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# PM Emissions from HCCI Engines

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**Particulate matter and measurement**

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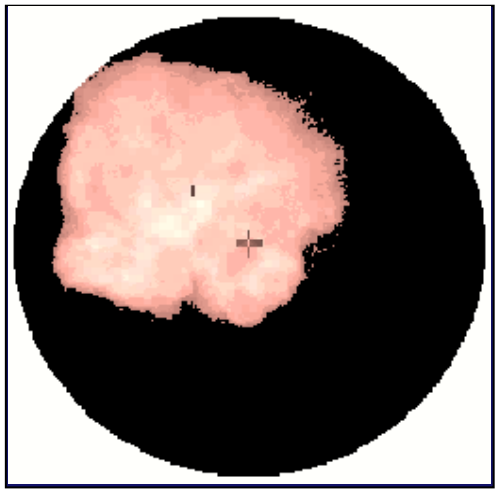
JAGUAR

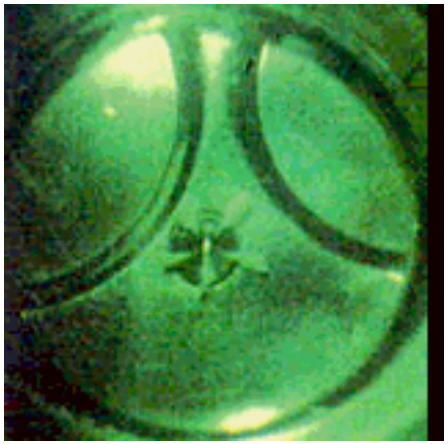
# Presentation outline

- **Background**
- **PM with Gasoline HCCI**
  - Varied valve timing
  - Varied injection timing
  - Effect of air temperature
  - Comparison with SI combustion
  - Effect of diesel addition
- **Summary and conclusions**

# HCCI – a generic name for new combustion mode

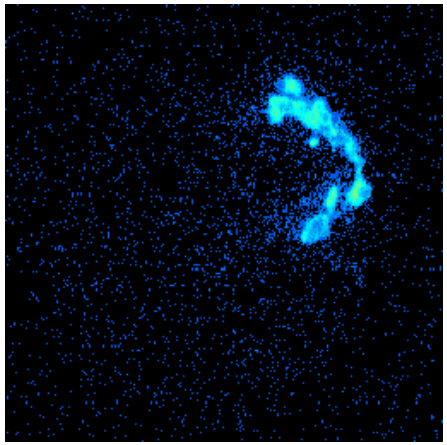


SI combustion



Diesel combustion

(Oxford Lasers)



Homogeneous Charge Compression Ignition

- spontaneous multiple-point ignition
- typically, rather homogeneous mixture and temperature distributions
- capable of running with extremely lean mixtures (AFR>80)
- load can be controlled by fuel quantity or air-EGR dilution

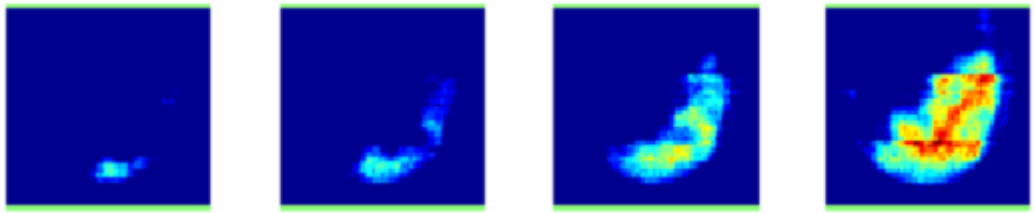
# Advantages of HCCI/CAI combustion

- Extremely low (1-5% of SI) NOx emissions
  - absence of high temperature regions

- High fuel economy (approach Diesel's )
  - un-throttling, lean combustion possible, increased heat release rate, removal of knock tendency, high CR possible

