PM Emissions Measurements from a Negative valve Overlap DI-Gasoline HCCI Engine and Comparison with SI Operation

Philip Price, University of Oxford

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Oxford University IC Engines Group

- Philip Price
- Dr Richard Stone

Birmingham University

- Jacek Misztal
- Dr Hongming Xu
- Professor Mirek Wyszynski

Jaguar Cars Ltd.

- Dr Trevor Wilson
- Dr Jun Qiao

Engineering and Physical Sciences Research Council

EPSRC

Outline

- Background and Motivation for Studying PM Emissions from a HCCI Engine
- Experimental Facilities and Setup
- Measurements:
  - *IMEP*, $T_{exhaust}$, *ISFC*, *ISNO* and *ISHC* as a function of valve timing
  - PM Number, Estimated PM mass and size distributions at representative operating points.
  - PM and gaseous emissions measurements
  - Some comparison of HCCI PM emissions with those from SI operation
- Summary and Conclusions

Background

- HCCI: Auto-ignition of a homogeneous mixture through compression
- In HCCI mode, the inducted air is not throttled, so thermal efficiencies are similar to diesel engines. In some cases a 20 % improvement in fuel economy has been demonstrated.
- Fuel and Air are pre-mixed, so there are less soot emissions than from diesel.
- Combustion temperatures are low, so there is not much production of thermal NO. For the same reason, emissions of CO and HC are higher than from conventional combustion
- Load controlled by varying the residual gas fraction in the cylinder

History

- To date, PM Emissions from HCCI have largely been overlooked and/or assumed to be negligible
- Kaiser *et. al.*[1] measured PM emissions from a gasoline HCCI engine and concluded that they were non-negligible and that number concentrations were similar to those from DI gasoline engines

[1] Kaiser, Yang, Culp, Xu, Maricq. *Int J Engine Research Vol* ***3*** *No 4*

Why will there be PM emissions from HCCI?

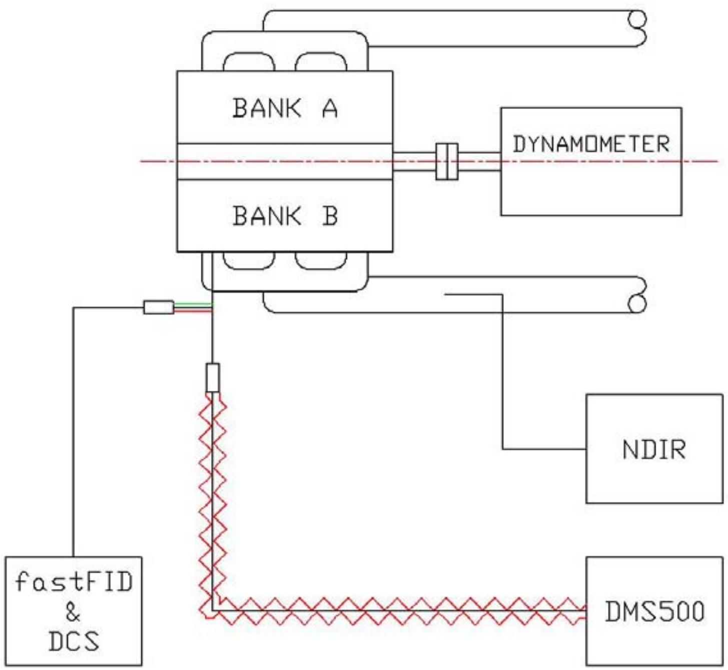
i) Direct fuel injection is likely to be used for its charge cooling effect. With DI, wall wetting is a known problem. With wall wetting comes diffusion burning and pyrolysis of fuel into soot precursors

ii) PLIF measurements have shown that even in 'homogeneous' charge engines, the local air-fuel ratio can vary significantly. Locally rich zones are a known contributor to PM formation. This is particularly true in DI gasoline engines when there is reduced time available for mixture preparation

iii) The increased fraction of inert species in the charge and the lower combustion temperatures mean firstly that the HC oxidation rate is reduced, and secondly that the temperature in the expansion stroke is not high enough to oxidise much of the HCs coming out of the crevice volumes

iv) A corollary of the above is that the volatile PM fraction derived from UHCs will be higher than normal

v) There will always be a contribution from the lubricating oil and sulphur in the fuel



Engine	Normally Aspirated V6 with Cam Profile Switching & Phasing System
Bore x Stroke	89 x 79.5 mm
Compression Ratio	11.2 : 1
Fuel	Reference ULG

