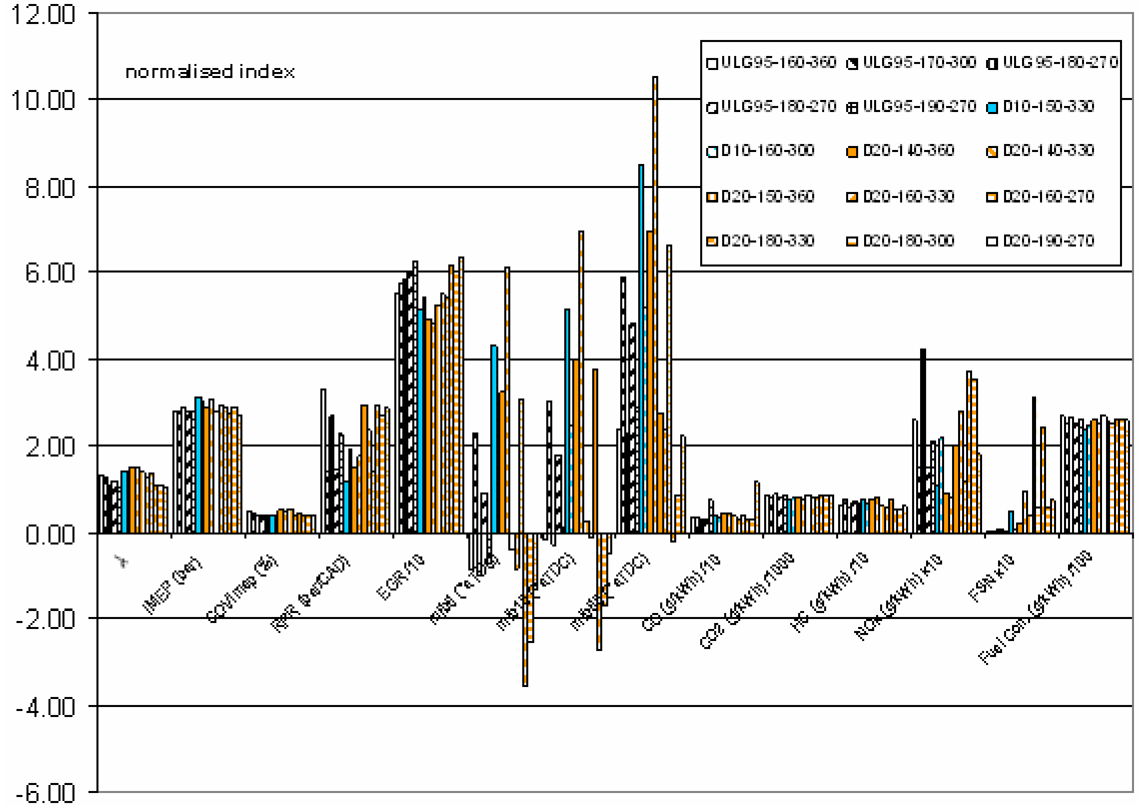




As a compromise, the diesel component increases the particulate matter although the absolute level with D10 is rather lower

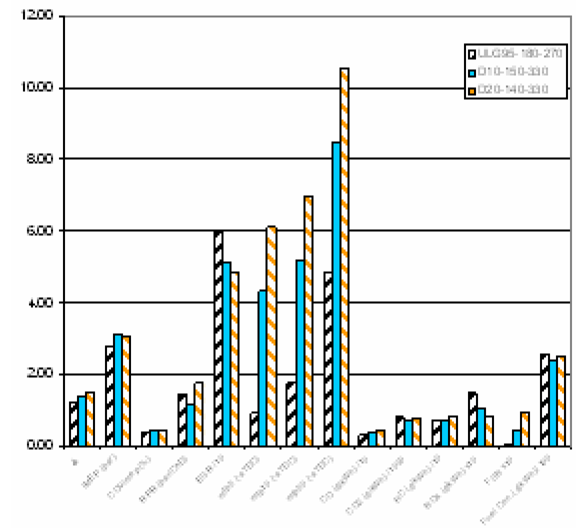
The fuel consumption with Dieseline is reduced, largely because of the lean mixtures. Further analysis indicated a lower pumping losses associated with the late injection timing for Dieseline.

