UNIVERSITY OF BIRMINGHAM

HCCI – How clean can it be?

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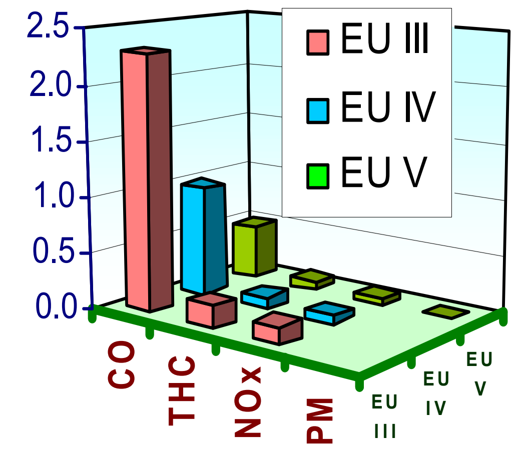
Homogeneous Charge Compression Ignition (HCCI) Symposium

Lund, Sweden, September 12-14, 2007

Presentation outline

- **Background and objectives**
- **PM with Gasoline HCCI**
  - Varied valve timing
  - Varied injection timing
  - Comparison with SI combustion
- **PM with Dieseline HCCI**
  - Combustion characteristics
  - PM mass fraction
- **Summary and conclusions**

New PM regulations are coming



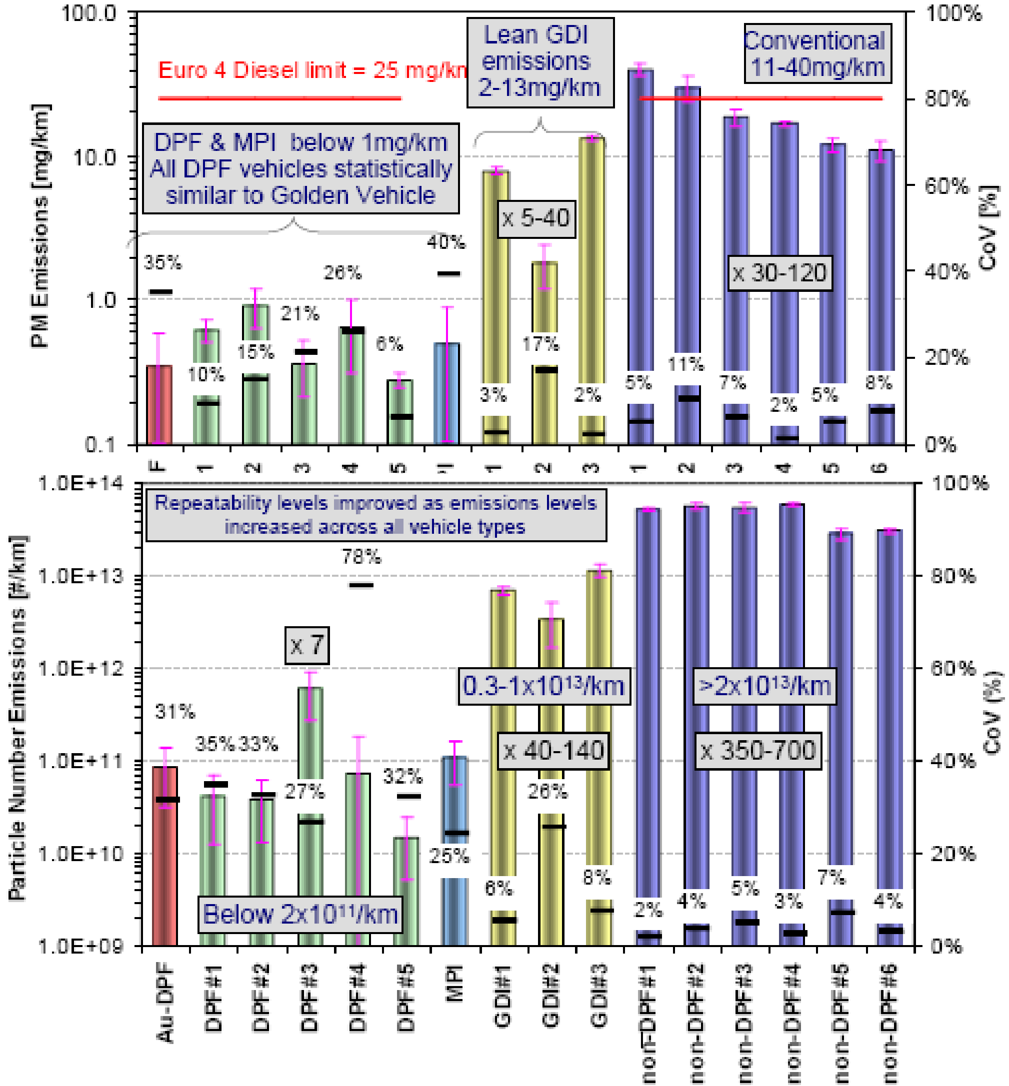
- Publication of final Light Duty Validation report is imminent
- Consideration of proposal to introduce PMP procedures in UN-ECE Regulation 83 for Light Duty Vehicles
  - GRPE 7th & 8th June 2007
  - WP29 November 2007 (proposed)
- Adoption of Particle Number limits in EU mid-Euro 5 & Euro 6 Regulations
  - Draft implementing measures currently including limit for diesels from 1 September 2009 of 5×10^{11} particles/km (>20nm)
  - European Parliament & Council agreement requires particle number limits as soon as possible and at the latest upon entry into force of the Euro 6 stage
- Proposed inclusion of PMP procedures in UN-ECE Regulation 49 for Heavy Duty Vehicles

Source: Chris Parkin, UK Transport Department

UN-ECE GRPE PMP - Typical states

Mass
mg/km

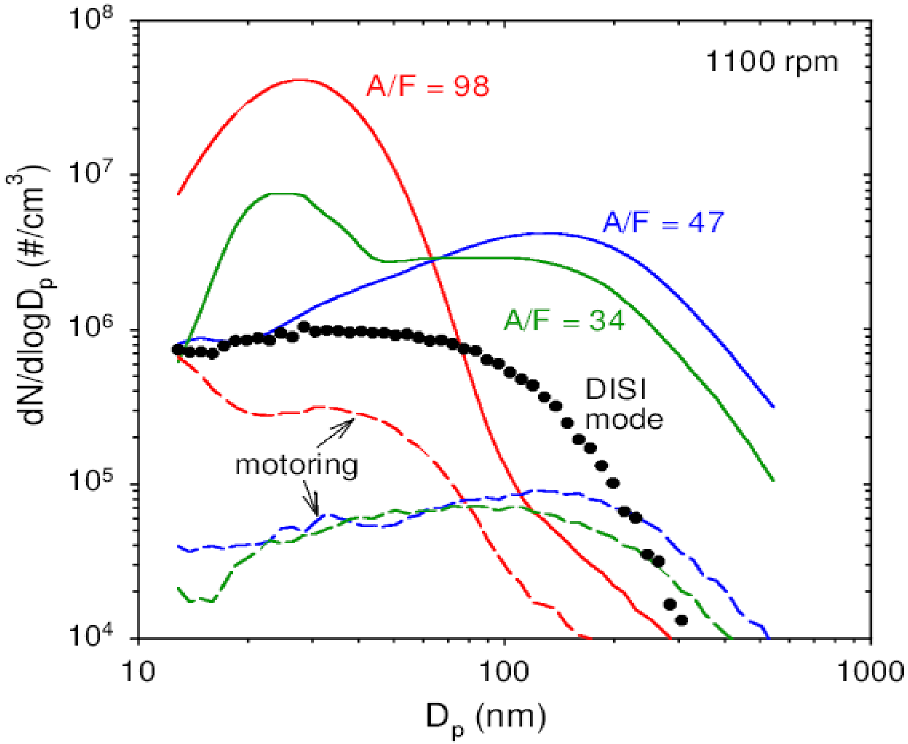
Number
#/km



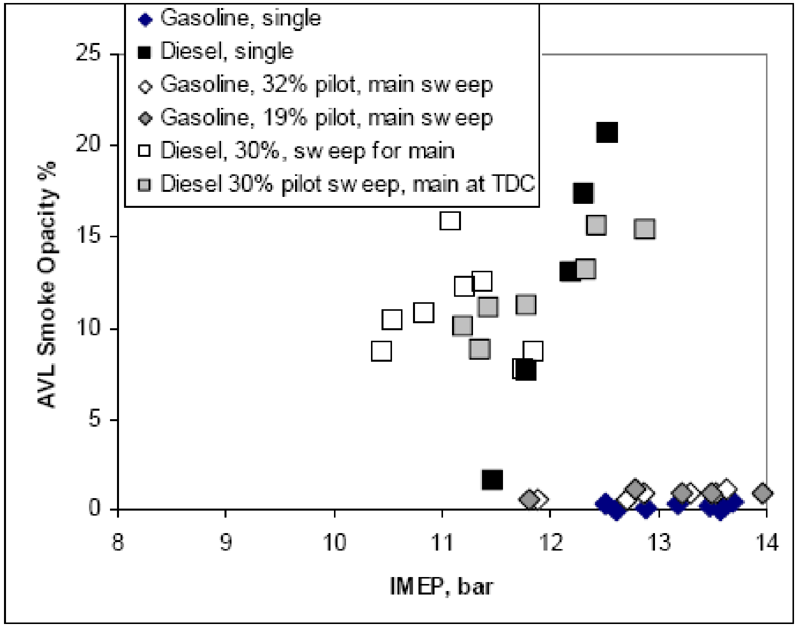
Source: Chris Parkin, UK Transport Department

How much PM is HCCI producing?

HCCI is becoming a generic name for the next generation of combustion system promoting premixed charge compression ignition



Kaiser et al, 2002



Kalghatgi et al, 2007

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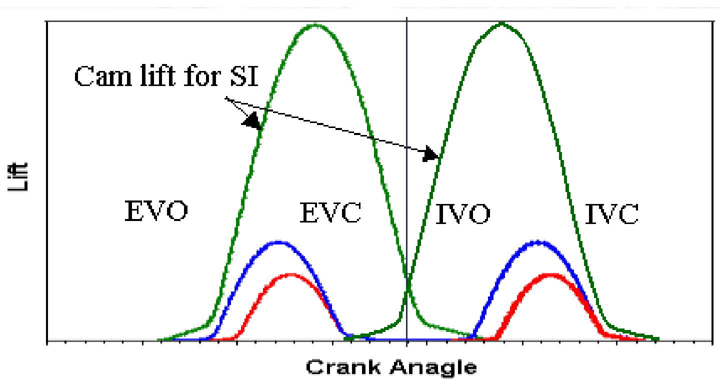
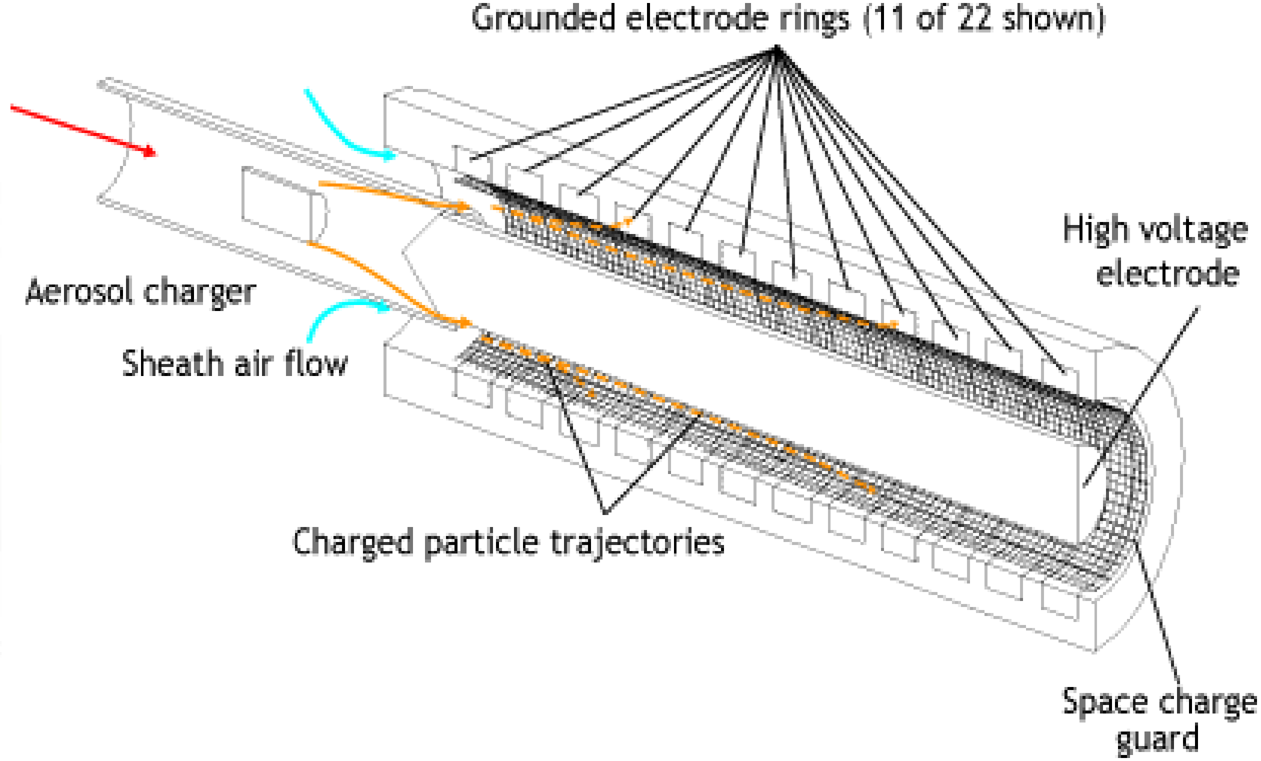
Jaguar HCCI engine