Instrument	Measurand
Cambustion DMS500	Particle number concentration & electrical mobility diameter
Cambustion fastFID	UHC
Non-Dispersive Infra-Red	NO, CO, CO_2

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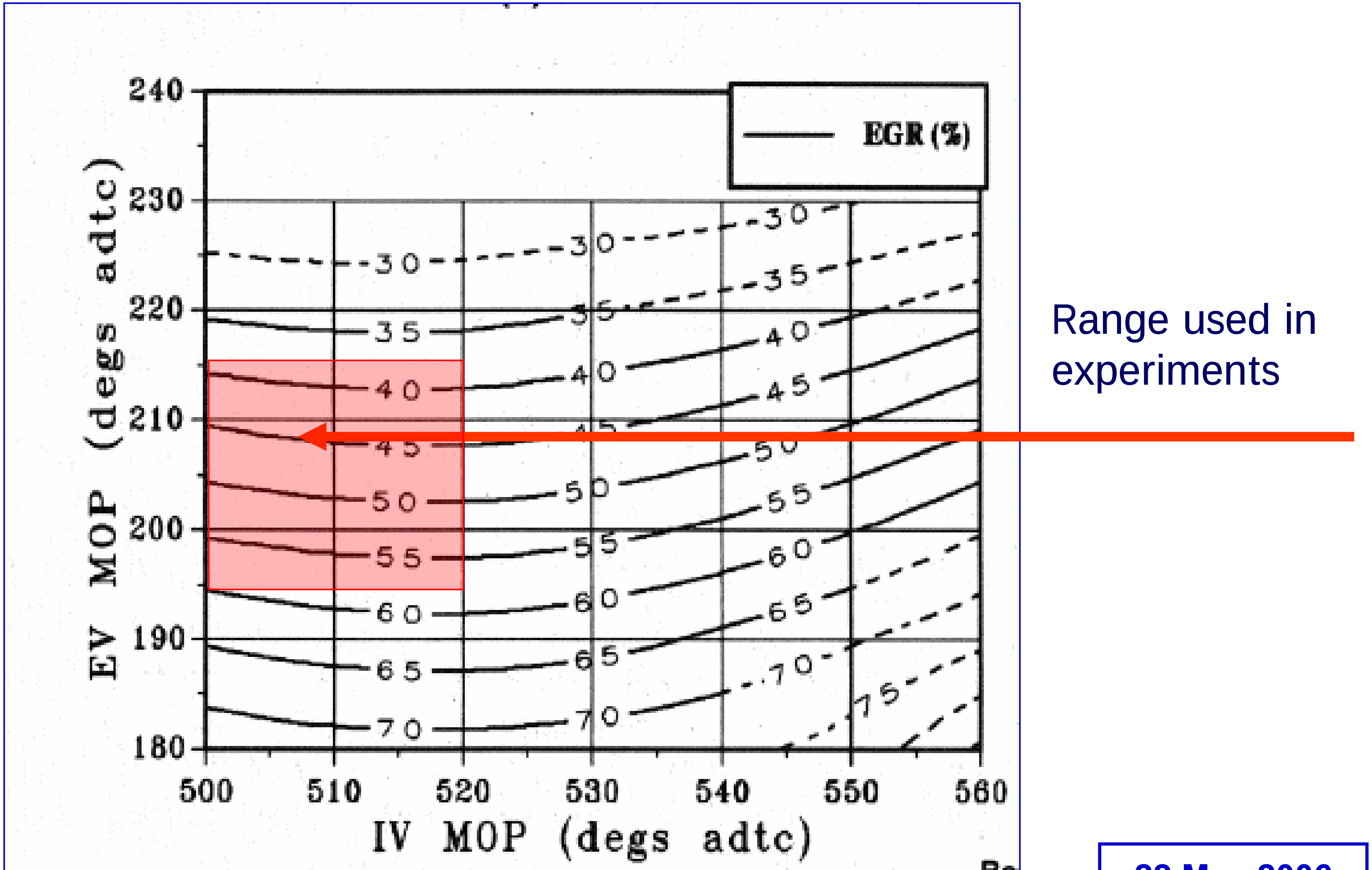
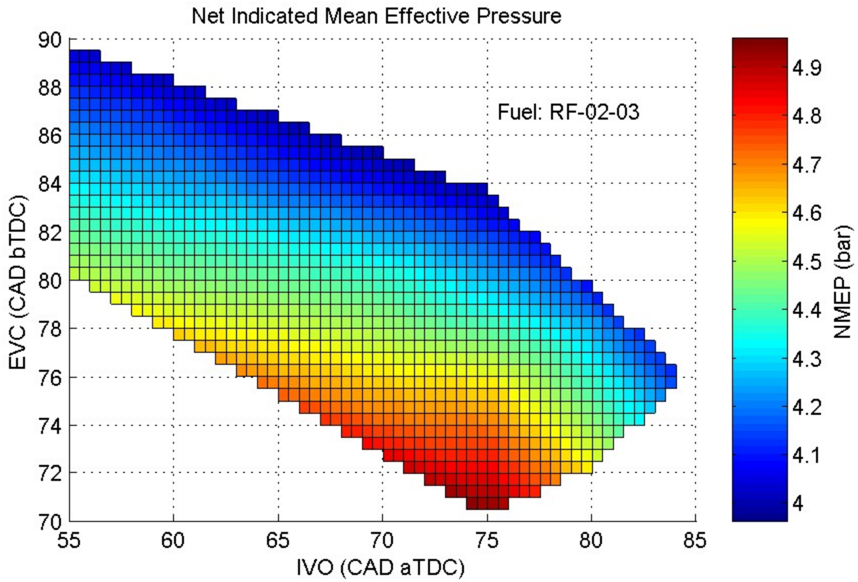
Wave Modeled residual gas fraction as a function of valve timing