- Very low cycle-by-cycle variations ?
  - multipoint flame initiation

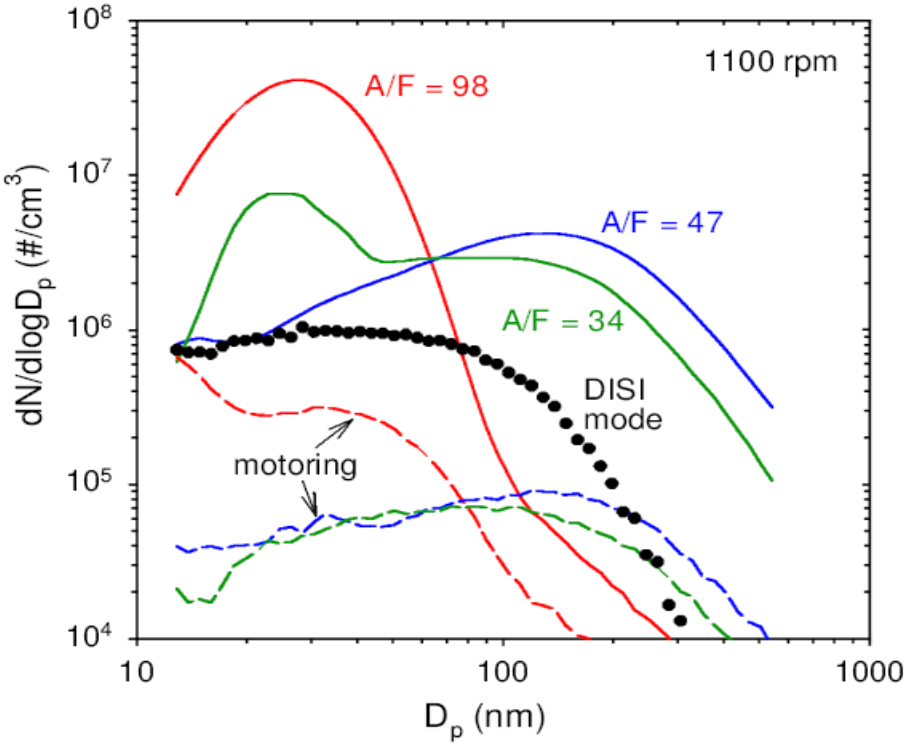
- "**Smokeless" ?**



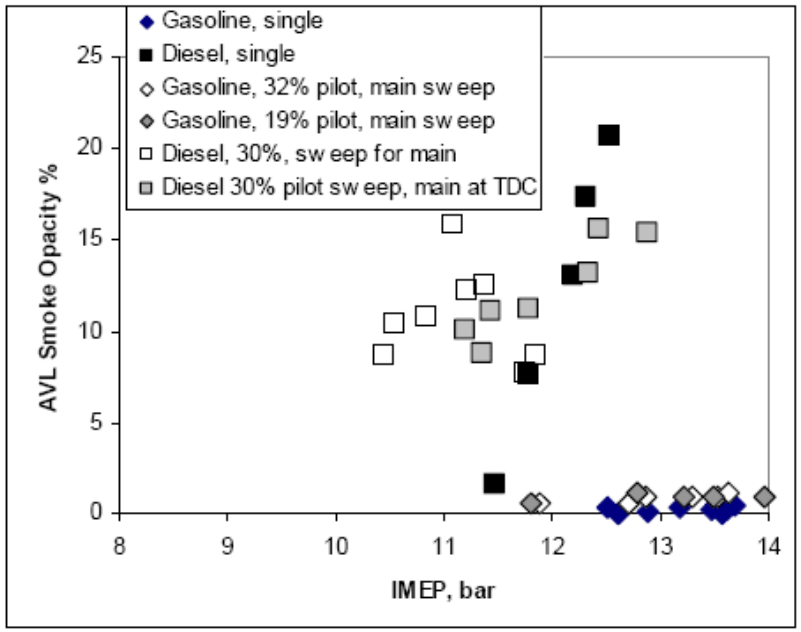
Combustion images – Wilson *et al* SAE Paper 2005-01-2129

# How much PM is HCCI producing

The first measurement of HCCI PM by Ford was ‘surprising’, although clearly HCCI smoke numbers will be low compared to diesel