Comparison of the testing cases with IMEP3.0bar

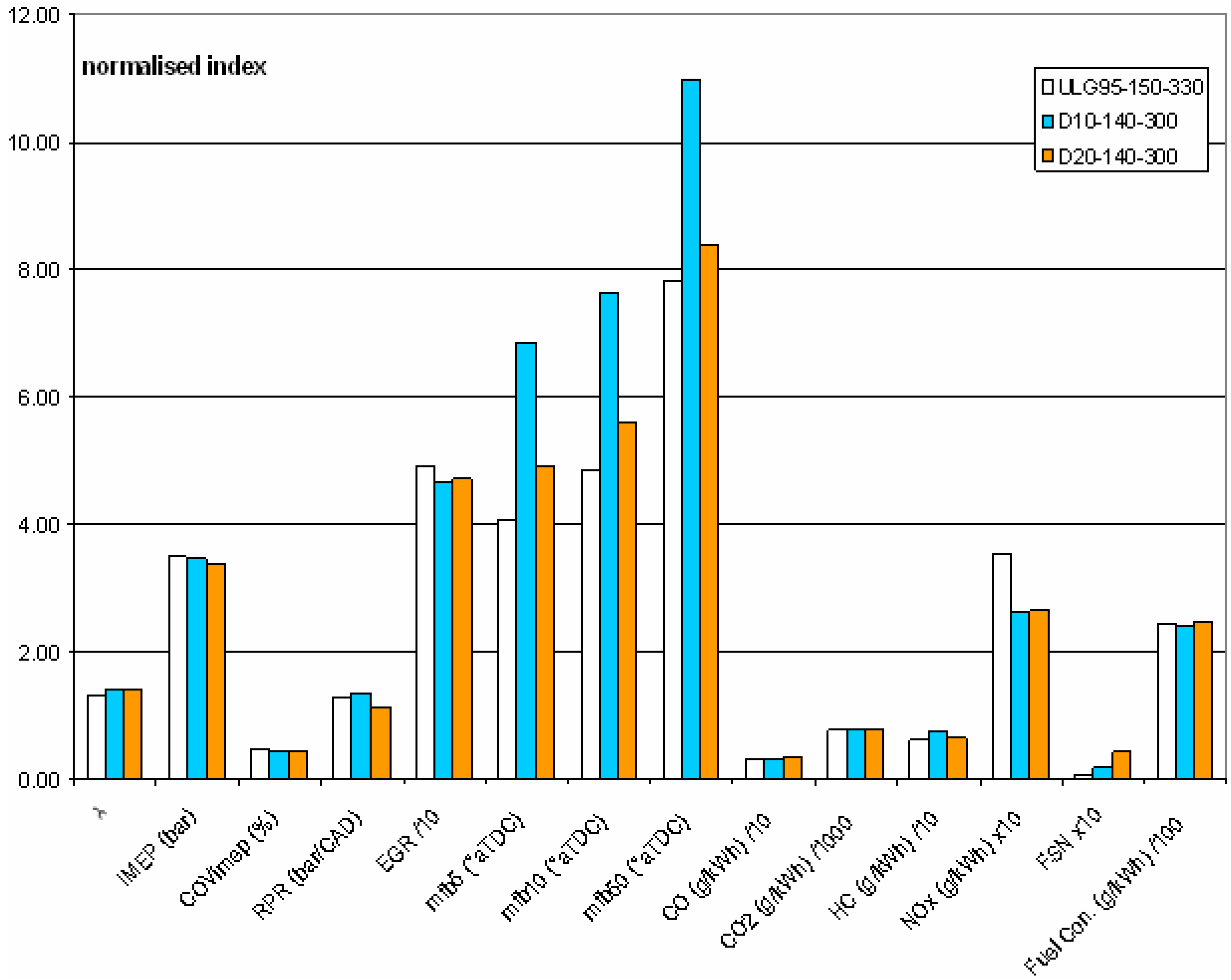


Various engine conditions were tested to characterise the combustion and identify optimum valve timing

D10 can be used with trade-off between NOx and PM emissions, while with reduced pressure rise rate



Combustion and emissions with IMEP 3.45 bar



- For the same load, the valve and injection timings are optimised to that the combustion is later to reduce the pressure rise rate to the gasoline level.