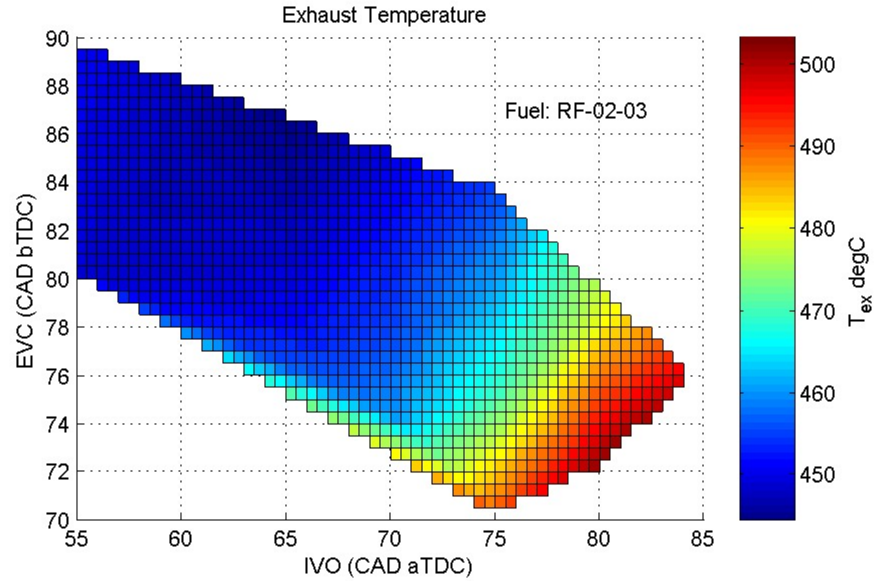


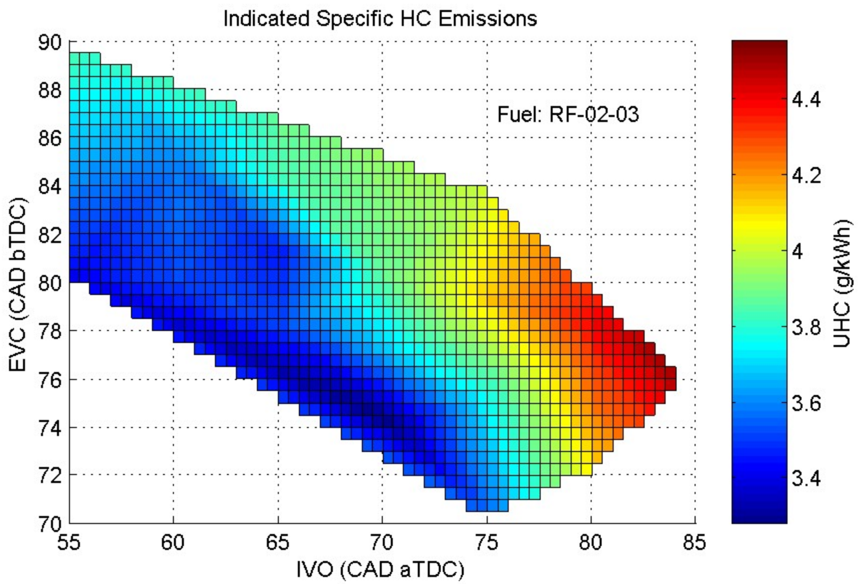
Range used in experiments

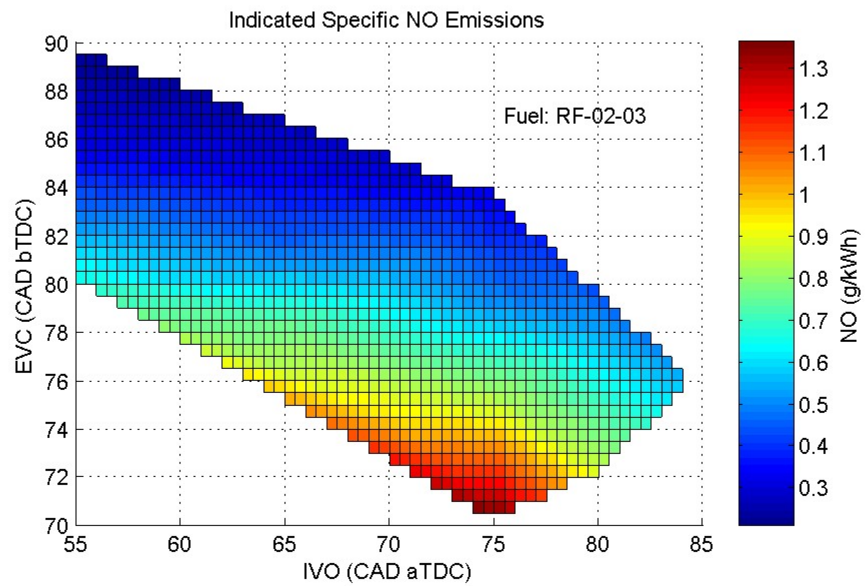
Source: Xu, H *et. al.* JSAE 20030333.