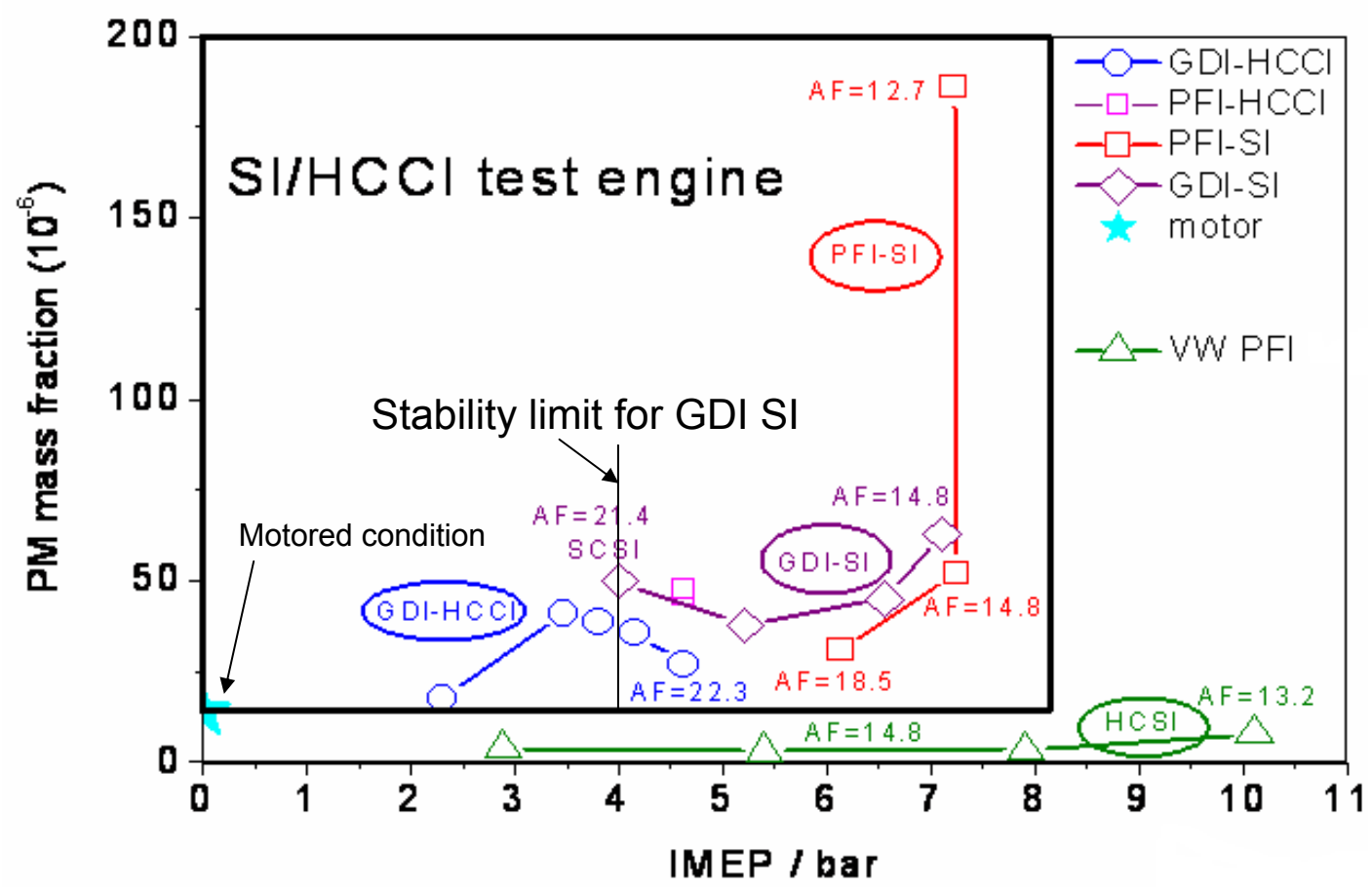



Kaiser *et al*, 2002




Kalghatgi *et al*, 2007

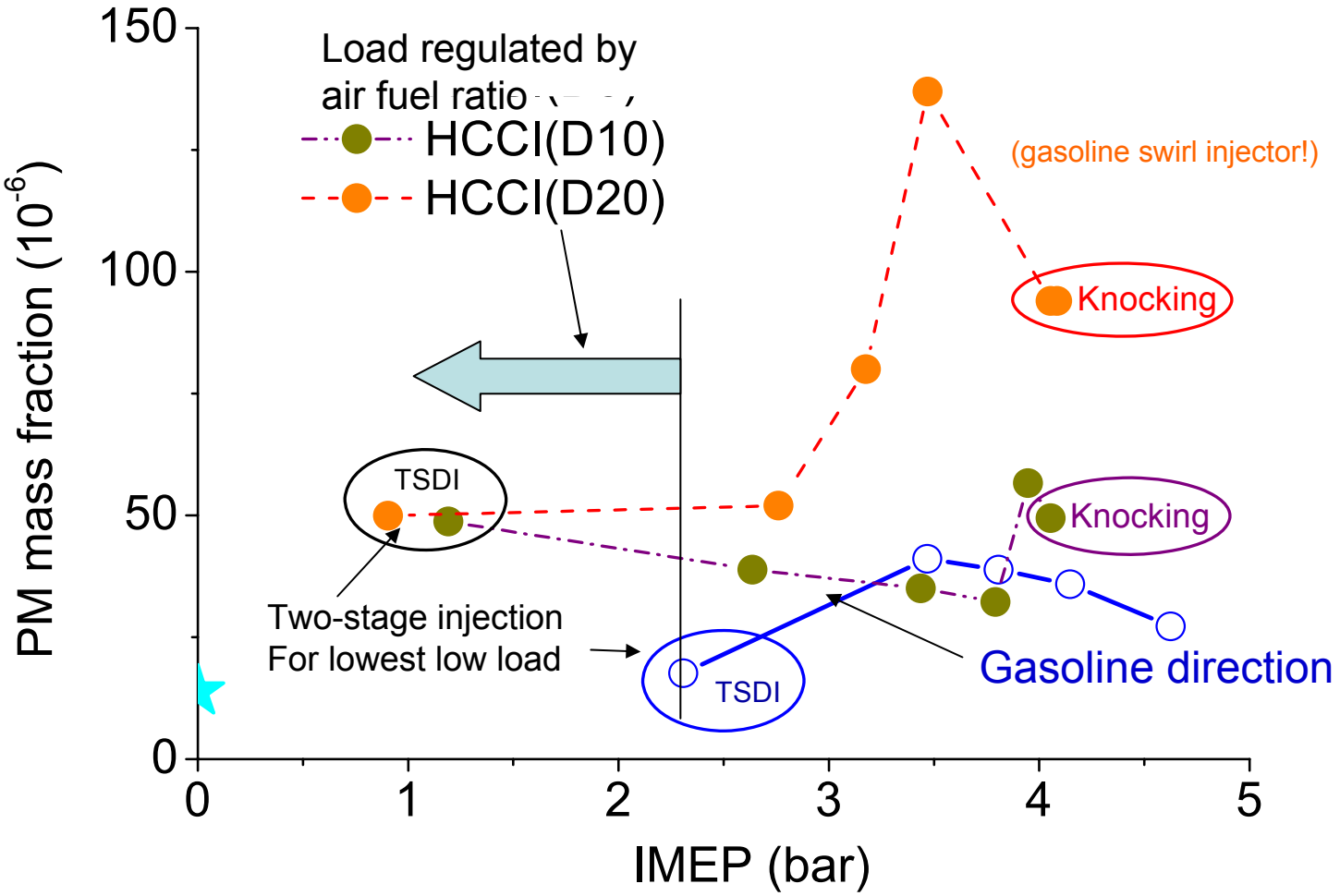
# Comparison of PM for different combustion systems




The load of the GDI engine is regulated by air