- The valve overlap is 10CAD smaller with EGR 3% lower
- Approximately.

- The injection timing is 30 CAD later.

- NOx level is 25% lower

Summary and Conclusions

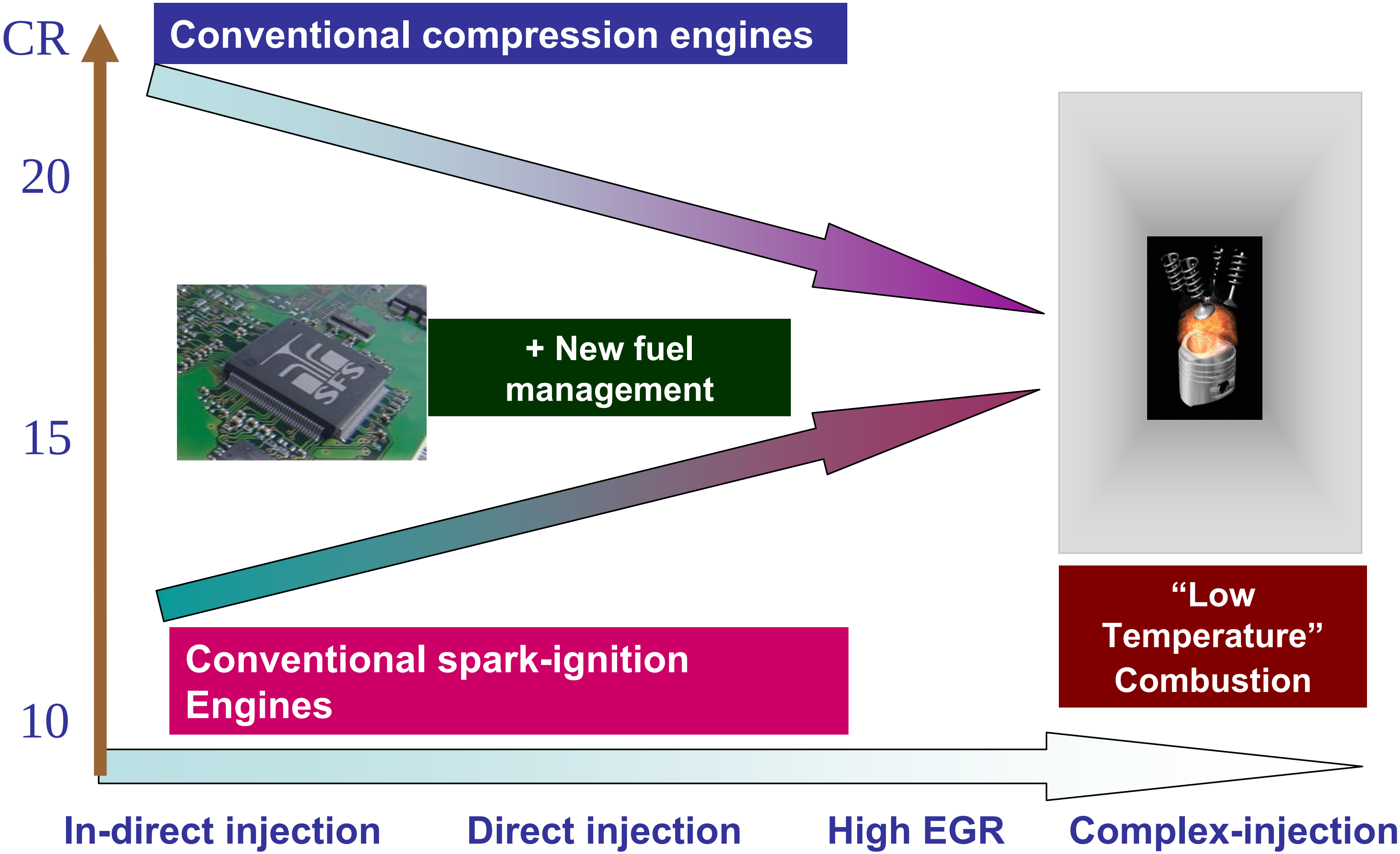
1. Since there is no single fuel which can meet the requirement of future fuels for HCCI engines, a mixture of gasoline and diesel fuels (Dieseline) is probably one of the solutions.