1500 rpm, λ=1.0, Reference ULG, EOI = 60 CAD aTDC

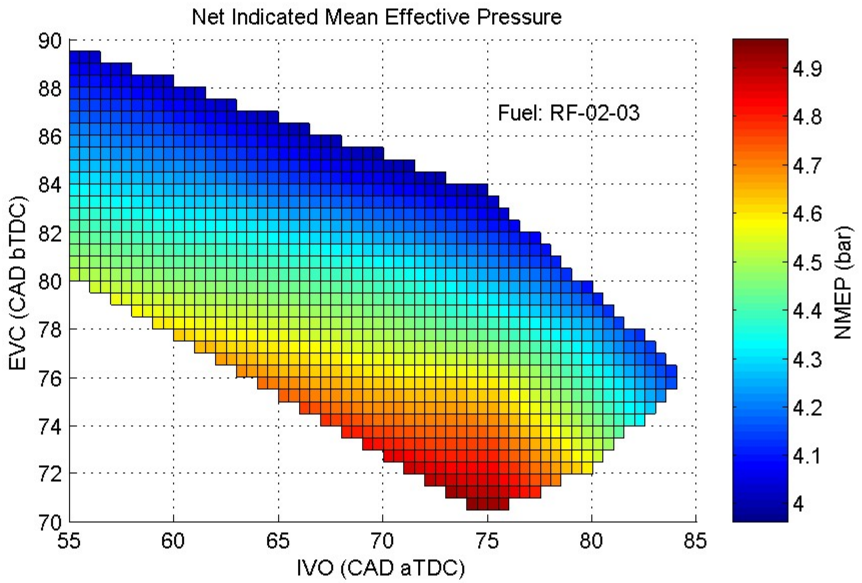


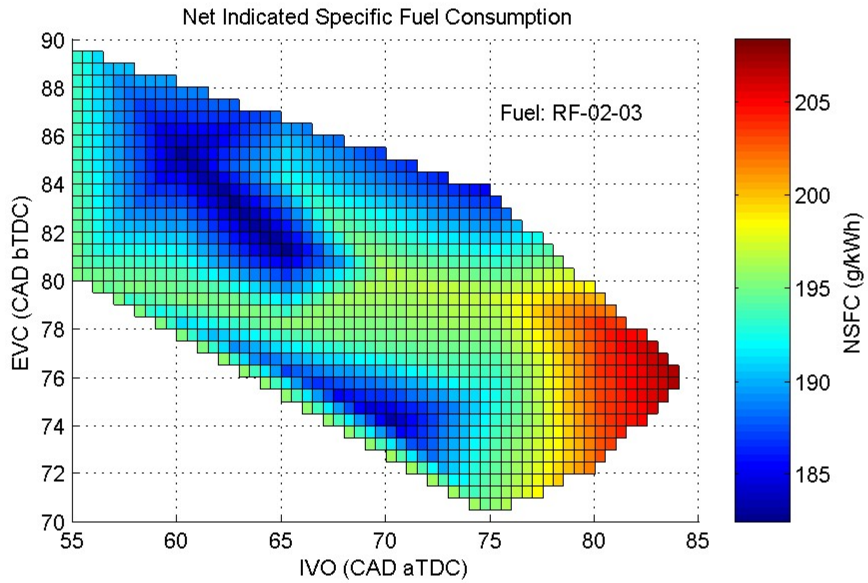