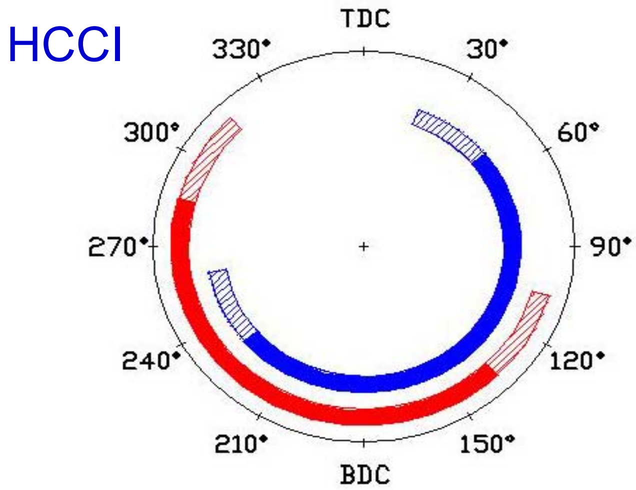
Base Engine	3.0L V6
Bore	89 mm
Stroke	79.5 mm
Compression Ratio	11.3
Con Rod Length	138.1 mm
Fuel	UL95 gasoline
Dual Variable Cam Timing (VCT)	
Dual Cam Profile Switching (CPS)	
Direct injection	

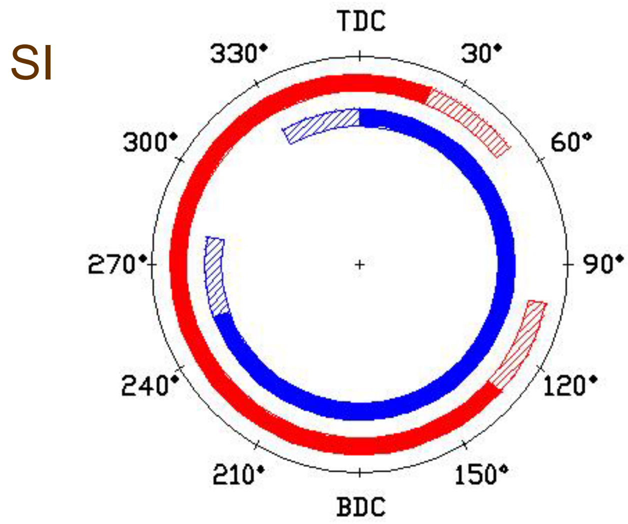
Cambustion DMS500 Particulate Spectrometer

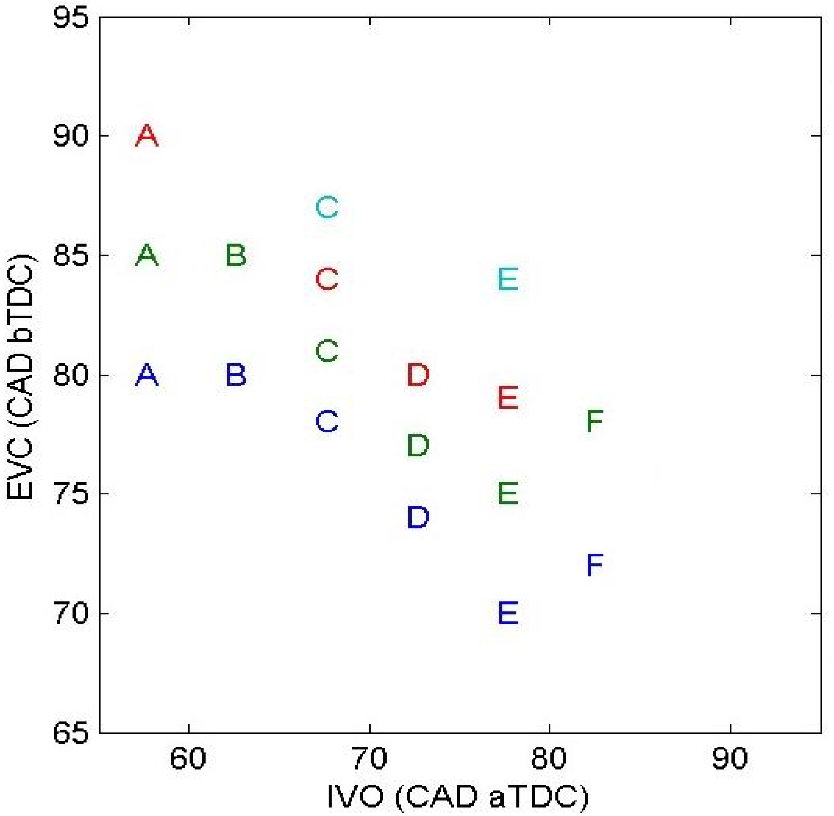


Source: Cambustion

Engine valve timing setup



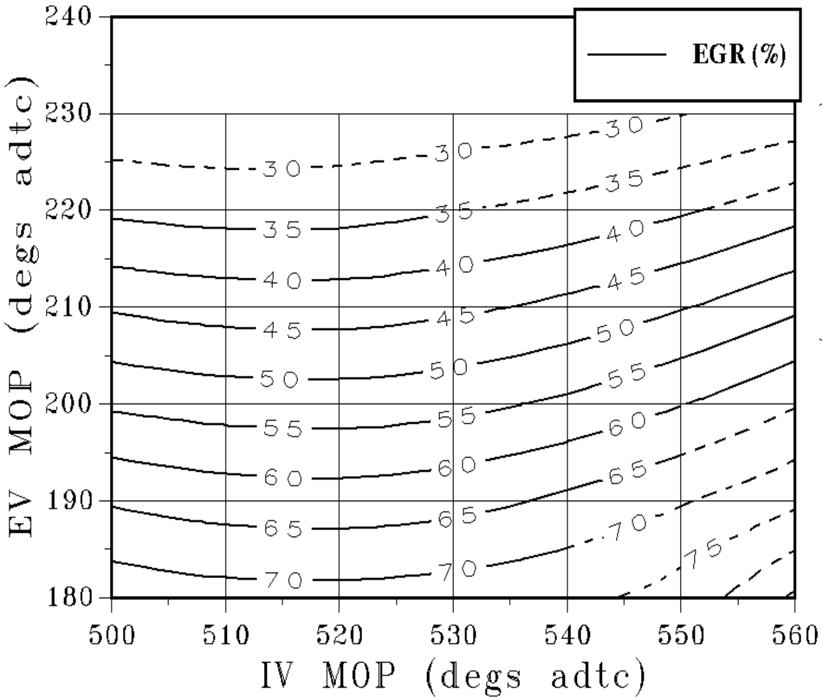


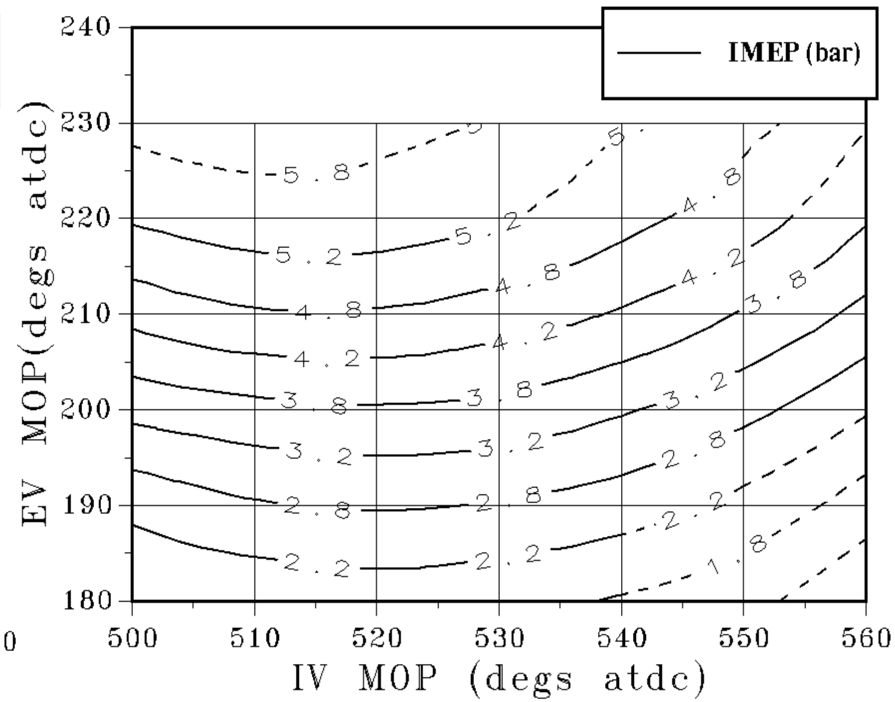


IVO delay: A>B>C>D>E>F
EVC advance indicated by colour bar
Engine speed: 1500 rpm

Relationship between internal EGR and load

Modelling of the Jaguar V6 HCCI engine

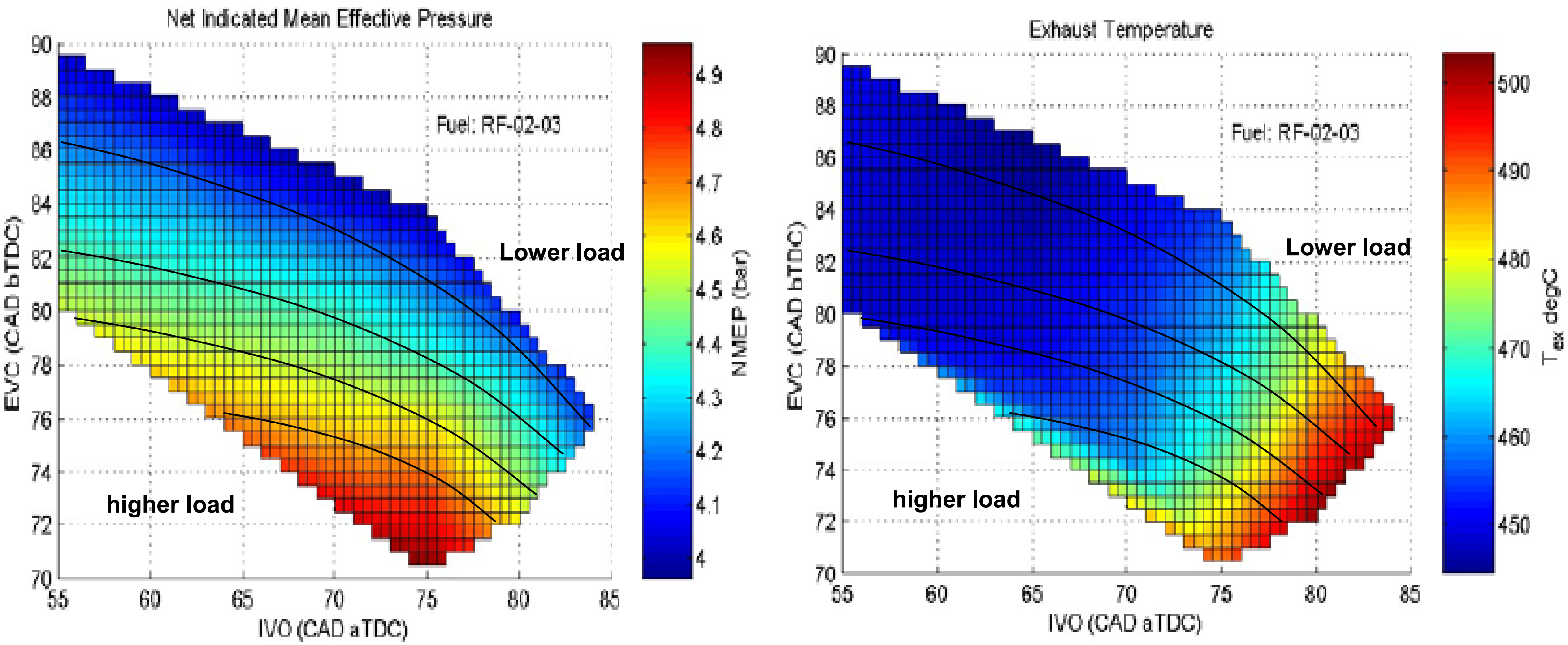




- In an HCCI engine with NVO, load is inversely proportional to internal EGR which increases largely with the advance of EVC