2. With a gasoline direct injection engine configuration, it is demonstrated that 10% diesel addition is more than enough to modify the auto-ignition property of gasoline.

3. Dieseline combustion allows the burn of leaner mixtures with higher dilutions near the upper and lower load boundaries, corresponding to retarded combustion, lower NOx and pressure rise rate, and thus an extension of the window size.

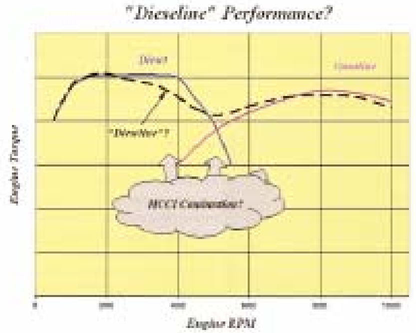
4. The benefits will be depending on the baseline engine configuration and the modification adopted.

Gasoline and Diesel Engine Technologies are emerging



Multi-fuel (jet printer type) injection system – the future of new engines?

BELOW A summary of the potential torque curve resulting from the dieseline fuel concept in operation. The centre portion of the curve will need to be optimised to minimise the torque dip effect but give excellent torque 'back-up'



However, introducing quantities of two fundamentally different fuels (a diesel-type fuel and a gasoline-type fuel), some level of control may be achieved. By varying the fuel blend, the rate of heat release and peak pressures can be altered. This should make it possible to achieve even greater fuel-air ratios and therefore improve part-load performance, even possibly up to full-load.

Xu may be sitting in an 'Ivory Tower' of academia but he still has a strong grasp of the automotive world around him and is a great believer in the reciprocating internal combustion engine. "Not withstanding environmental issues, people will always want speed, performance and comfort from their cars," he says. "The internal combustion engine will therefore be around for a long time to come. And with performance and reliability honed to nigh-on perfection, there is little on the horizon that I can see that will be able to challenge it for many years to come. Even if you have concerns about size and weight, this form of motive power still has a high power density and that will always be viewed as an advantage in any form of competition.

"So how do we produce the most powerful engine for minimum size and weight?" he asks. Sounding less like an academic and more an enthusiast, he expounds his ideas. "At reduced weight and cost, nothing can beat the gasoline engine for power density at the high end of our speed range. That's why I don't see gasoline-type – I say 'type' fuels – being totally replaced.

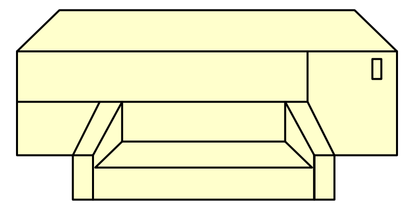
"High torque at the lower end of the spark ignition engine speed range is characterized by combustion 'knock' or detonation unless we use very low compression ratios (and we don't want that). At lower speeds the diesel has the advantage with higher torques, which can, of course, be boosted to give even more power using some form of super/turbocharger. As an added benefit, this also produces excellent fuel economy."

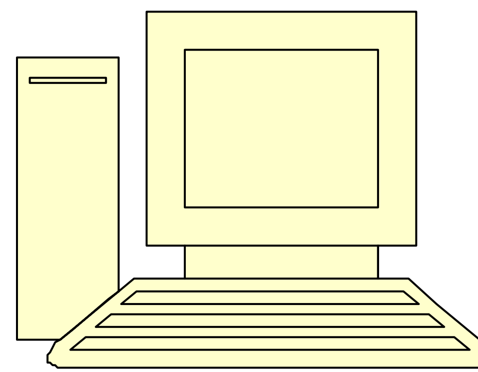
Thus at one end of the performance 'envelope' – at low and medium engine speeds – we have the requirement for a diesel-type fuel, while for higher speeds a gasoline-type fuel would seem to be more appropriate. In the centre and at part throttle (and let's not forget that race engines do run a part throttle for much of the time) we have a bit of a grey area and that's the zone where HCCI combustion will come into play.