1500 rpm, λ=1.0, Reference ULG, EOI = 60 CAD aTDC



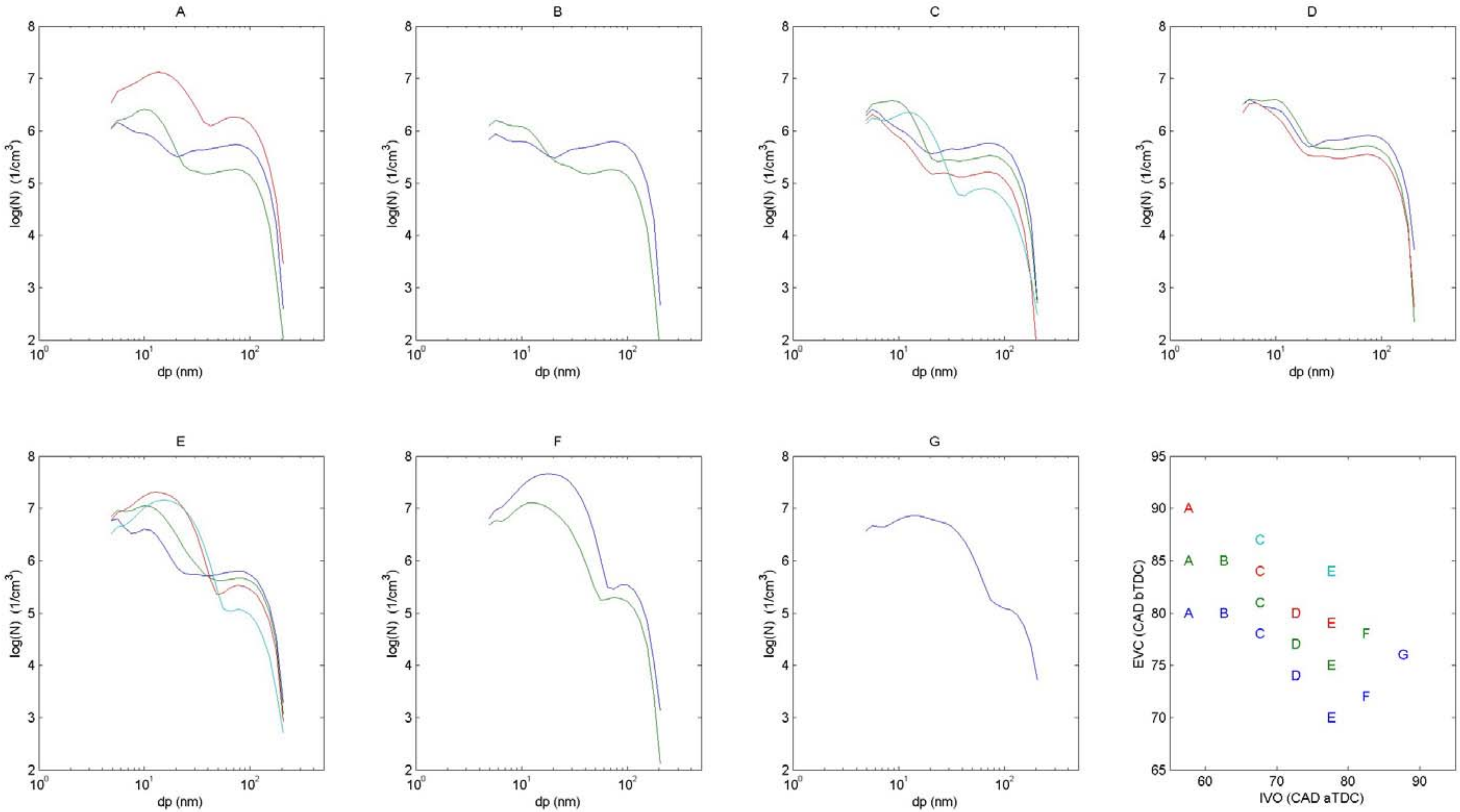


IMEP is nearly a sole linear function of the trapped residual gas quantity.