(SAE paper 2003-01-1859)

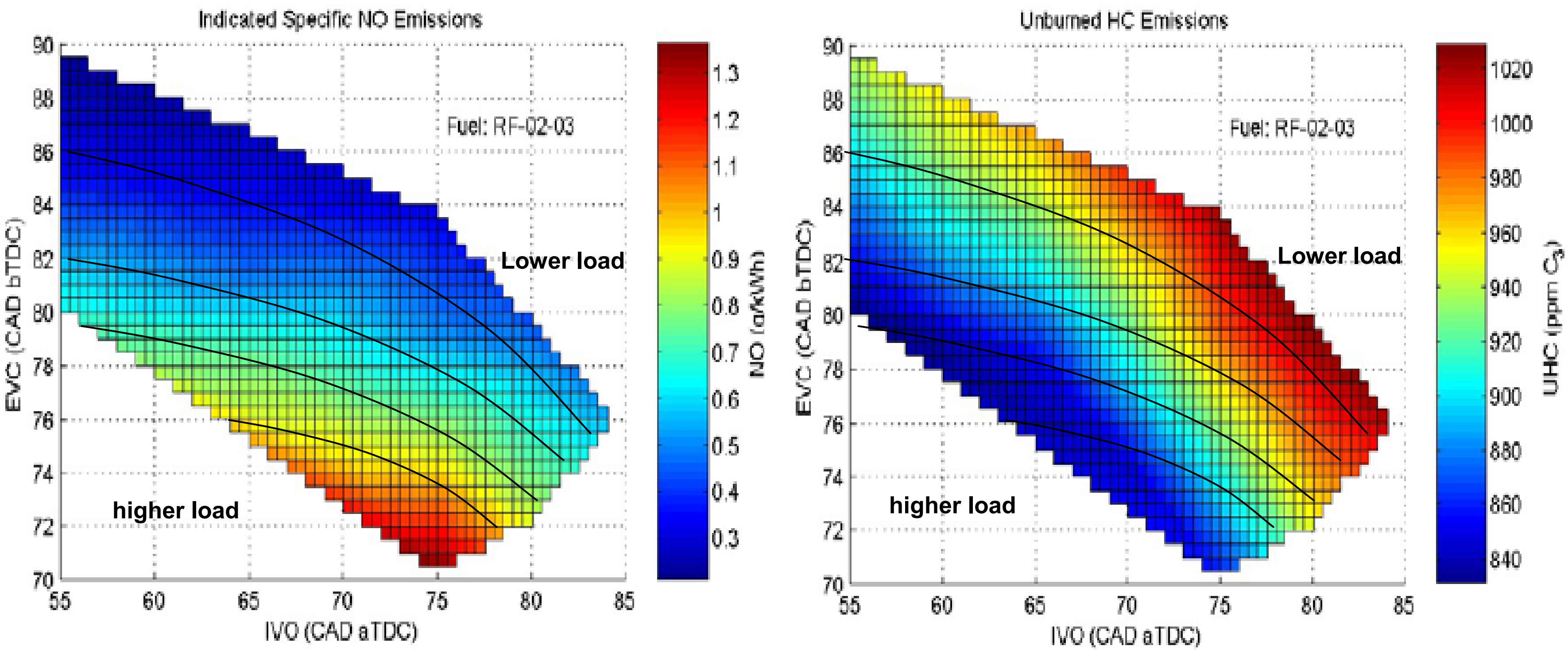
Load and Exh. Temp. vs valve timing



________ Iso-IMEP valve timings

- For a given load, maximum EVC/IVO advance leads to a lower exhaust temperature

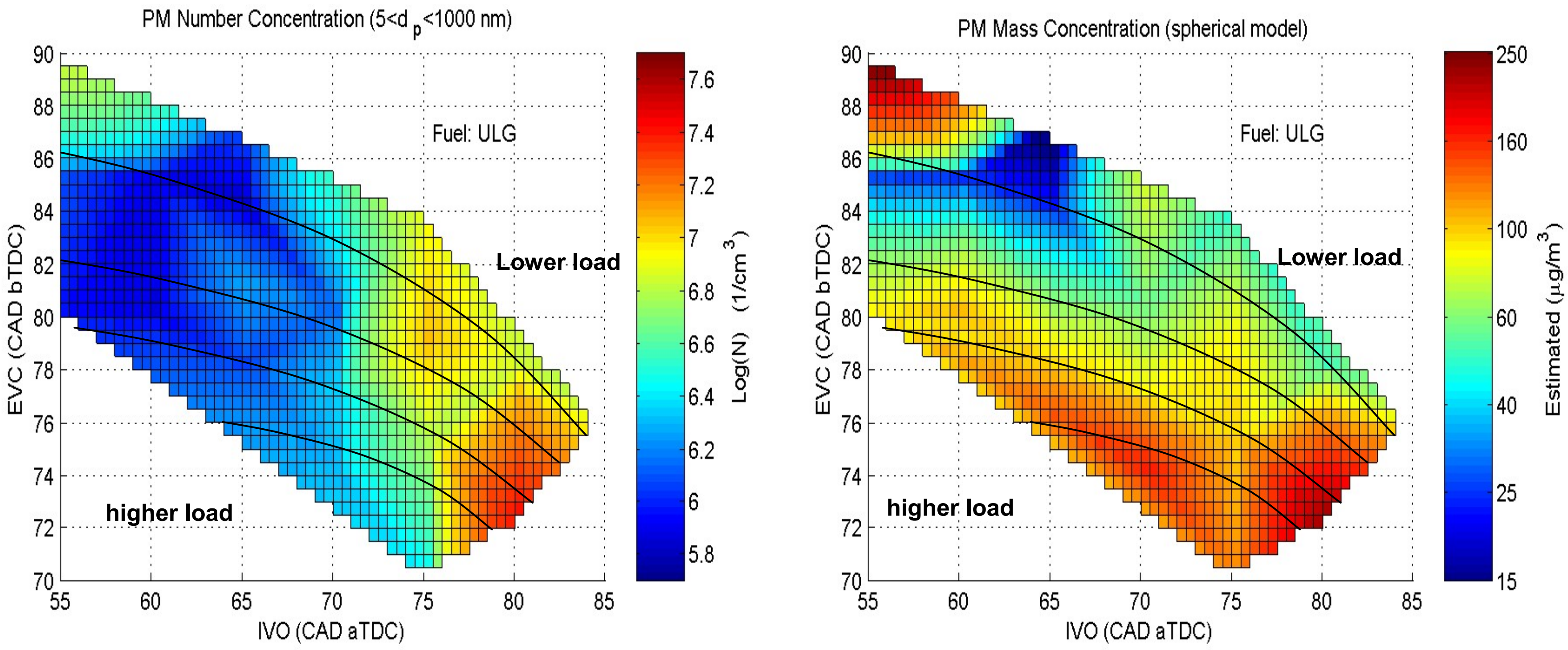
NO and HC vs valve timing



——— Iso-IMEP valve timings

- NO level is proportional to load, and inversely proportional to internal EGR
- For a given load, later IVO leads to a higher HC level