fuel ratio and stratified charge is used for low load **- Data measured at Tsinghua University**

Xu *et al*, 2008 SAE HCCI Symposium

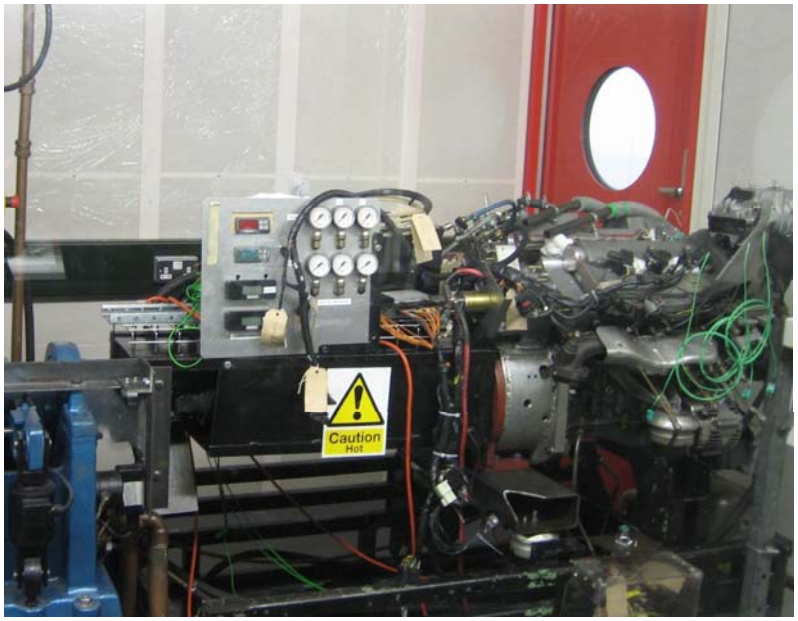
# Extension of the low load HCCI boundary by **Dieseline**