High *NSFC* for late IVO because the <u>effective</u> compression ratio (and thus ideal cycle efficiency) is reduced.

PM size distributions - HCCI

1500 rpm, λ=1.0, Reference ULG, EOI = 60 CAD aTDC



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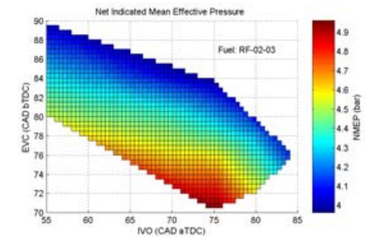
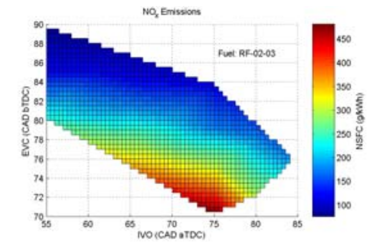
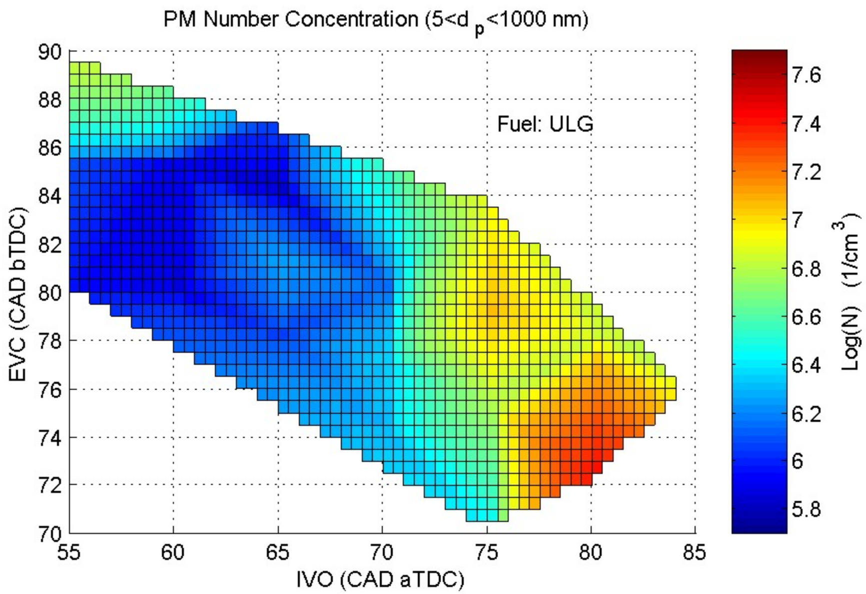
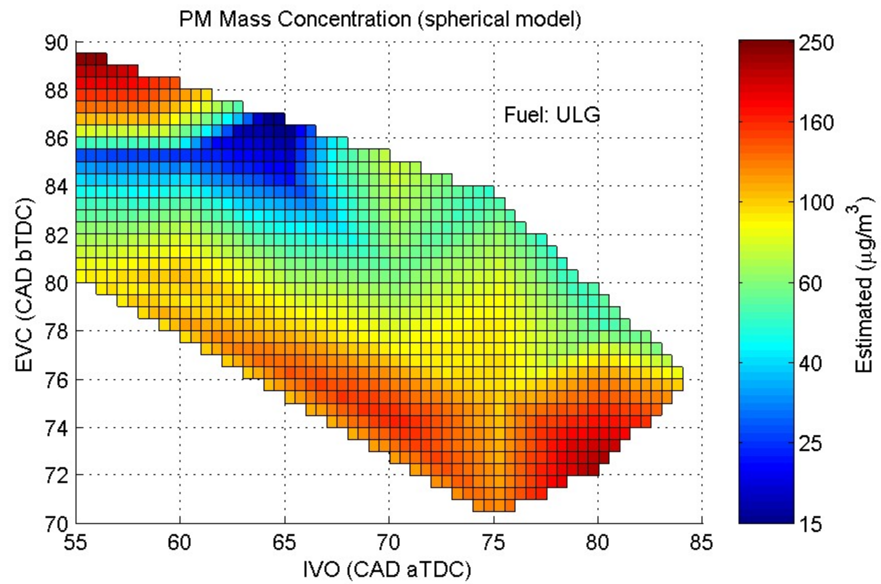
Integrated PM Number and Mass (NMEP & NO inset)