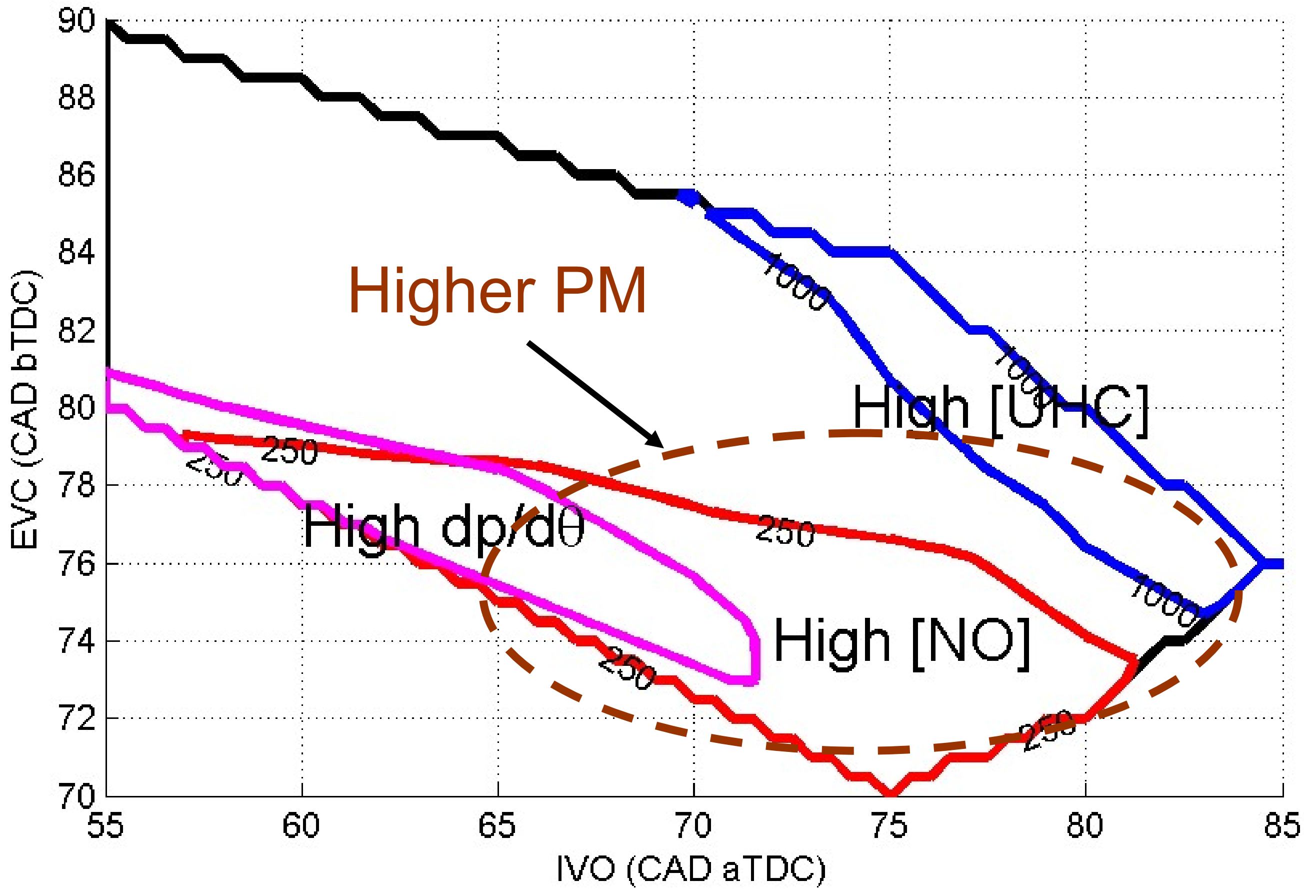
PM number vs valve timing



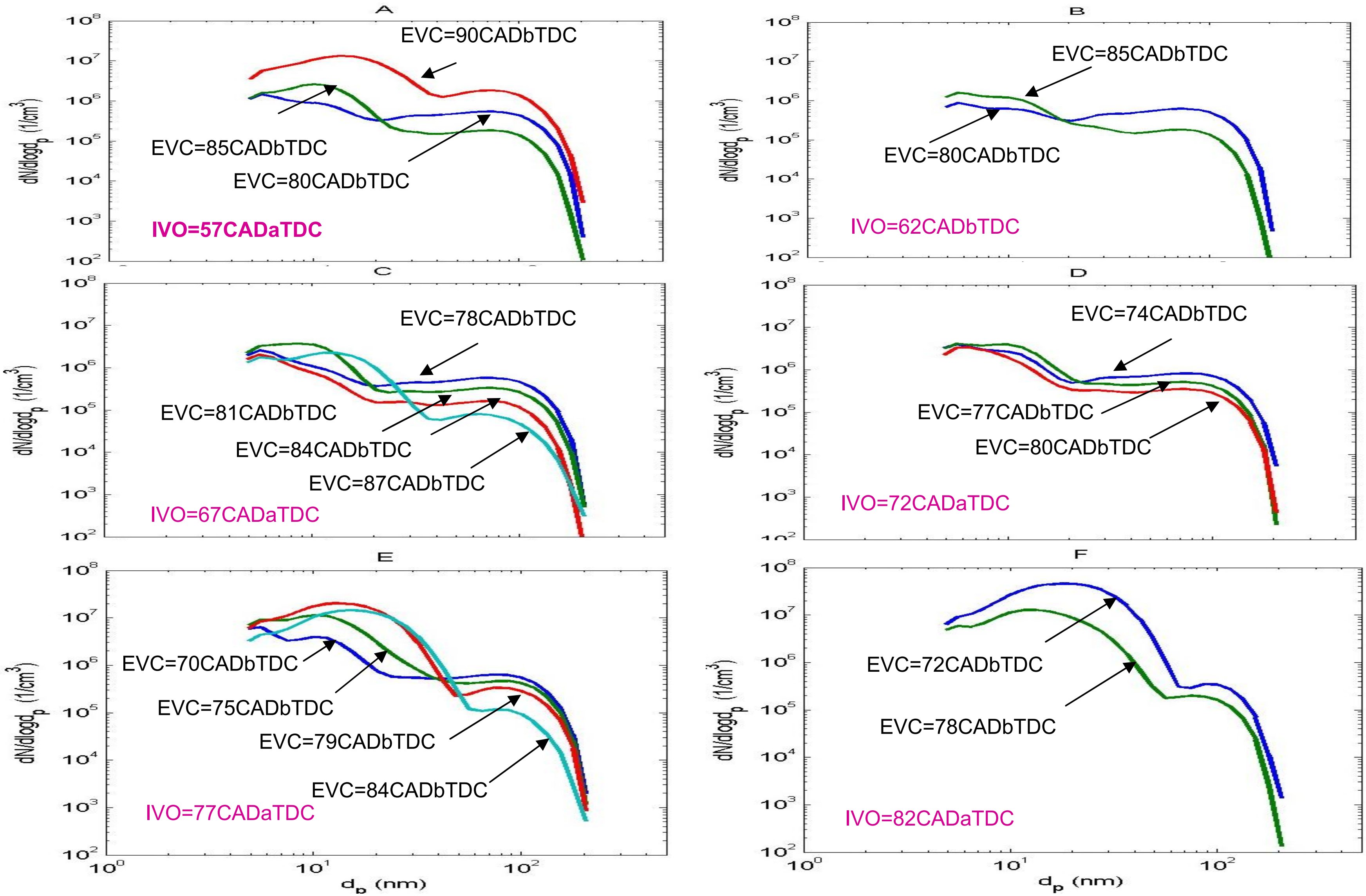
________ Iso-IMEP valve timings

- PM number increases for very late IVO
- PM mass tends to increase with load and is also inversely proportional to internal EGR, except at very early IVO

Emission characteristics of the HCCI engine

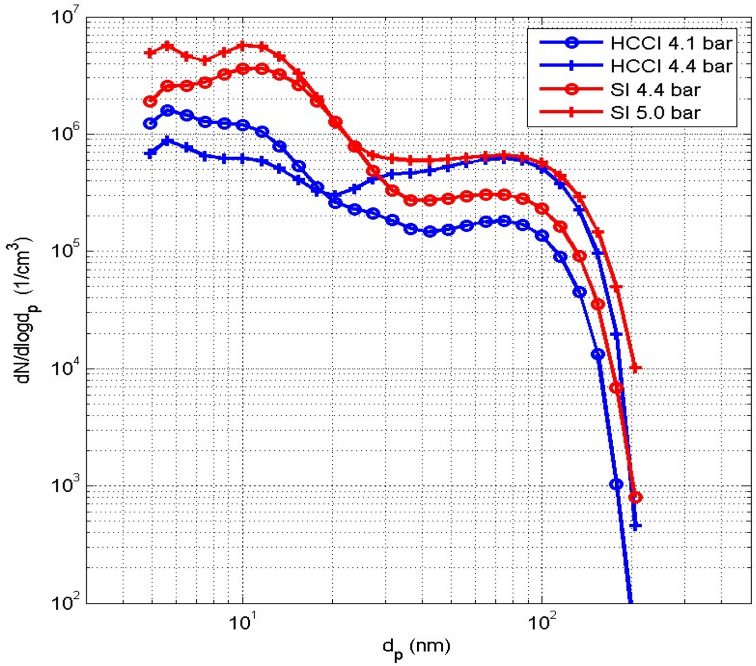


PM mode levels vary with valve timing (iEGR)

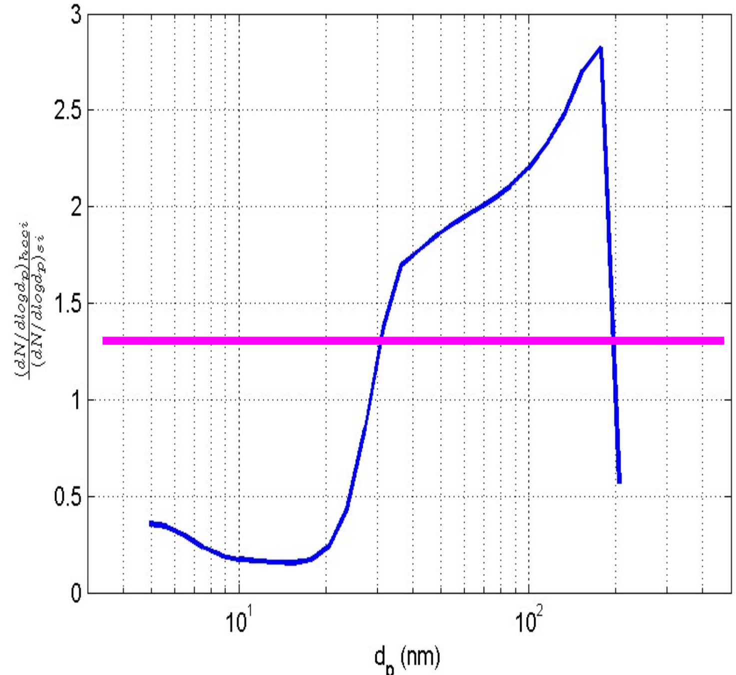


PM comparison for HCCI and SI (1)

HCCI

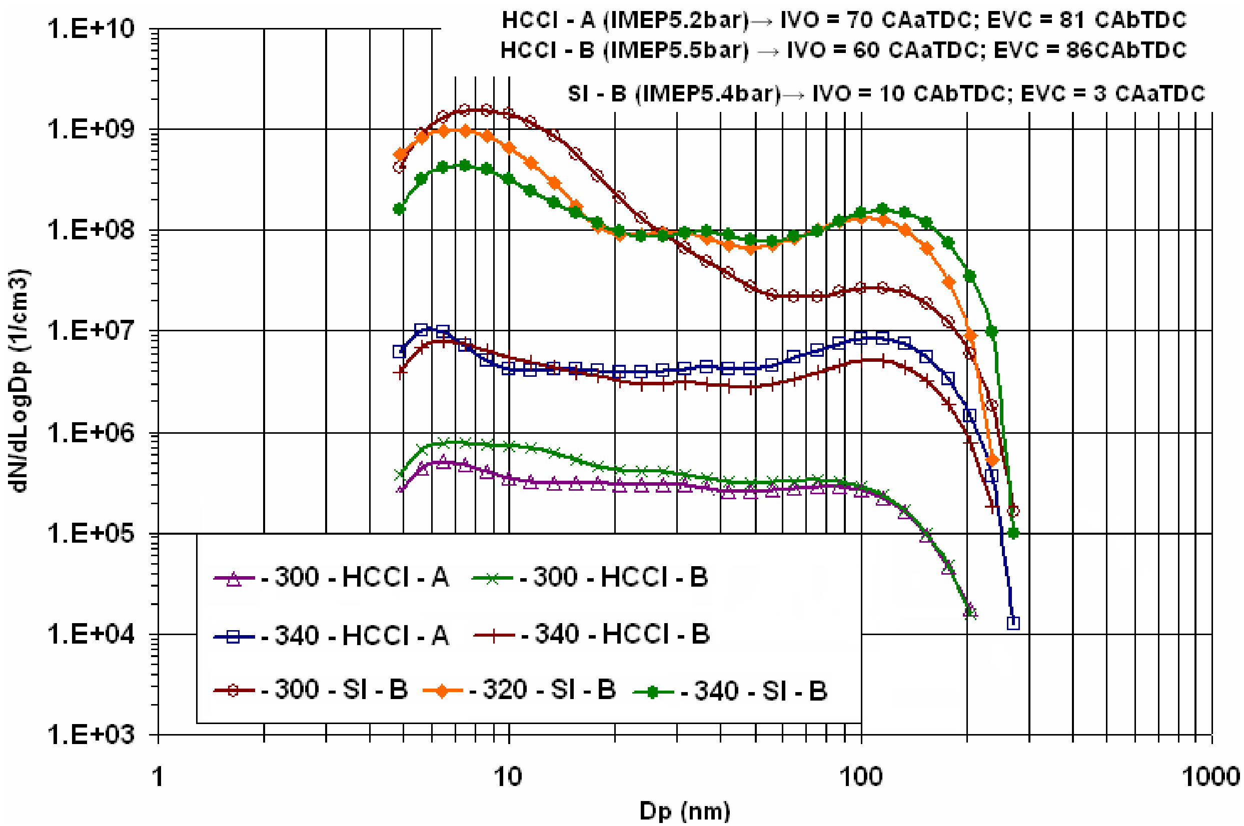


Ratio HCCI/SI



1. The accumulation mode level may trade off with the nucleation mode level
2. At the selected experimental conditions for **IMEP of 4.4 bar**, PM with HCCI shows a higher accumulation mode and a lower in nucleation mode levels than SI;

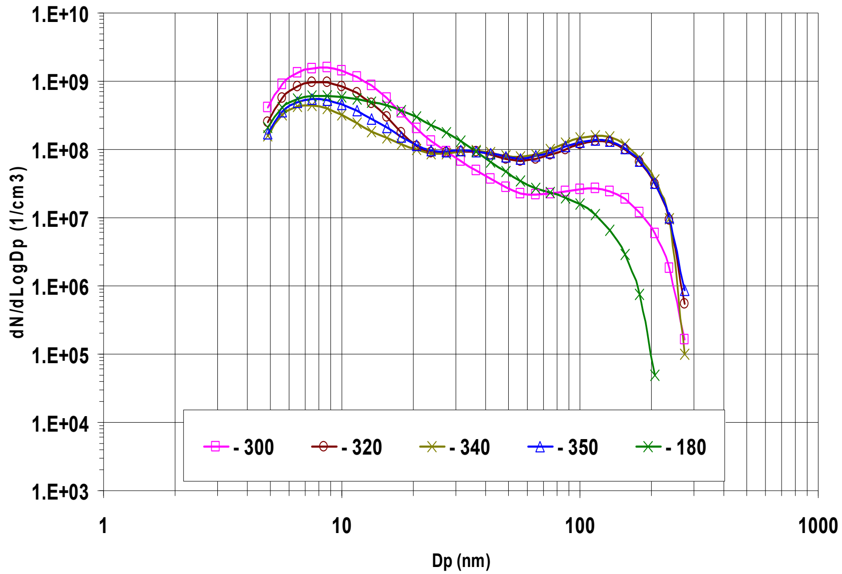
PM comparison for HCCI and SI (2)