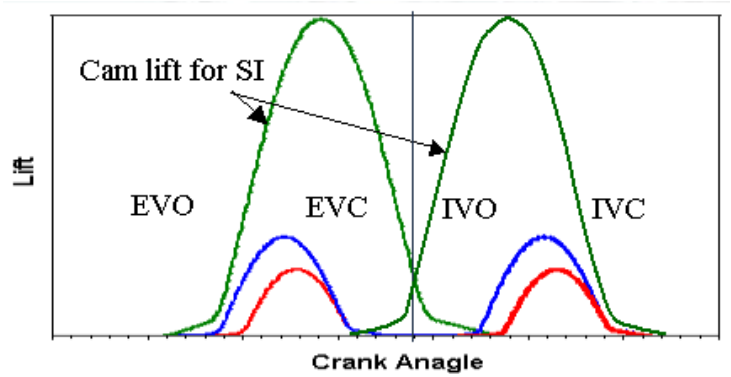



**Dieseline**- Mixture of gasoline and diesel fuels **- Data measured at Tsinghua University**

Xu *et al*, 2008 SAE HCCI Symposium

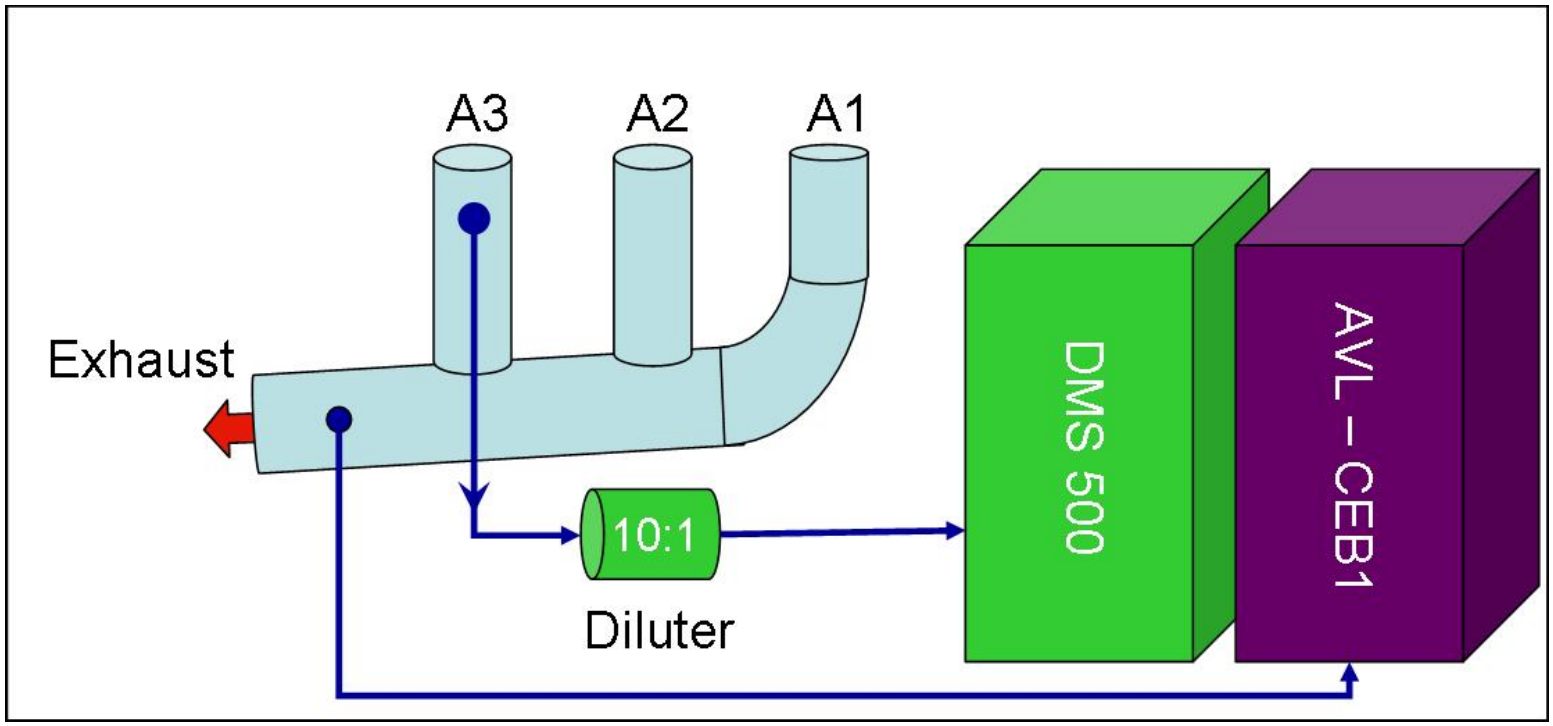
# Jaguar HCCI engine



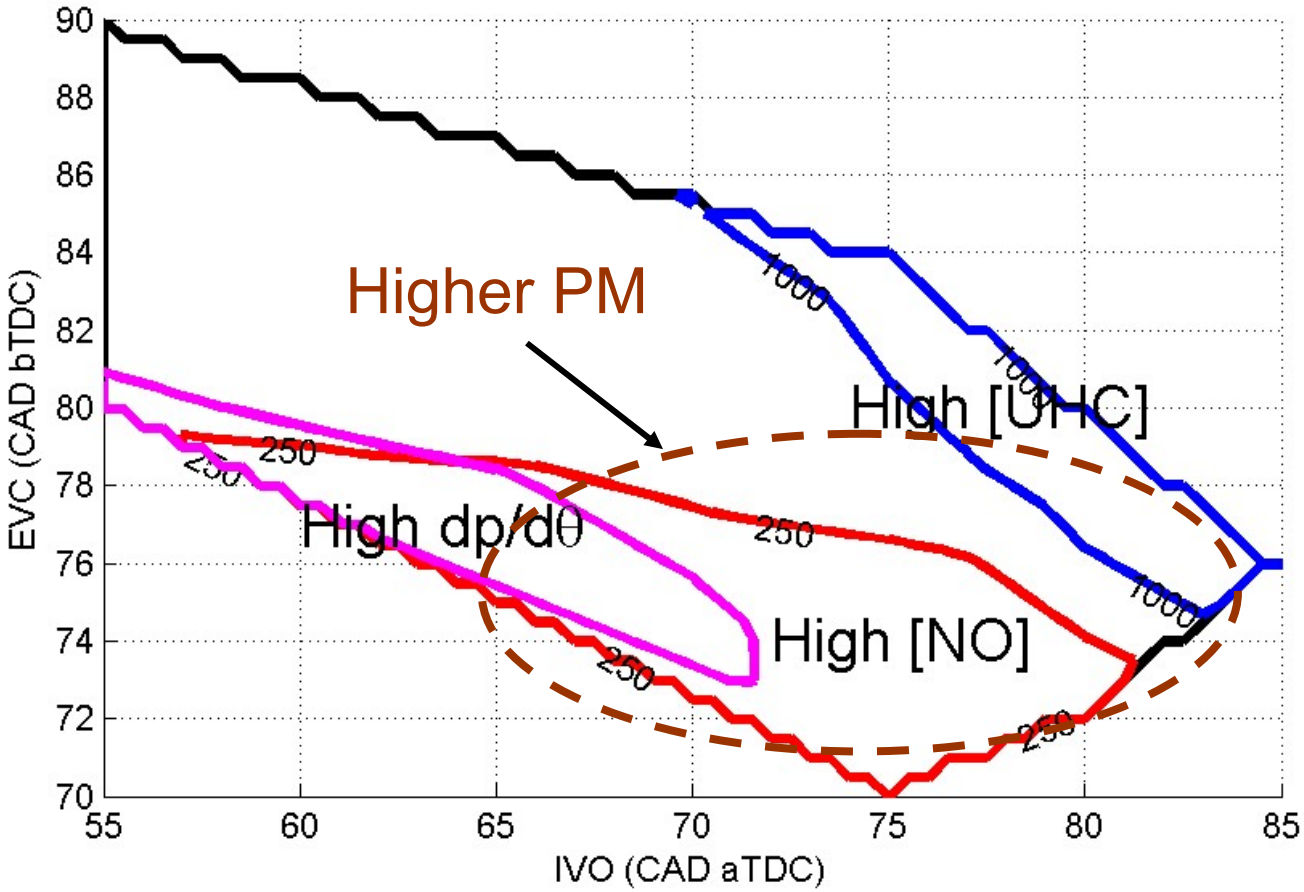




| | |
|---|---|
| Base Engine | 3.0L V6 |
| Bore | 89 mm |
| Stroke | 79.5 mm |
| Compression Ratio | 11.3 |
| Con Rod Length | 138.1 mm |
| Fuel | UL95 gasoline |
| Dual Variable Cam Timing (VCT) | |
| Dual Cam Profile Switching (CPS) | |
| Direction injection | |