1500 rpm, λ=1.0, Ref ULG
EOI = 60 CAD aTDC





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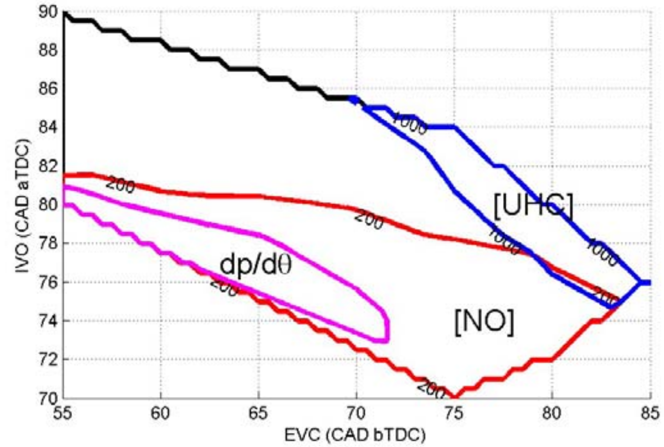
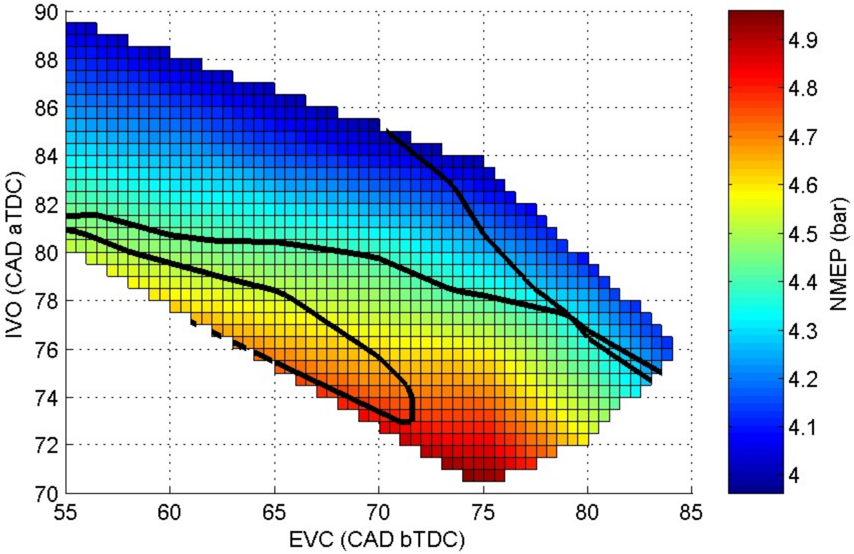
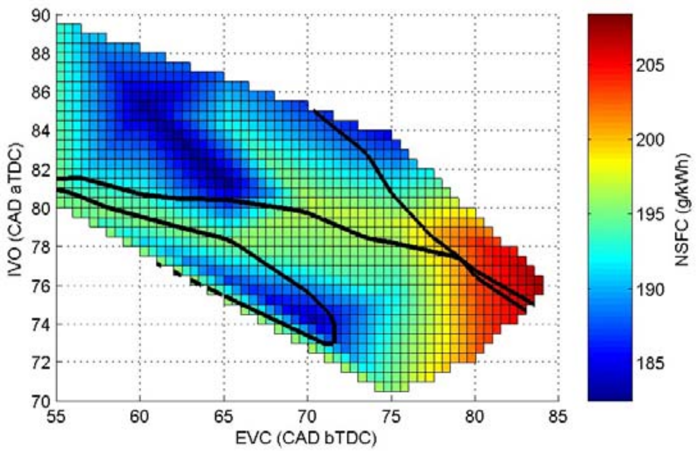
Comparison with conventional Spark Ignition