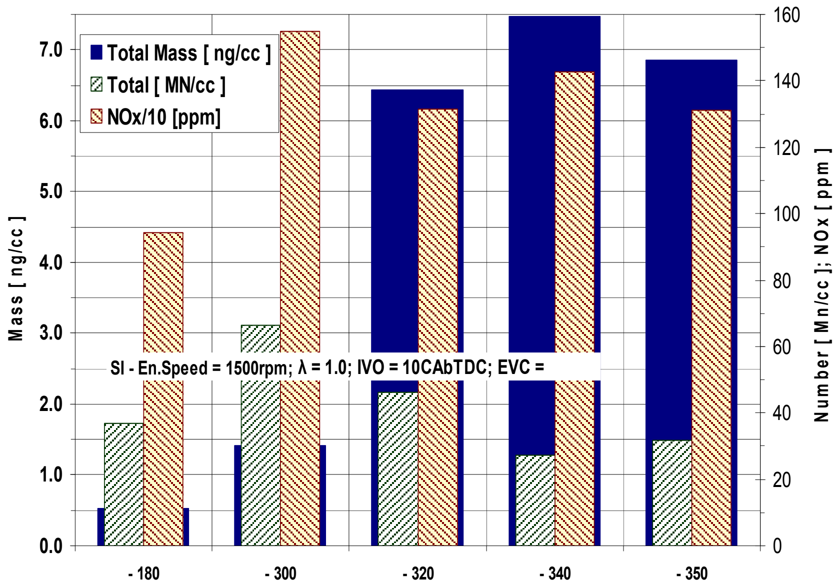
1. At a higher load condition for **IMEP of 5.2-5.4 bar**, PM with HCCI shows a lower level in both accumulation mode and nucleation mode than SI
2. Varied injection timing (-300 or -340) can make a big difference, greater for that in the case of varied valve strategies (A or B) or SI

PM for varied injection timings - SI

SI - 1500rpm; λ = 1.0; IVO = 10CAbTDC; EVC = 3CAaTDC



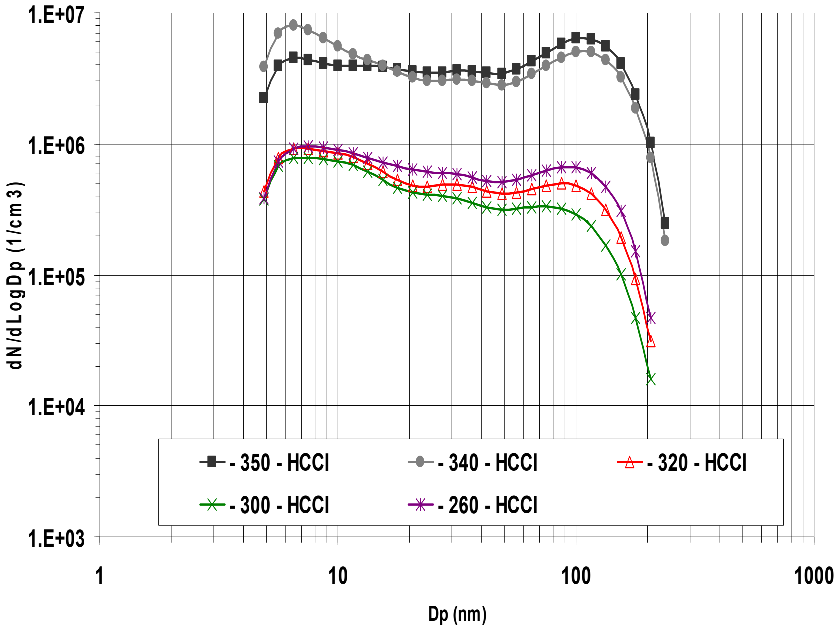
Total number is smaller with early injection (lower nucleation mode)



Accumulation mode
(larger effect on mass)
increases when injection advances

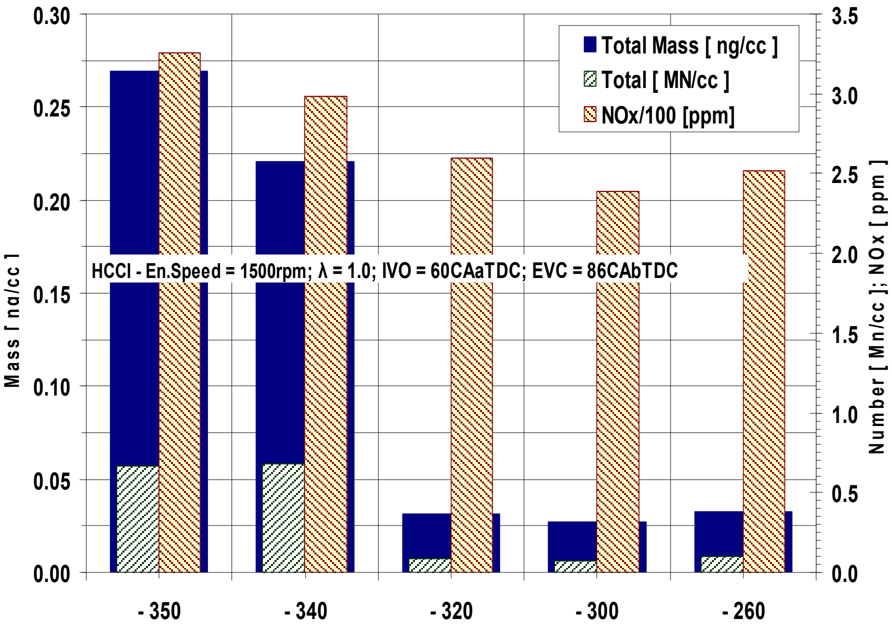
PM for varied injection timings - HCCI

HCCI - 1500rpm; λ = 1.0; IVO = 60CAaTDC; EVC = 86CAbTDC

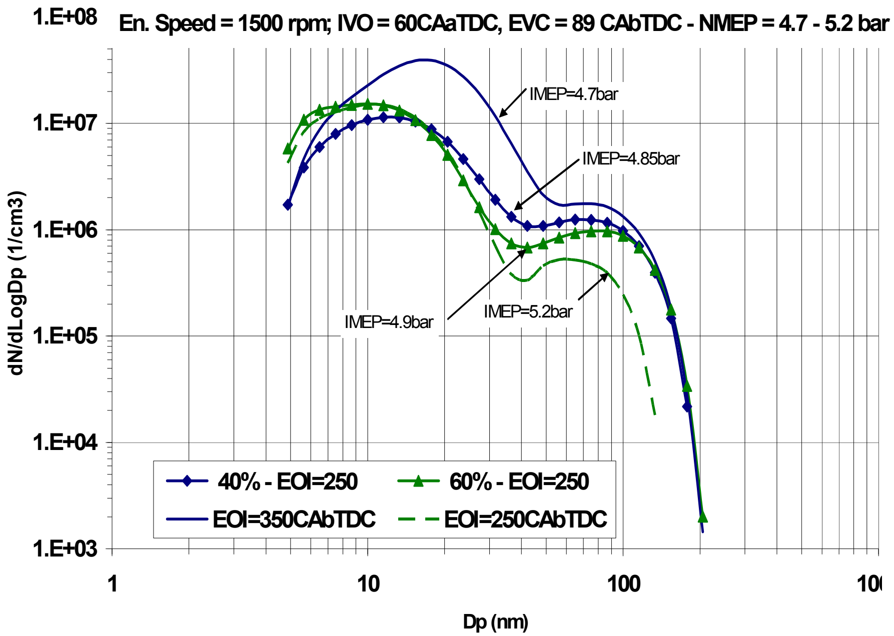


Matching of the injection and the intake valve timing may be important

The difference between early and late injections is much greater

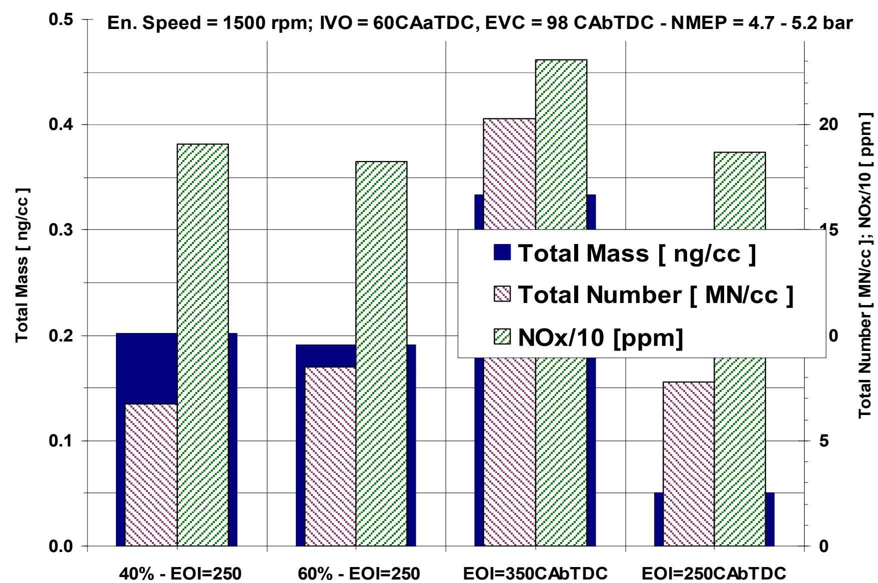


PM with split injection

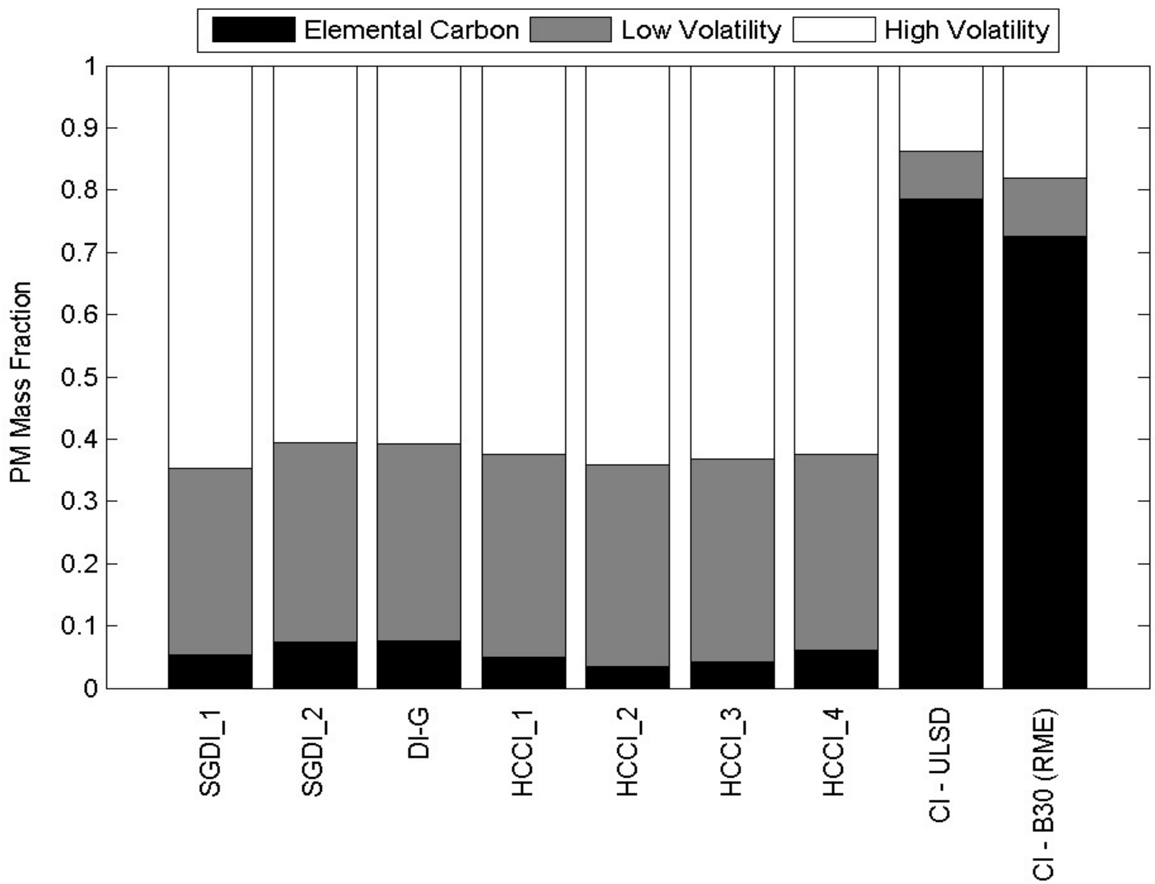


More pilot injection may increase PM

PM will fall between the boundaries for one injection in recompression or late induction