# Emission measurement system

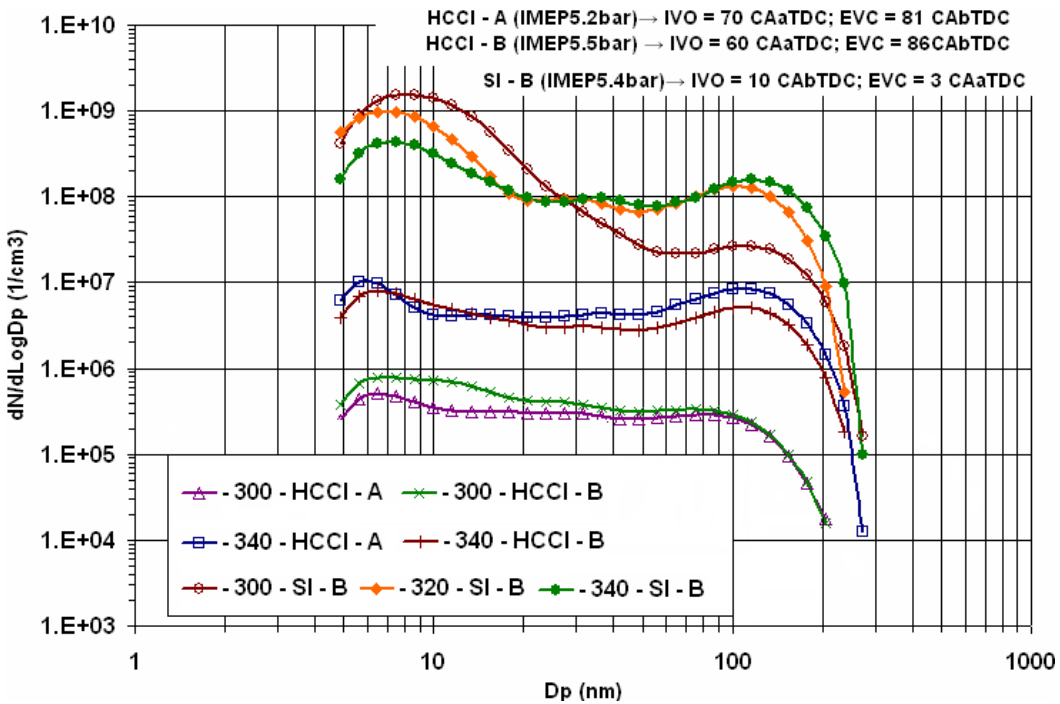


# Emission characteristics of the Jaguar HCCI engine




Price *et al* SAE paper 2007-01-0209

# PM comparison for HCCI and SI

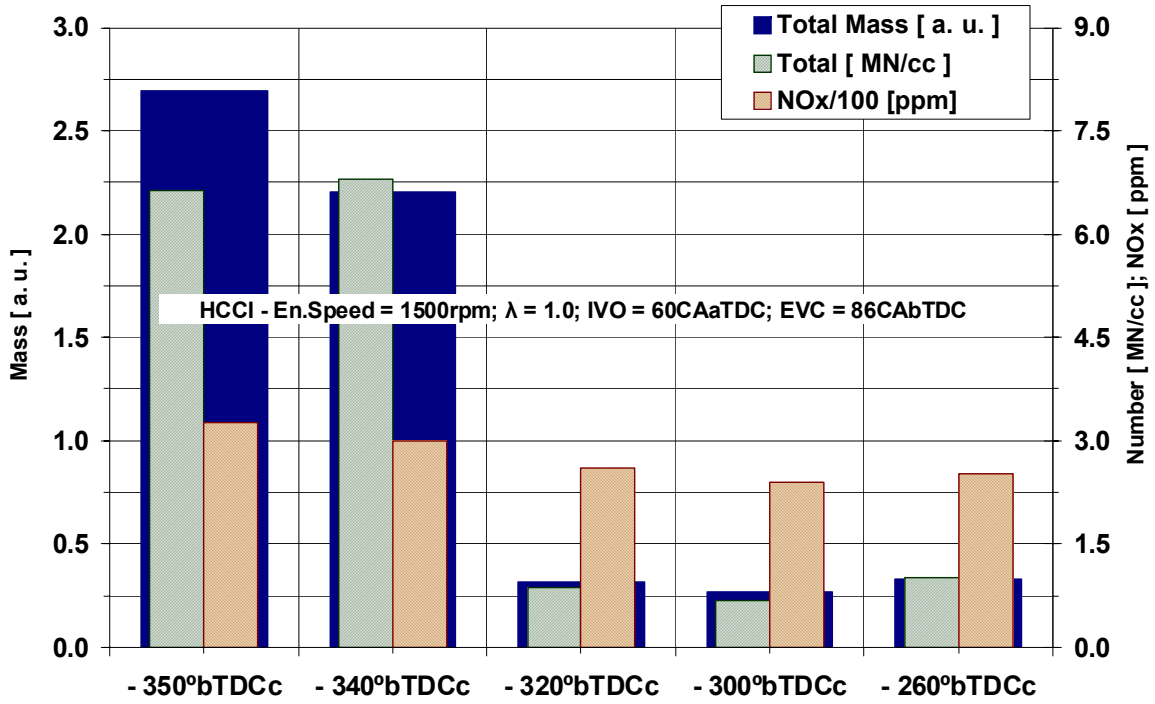



1. At a higher load condition for IMEP of 5.2-5.4bar, PM with HCCI shows a lower level in both accumulation mode and nucleation mode than SI
2. Varied injection timing (-300 or -340) can make a big difference, greater for that in the case of varied valve strategies (A or B) or SI

Xu *et al*, 2008 SAE HCCI Symposium

# PM for varied injection timings - HCCI

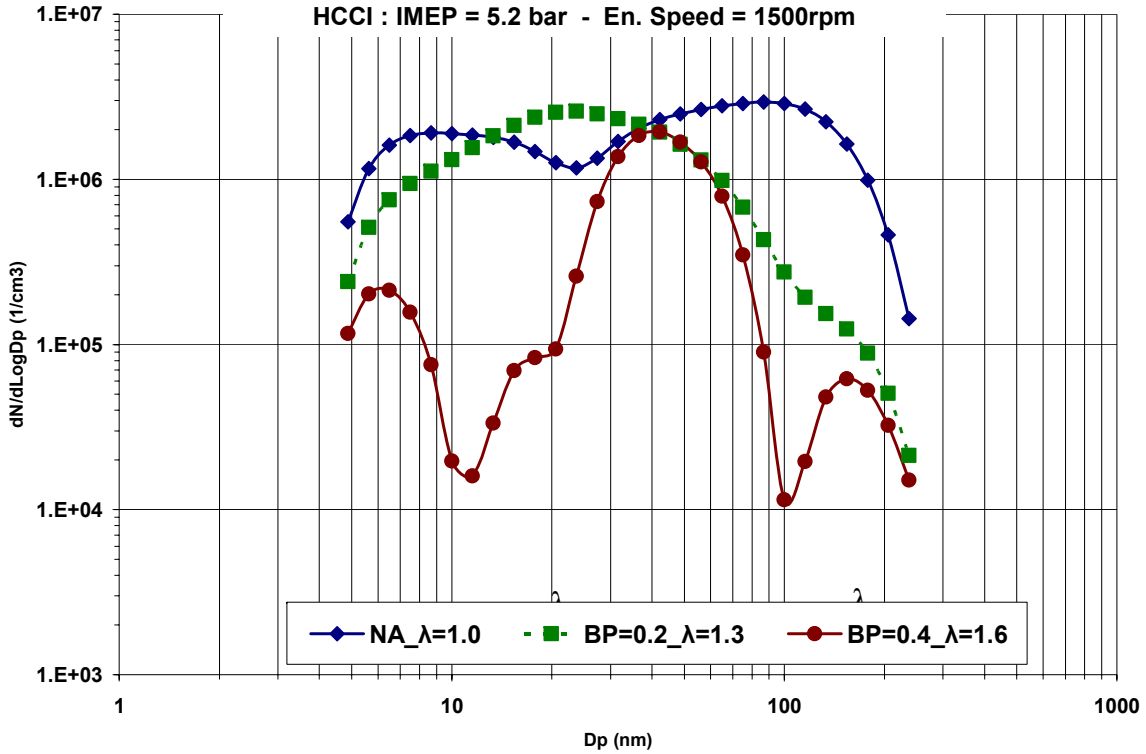
HCCI - 1500rpm; λ = 1.0; IVO = 60CAaTDC; EVC = 86CAbTDC