On the hardware side, Xu confirms my observations. "Apart from the differences in strength of some of the internal components, the differences between modern diesels and gasoline engine configurations are now becoming smaller and smaller and this trend, I believe, will continue. They will all use moderately high ▸

"Part throttle is a grey area where HCCI combustion will come into play"

BELOW An HCCI V8 engine under test at the University of Birmingham

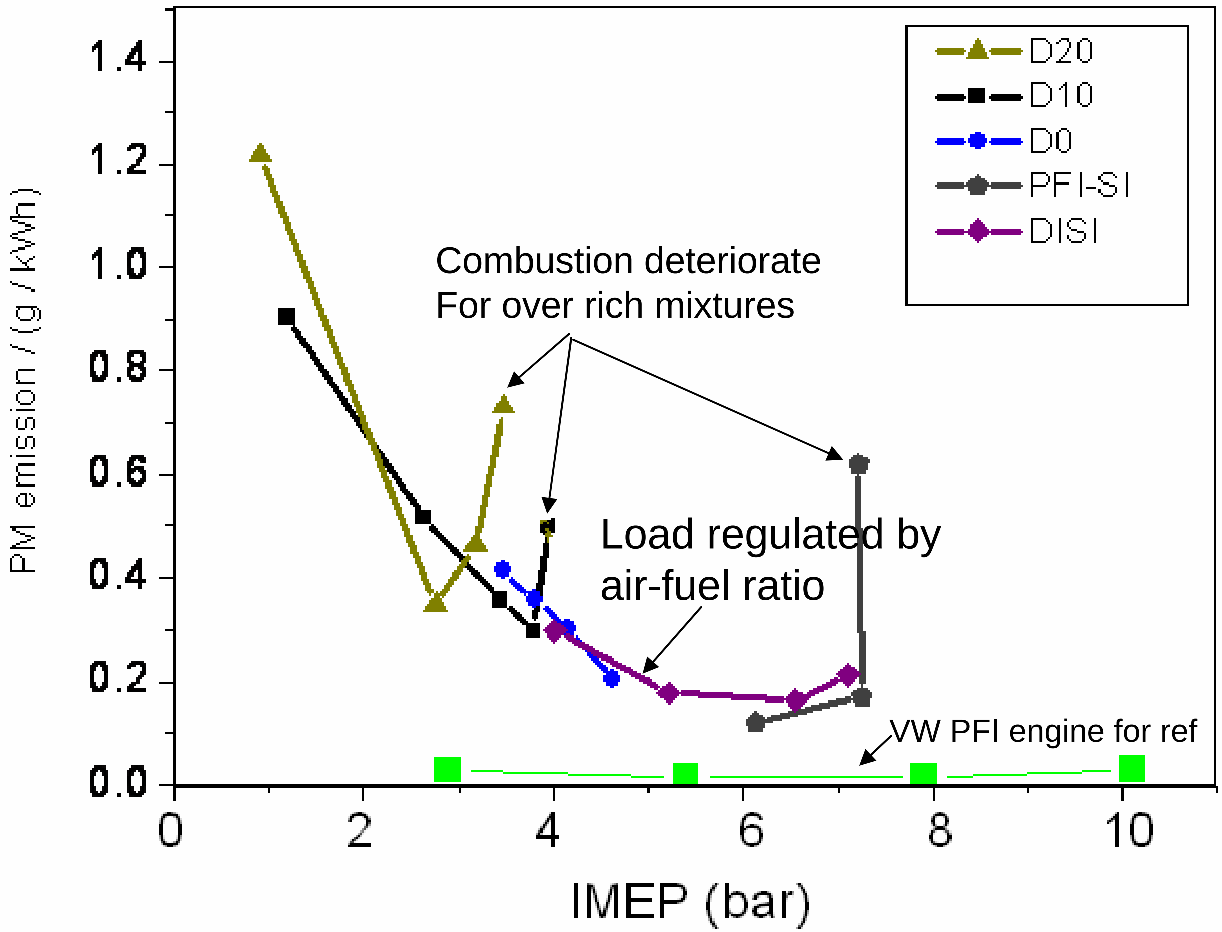




The convergence of diesel and gasoline technologies raises the possibility of combining the best of both in the one engine. **John Coxon** meets an eminent researcher working on a new fuel system that could turn the dream into reality

Questions?

Backup slide - Specific PM levels versus load



Xu et al, 2007 SAE HCCI Symposium