PM mass fraction – Volatility study by TGA



1750 rpm

HCCI 1:
IMEP=4.6BAR,
IVO=85, EVC=60.
EOI=-
350

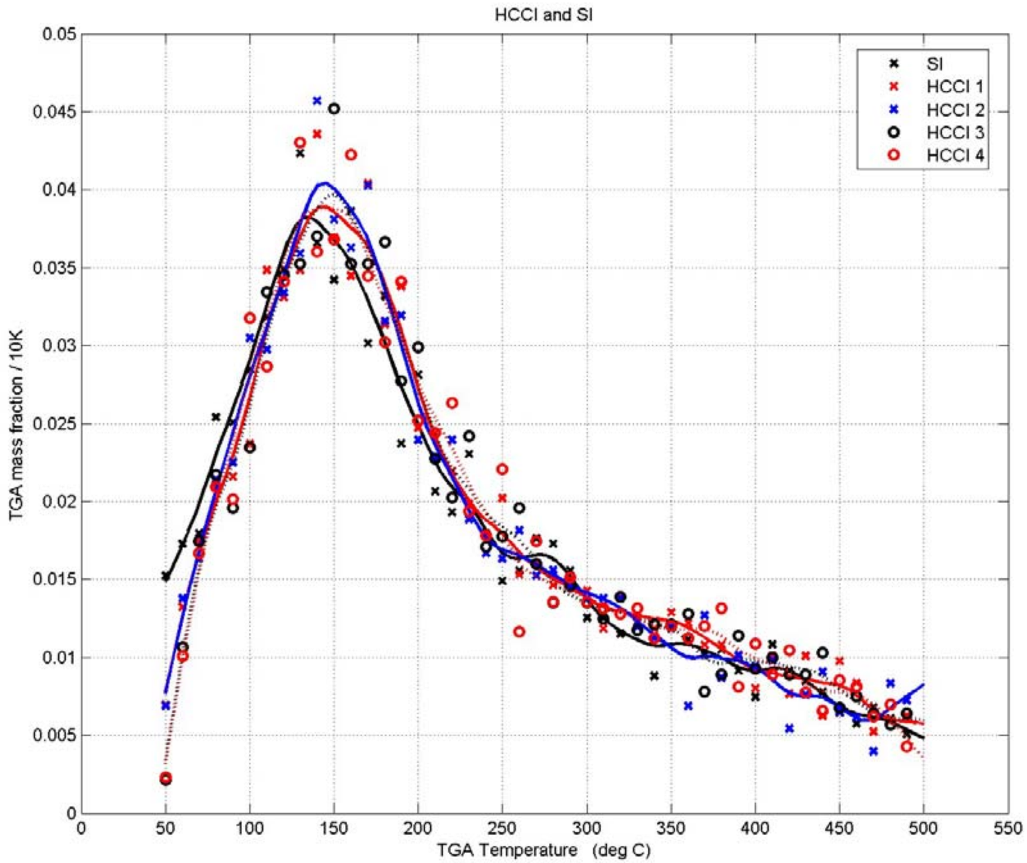
HCCI 2:
IMEP=4.9BAR,
IVO=85,
EVC=60, EOI=-
300

HCCI 3:
IMEP=4.6BAR,
IVO=80, EVC=77,
EOI=-
300.

HCCI 4:
IMEP=4.9BAR,
IVO=75,EVC=80.
EOI=-350

Particulates from HCCI engines have a significantly larger portion of high volatility content than diesel PM, similar to those from 2nd generation GDI SI engines.

Volatility characterised by TGA temperature



Volatility peaks at temperatures around 150 C and results are very similar for HCCI and SI PMs

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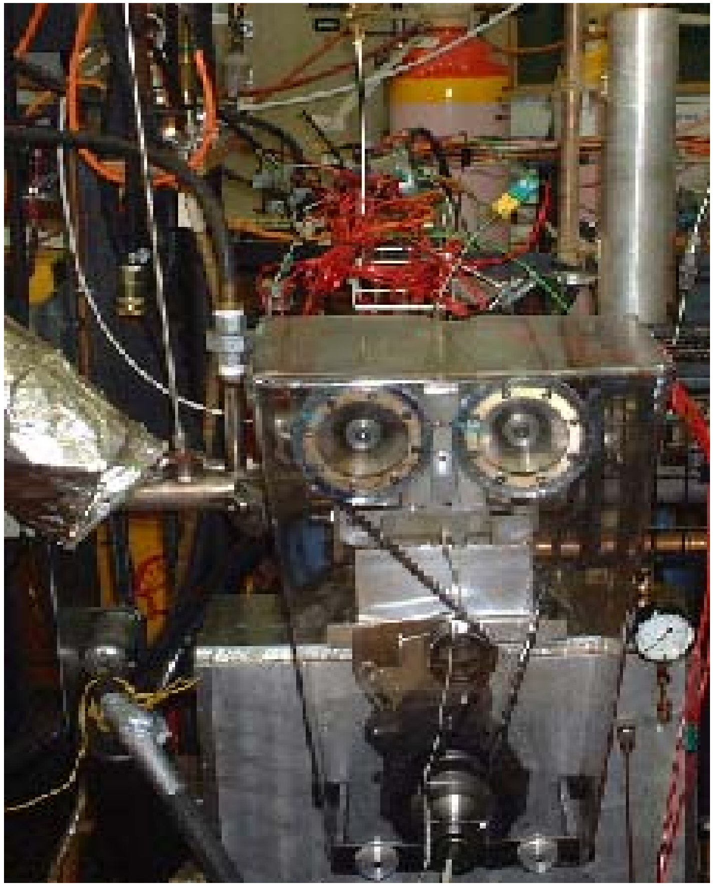
What is dieseline and why?

- Gasoline, which has high volatility but low self-ignitability, is generally produced as a high octane number fuel. In the HCCI engine it is associated with the main problem 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 longer carbon chains (larger carbon content only for aromatics in diesel) and heavier molecular weight with low volatility, is better suited to auto-ignition but often requires a lower compression ratio than in a conventional Diesel engine if the HCCI mode is adopted.

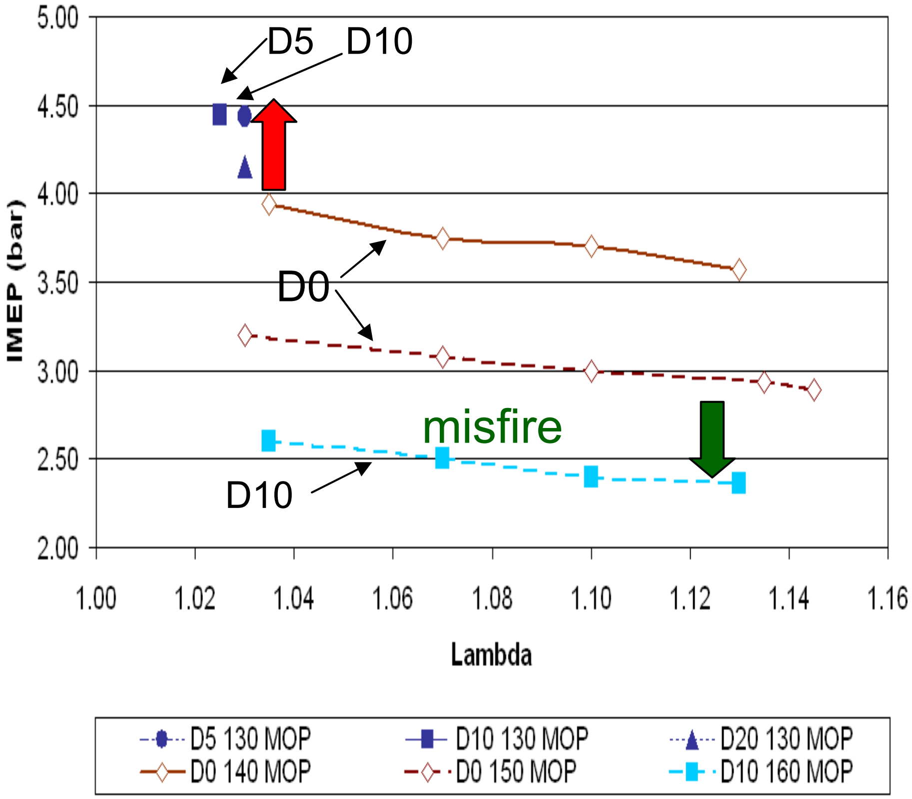
- A mixture of Diesel and Gasoline (dieseline), mixed either on-line or off-line, avoids any compromise and makes it possible to use the complementary properties of the 2 different fuels.

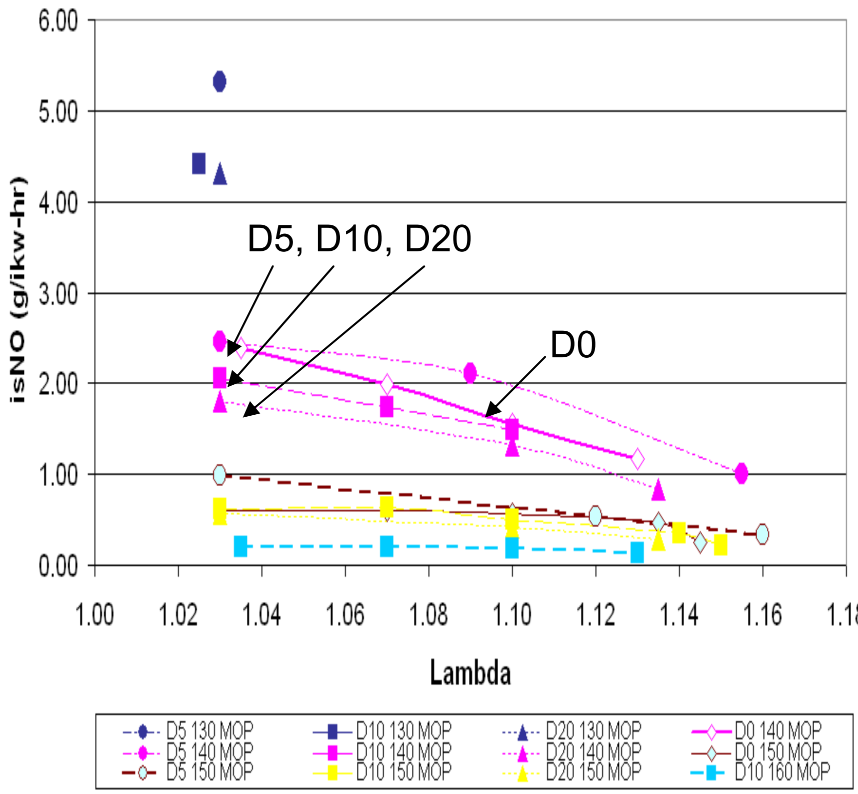
Mixed dieseline in a single-cylinder thermal engine