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

Xu *et al*, 2008 SAE HCCI Symposium

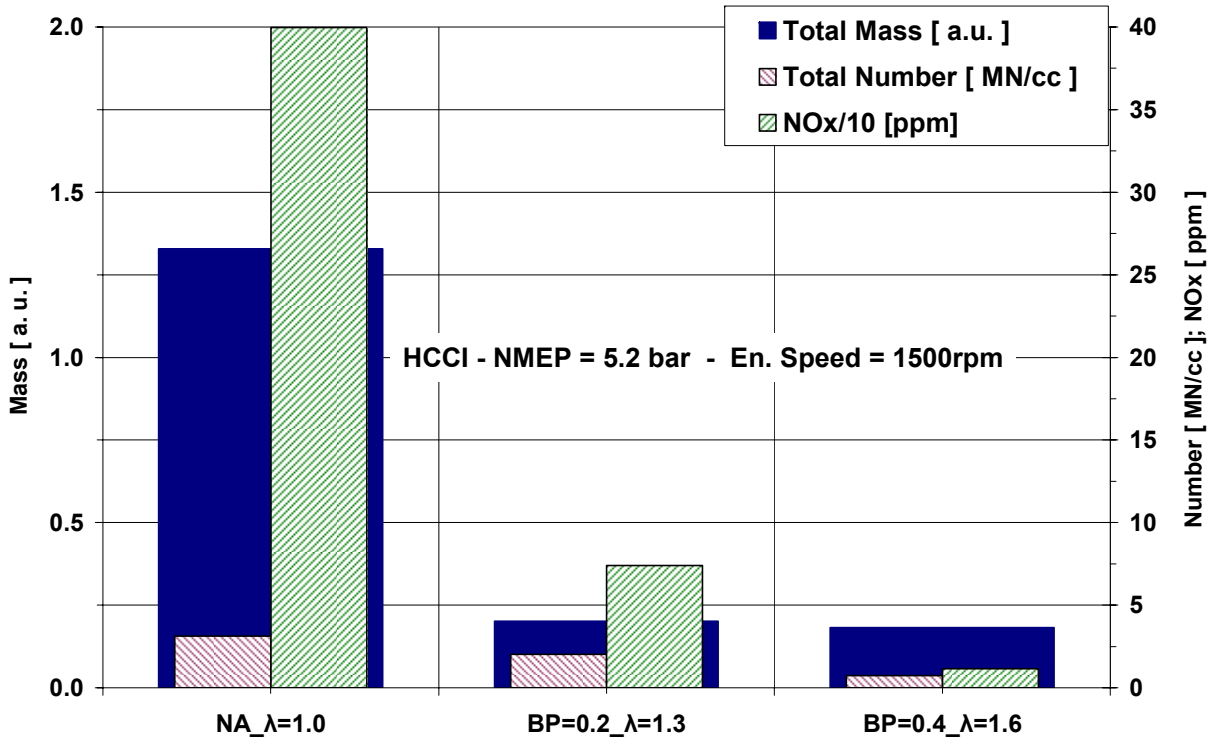
# PM for lean burn with boosting - HCCI




lean burn significantly reduces PM
over the full spectrum

Xu *et al*, 2008 SAE HCCI Symposium

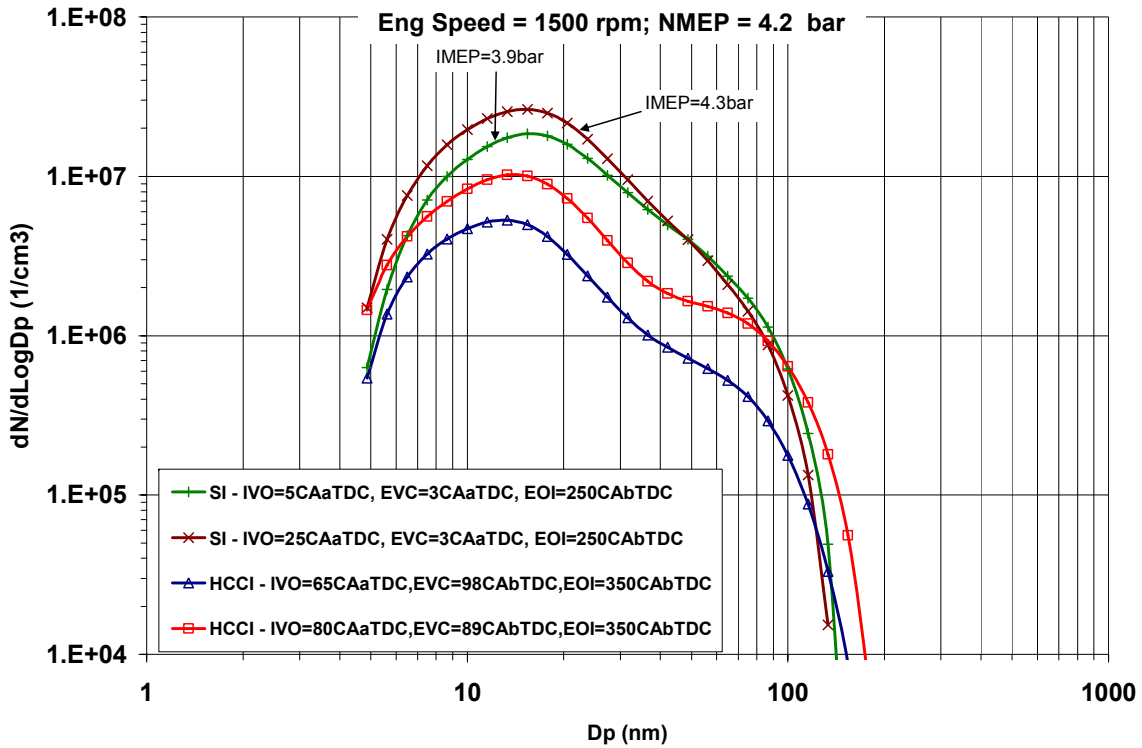
# PM for lean burn with boosting - HCCI




lean burn significantly reduces PM, both in mass and number