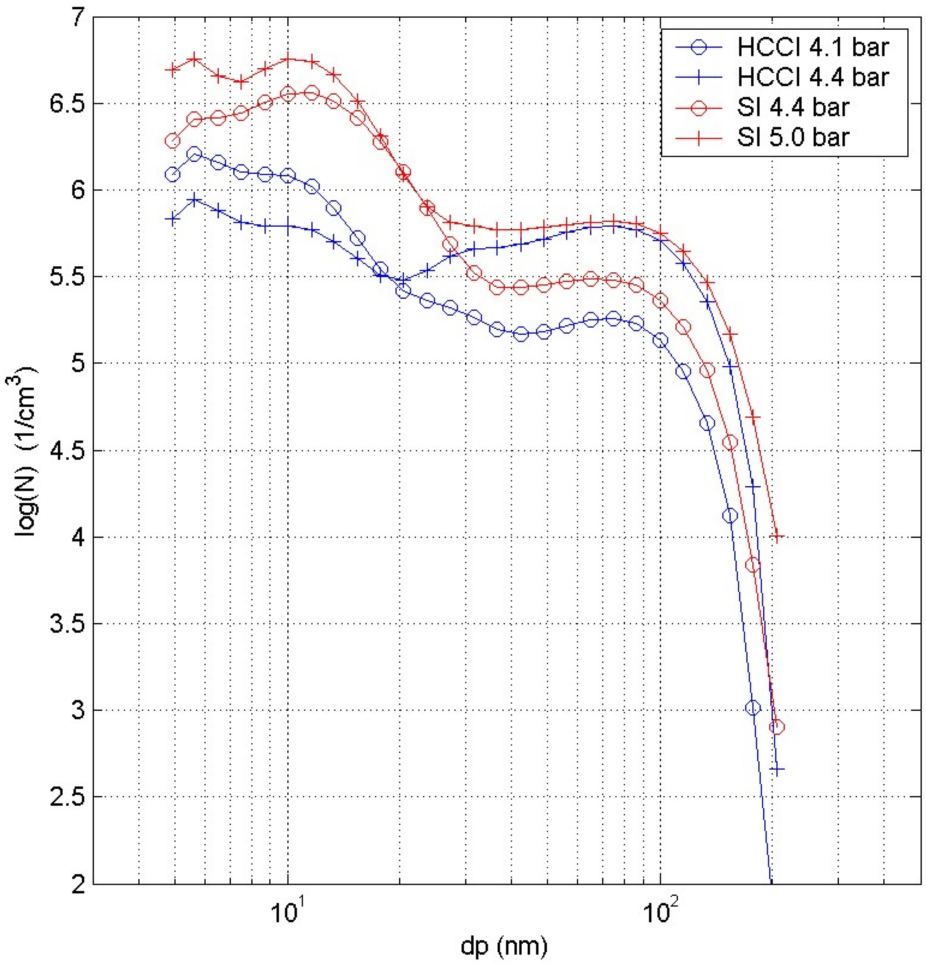
It is possible to get many different emissions data-sets for the same load with HCCI





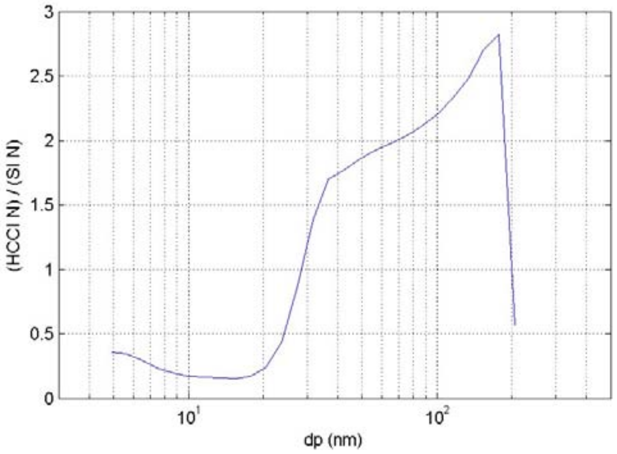


PM size distributions – HCCI and SI



At the same load (4.4 bar), the # concentration of the acc' mode from HCCI is a factor of ~3* > than from SI

However, the # concentration of the nuclei mode is ~4 times lower



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Summary

- PM Number and size measured with Cambustion DMS500. HCs were measured with a fastFID and NO was measured with NDIR from a NVO DI Gasoline Engine

Conclusions – Gaseous Emissions

- In HCCI mode, NO_x emissions were reduced by a factor of 5 compared to SI. (Exhaust temperature was 25 % lower (140 K)

- In HCCI mode, HC emissions were 10 to 20 % higher than SI, rising to 50% at low load HCCI when the residual gas fraction was highest

Conclusions - Particulates

- Comparison with SI requires caution because of there are several combinations of valve timing that can give the same operating point, each with different emissions
- PM emissions have been measured and were non-negligible
- Compared to SI at the same operating point, PM Number concentrations were found to be higher in the accumulation mode by about a factor of 3, but the nuclei mode number concentrations were lower.
- These levels put HCCI somewhere between first and second generation early injection DISI. This is still one or two orders of magnitude lower than diesel
- With HCCI, the accumulation mode PM concentration varies inversely with the amount of residual gas. Since NO emissions vary proportionally to residuals, this leads to the opposite of the well known PM-NO_x trade off in diesel engines

Thank you for listening

Philip.Price@eng.ox.ac.uk

01865 283 467