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

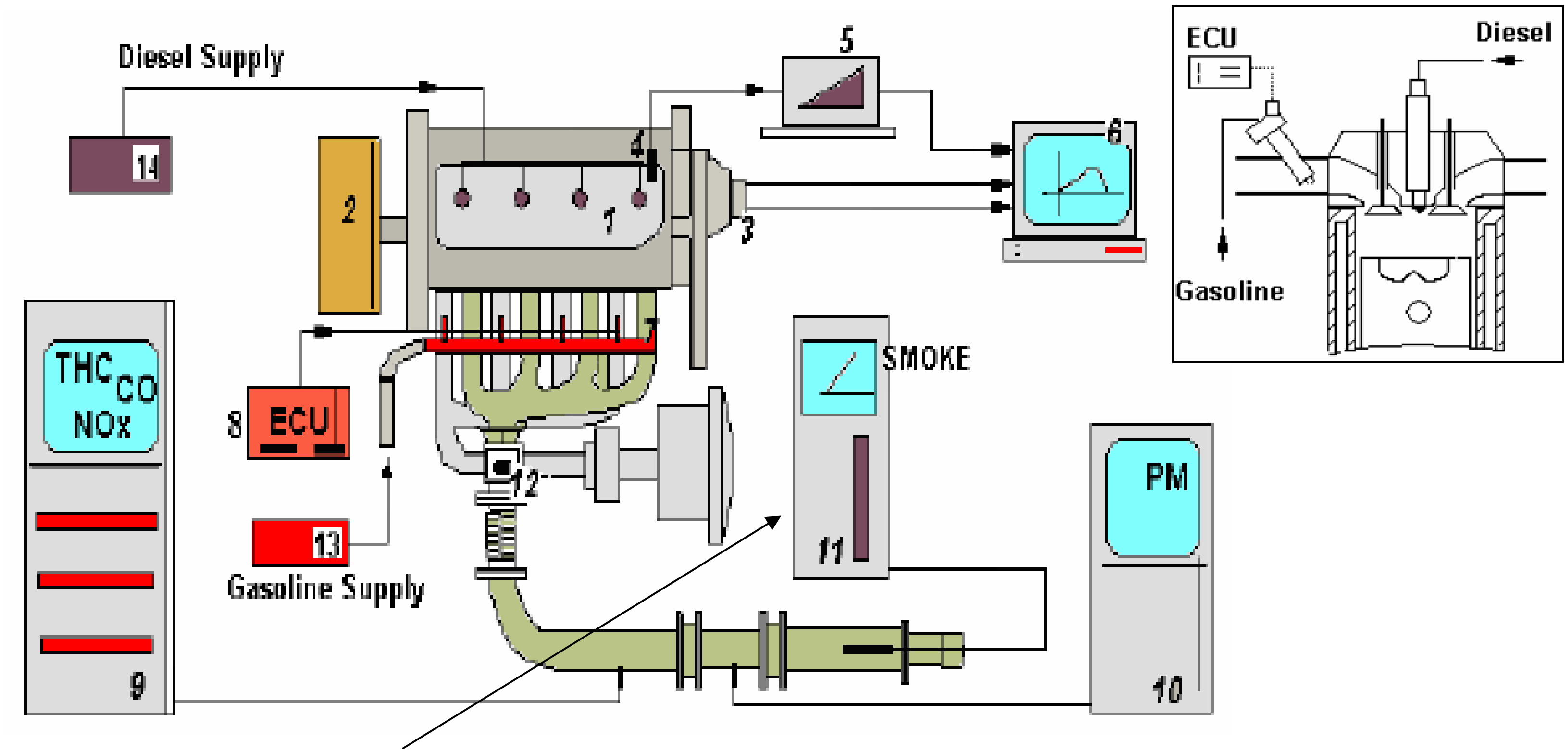
Effect of dieseline on load boundary and NO





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

Diesel pilot injection in premixed gasoline

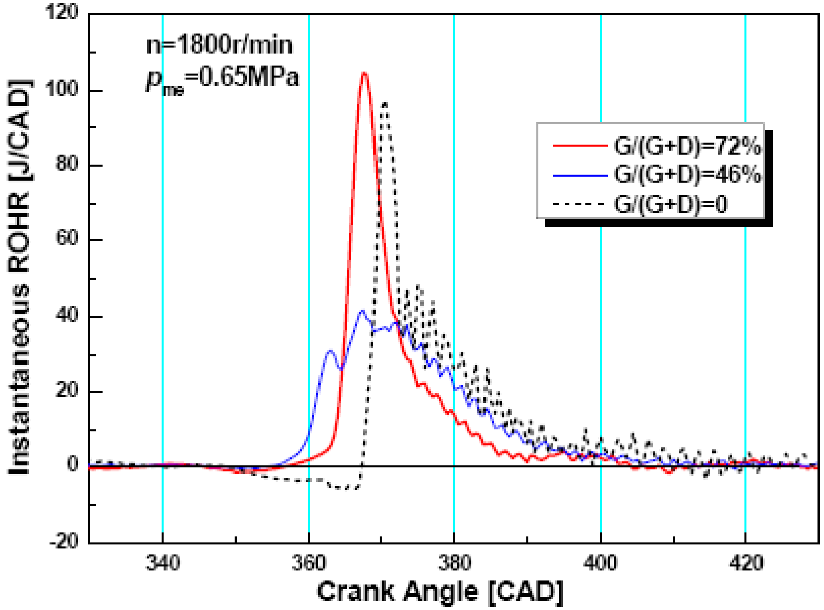


AVL SPC 472 particulates collector

5 levels collection

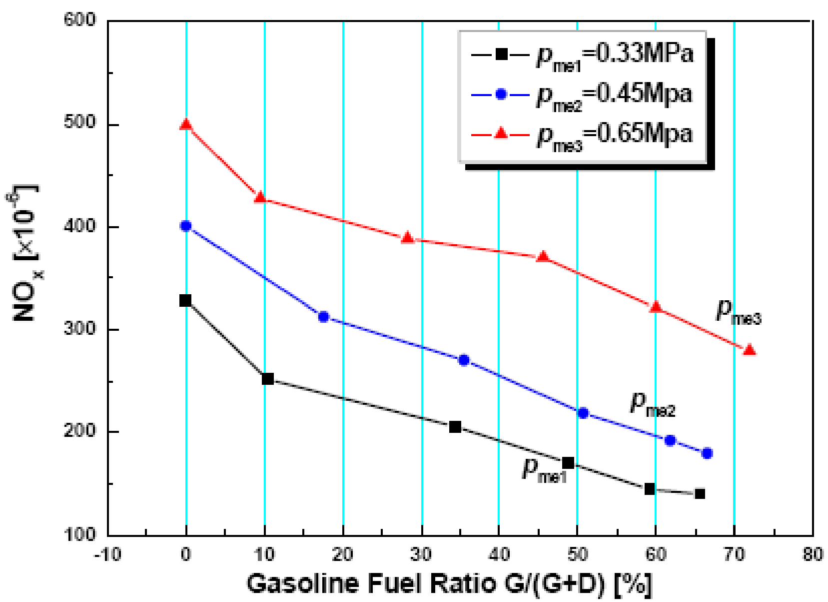
< 0.2 μ m, 0.2-0.5 μ m,0.5-1 μ m, 1-2.5 μ m, >2.5 μ m

Homogeneous Charge Induced Ignition (HCII)



The slower heat release (than as in HCCI) and relatively more homogeneous mixture (than as in diffusion combustion) may be responsible for the lower NOx levels

Variation of ratio of gasoline and diesel fuel can change the heat release rate

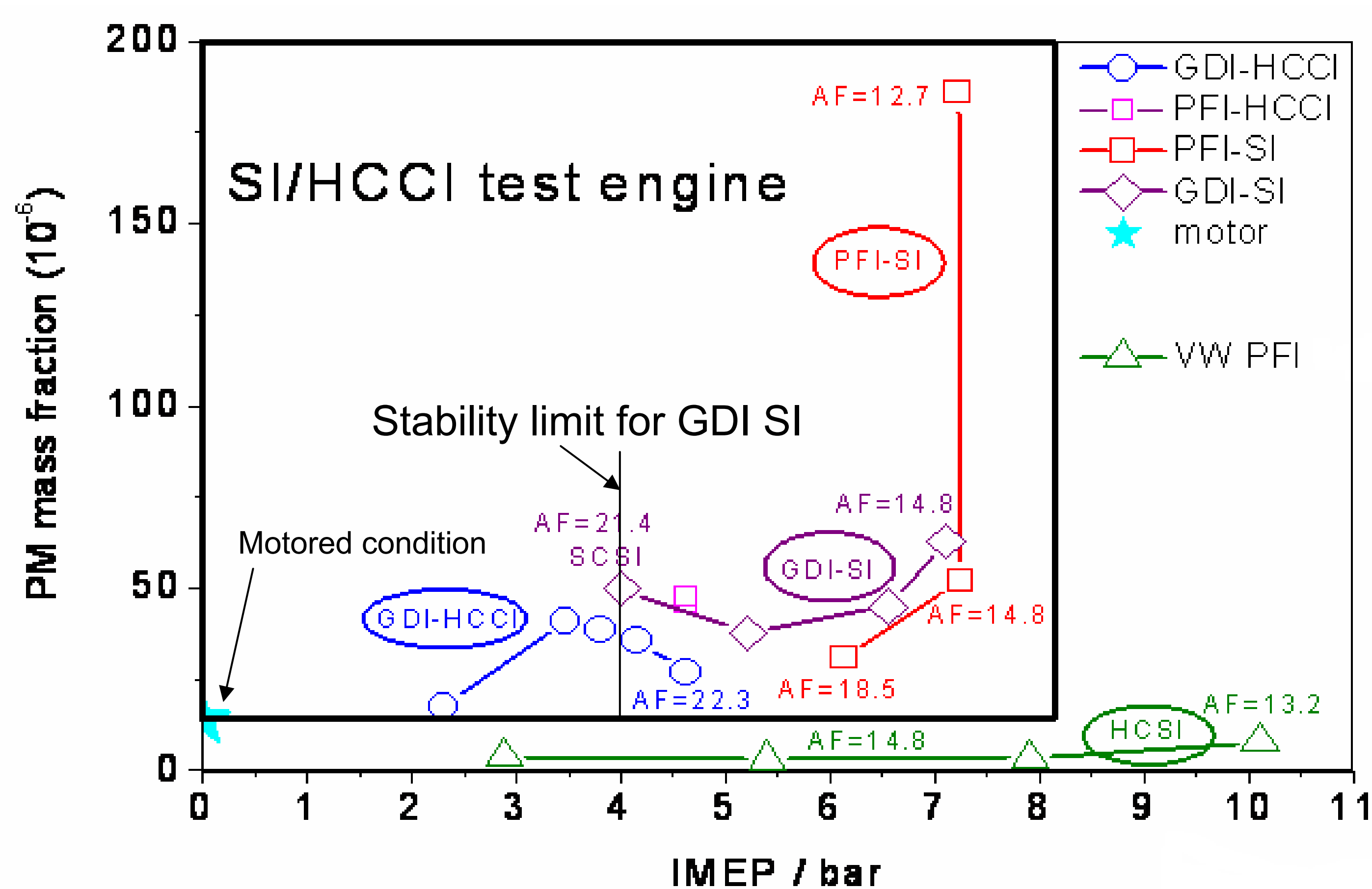


(SAE2005-01-0136)

Premixed dieseline engine

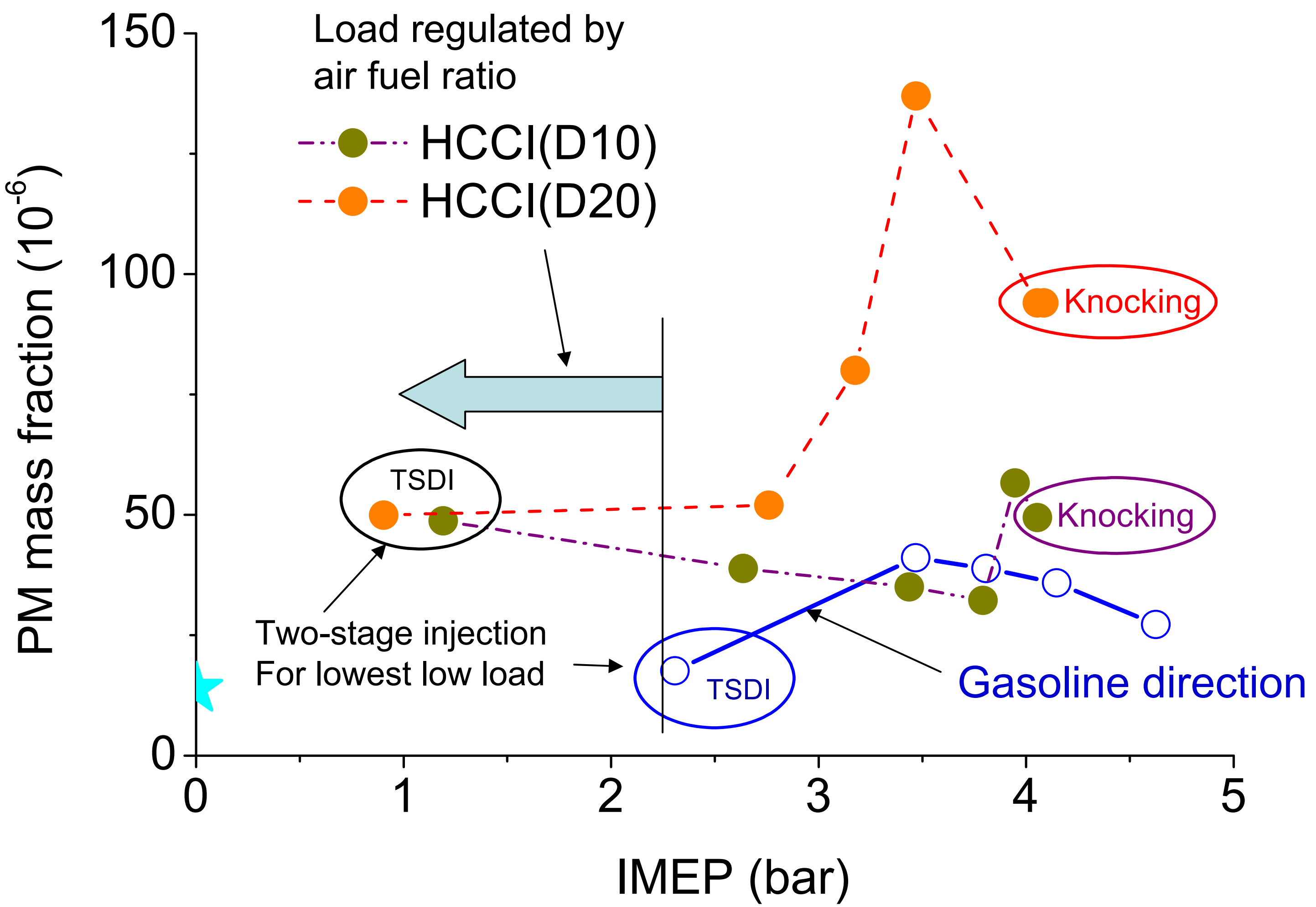
Type	2 cylinder, in-line, natural aspiration, 4 stroke, direct injection, gasoline engine
Number of Valves	2 per cylinder
Bore	95mm
Stroke	115mm
Connecting rod	210mm
Compression ratio	13
Injector	High pressure swirl injector
Injection pressure	6MPa
Flow rate of injector	15.7mm^3/ms
Spark plug	TORCH A7RC
Spark energy	70mJ
Head bottom	Flat
Intake port	Helical
Combustion chamber	Column-form bowl
Fuel	90# gasoline from market

Comparison of PM for different combustion system



The load of the GDI engine is regulated by air fuel ratio and stratified charge is used for low load

Extension of the low load HCCI boundary



Summary and Conclusions

1. Future engine emission regulations will include particulate matter in both mass and number. Measurement of PM in gasoline engines is sensitive to many factors associated with the experimental system and these factors include engine speed and load conditions, fuel systems, lubricating oil, and arrangement of the measuring equipment.
2. For HCCI combustion, either in a well premixed or partially premixed condition, particulate emissions are not negligible. At low load conditions, PM with HCCI may approach SI levels.
3. In the HCCI engine with NVO, PM varies with valve timing for a given engine speed and relates to engine load and internal EGR rate. When the (negative) valve overlap is reduced, both NOx and PM levels increase with engine load. The concentration of accumulation mode particles varies inversely with the amount of internal EGR, contrary to the well known PM-NOx trade-off in diesel engines.
4. For a given valve timing for the GDI engine, HCCI PM varies with injection timing. A later injection around the time of intake MOP gives lower PM and NOx emissions.

Summary and Conclusions

5. Lean burn with boosting will effectively reduce the PM level of HCCI.

6. A mixture of gasoline and diesel fuels (Dieseline) is probably one of the solutions to meet the requirements of future fuels for future engines. The trade-off (benefits and cost) will depend on the original engine design (e.g., diesel or gasoline as baseline) and the best results will require an optimisation of the combustion system.

7. A pilot injection of diesel into premixed air-gasoline mixture or injection of premixed dieseline up to 10% of diesel concentration seems to be adequate for expanding the operating window of HCCI engine based on a gasoline engine system with some increased PM at low load boundary.

8. Particulates from HCCI engines (like GDI SI engines) have a significantly larger proportion of high volatility content than diesel PM.

Acknowledgements

Birmingham University and Oxford University acknowledge the support of Jaguar Cars, Johnson Matthey and Shell for the research in relation to this presentation, which is partly funded by the UK DTI and EPSRC.

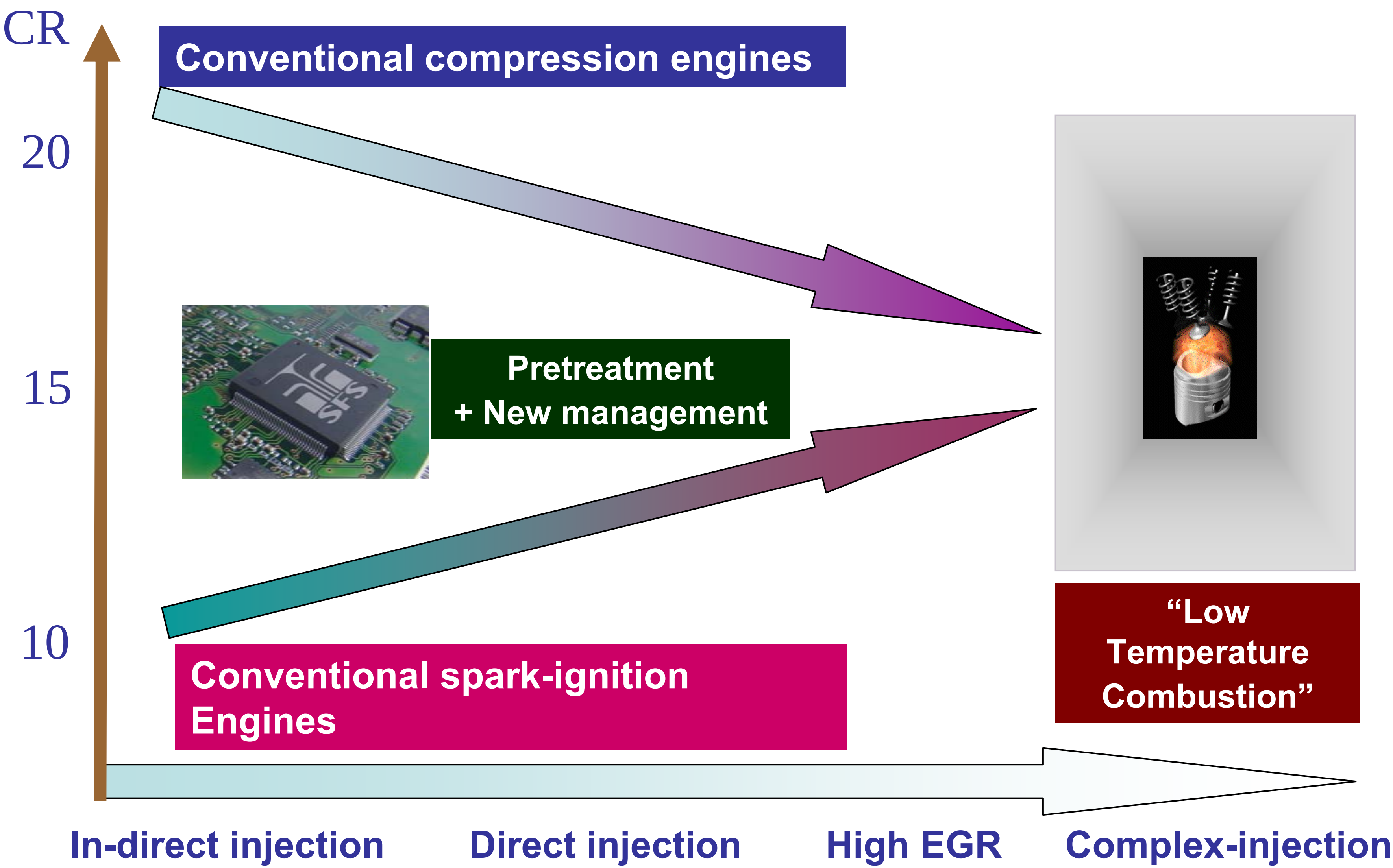
Tsinghua University wishes to acknowledge the funding from the Chinese National Key Basic Research Plan.

Contributions from people listed below to the related research work are also gratefully acknowledged

Dr Trevor Wilson, Dr Rob Stevens
Jaguar Cars
Dr Hengfei Jiang
Tsinghua University
Dr Roger Cracknell
Shell Global Solutions UK

Useful discussions have been carried out with Prof. Gautam Kalghatgi of Shell and Prof. Bengt Jonhansson of Lund University regarding the Dieseline research

Gasoline and Diesel Engine Technologies are emerging



What could the future IC engine be like?

Spark-ignition or spark assisted CI at high speed and full load

Mixture pre-treated and boosted

Cycle resolved on line model assisted control

Multi-fuels management capability

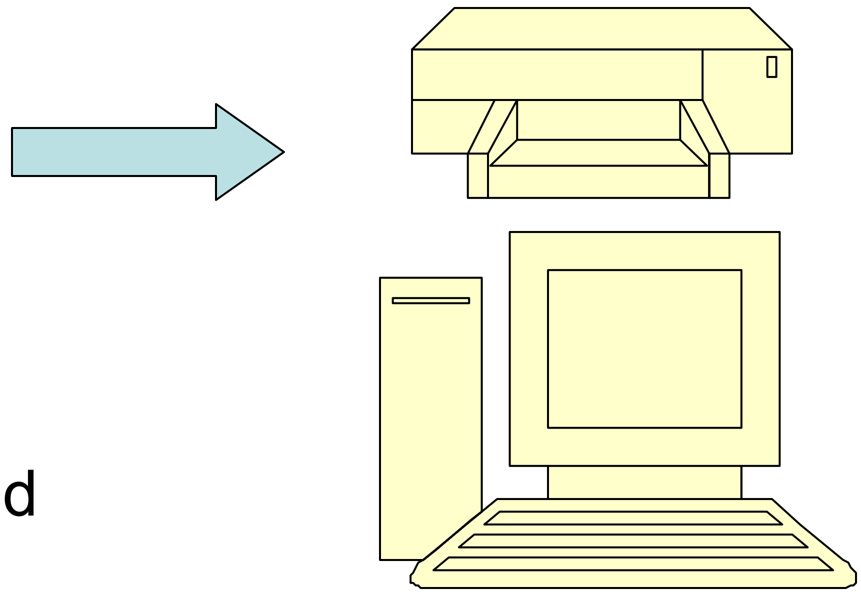
Variable strokes and CR with flexible valvetrains

Multi point fuel supply in each cylinder

Boosted and stratified auto-ignition at low speeds

Multi-fuel injection system – the future of new engines?

- A computer-controlled colour printer can print colourful pictures using 3 original coloured inks –



- If we have 3 different type of fuels, why can't a CPU-controlled fuel injection system supply a required fuel 'colour' (property) for 'printing a beautiful picture' – for optimised engine operation at varied conditions?

- Simply, a multi-channel fuel nozzle is required at gas stations to supply the fuels as for printer cartridges!