Xu *et al*, 2008 SAE HCCI Symposium

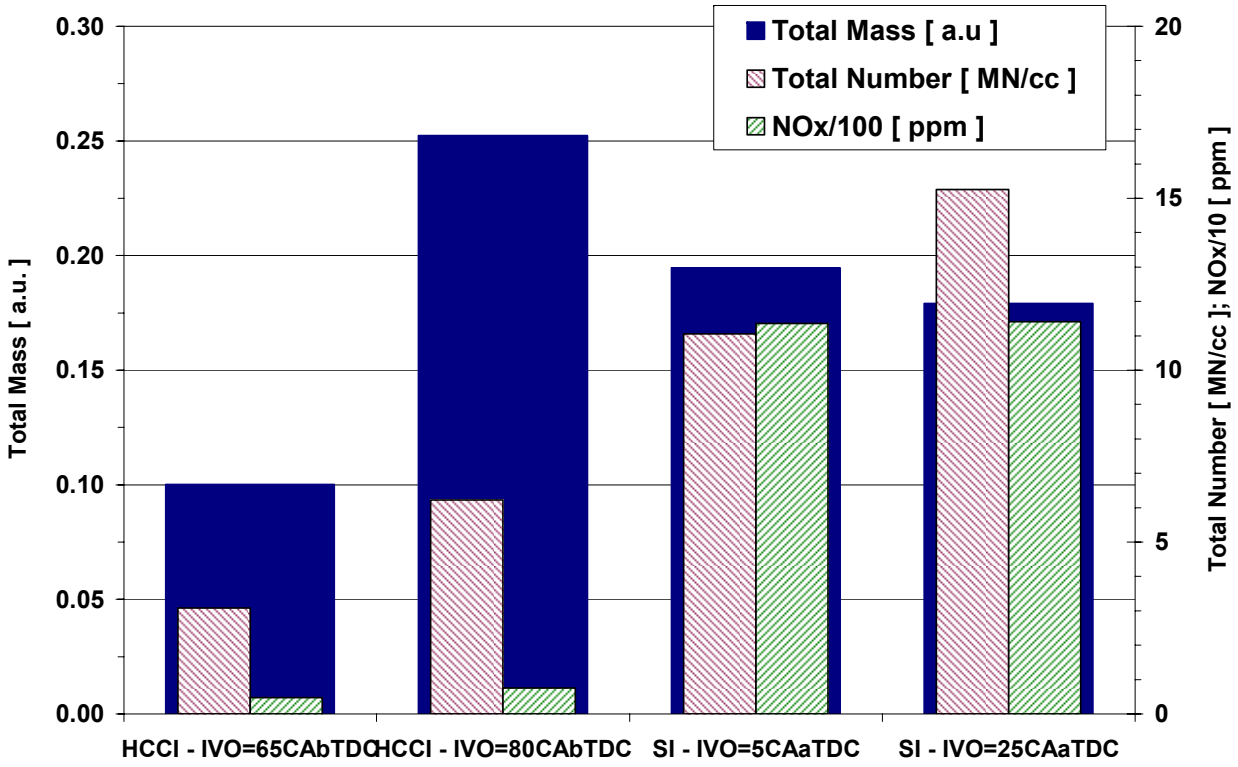
# PM may approach SI for smaller load




There are relatively more larger size of PMs with HCCI at lower load (increase of accumulation mode fractions).

Xu *et al*, 2008 SAE HCCI Symposium

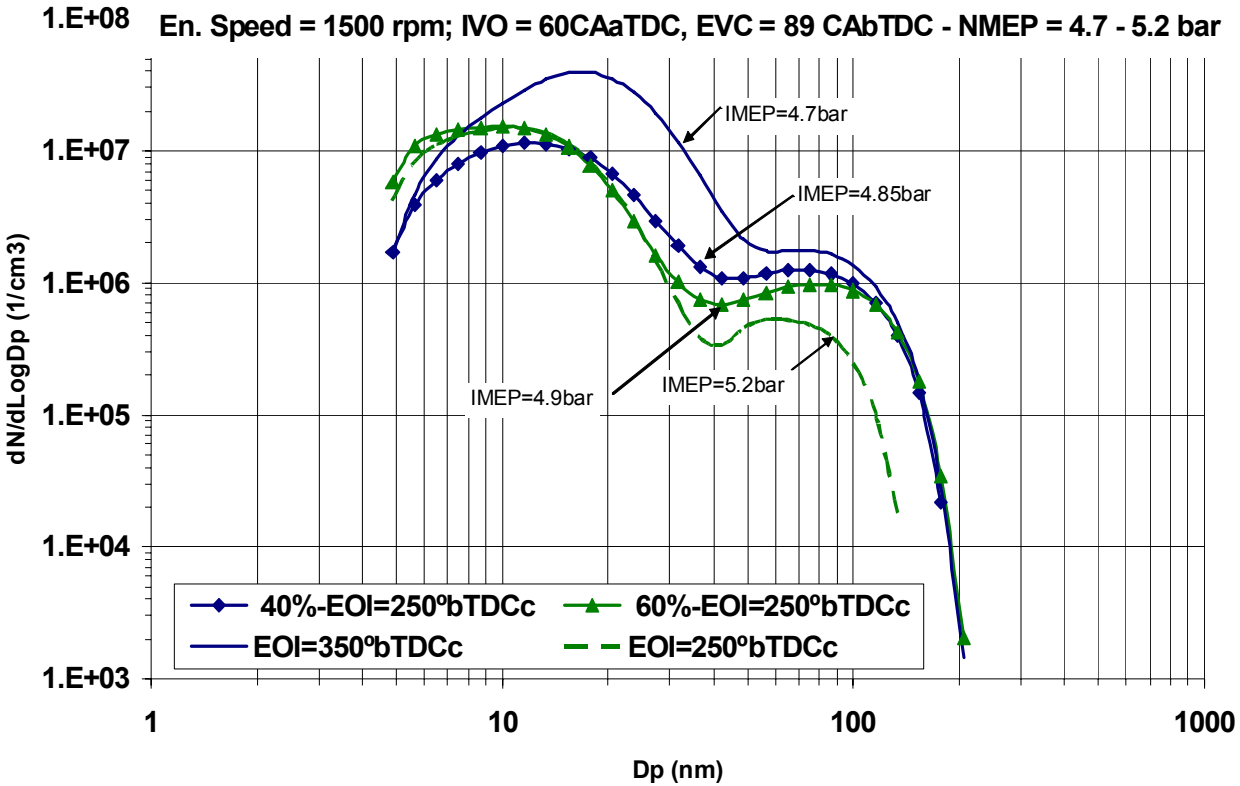
# PM may approach SI for smaller load




In one case, PM mass even
exceeded SI case for the same load

Xu *et al*, 2008 SAE HCCI Symposium

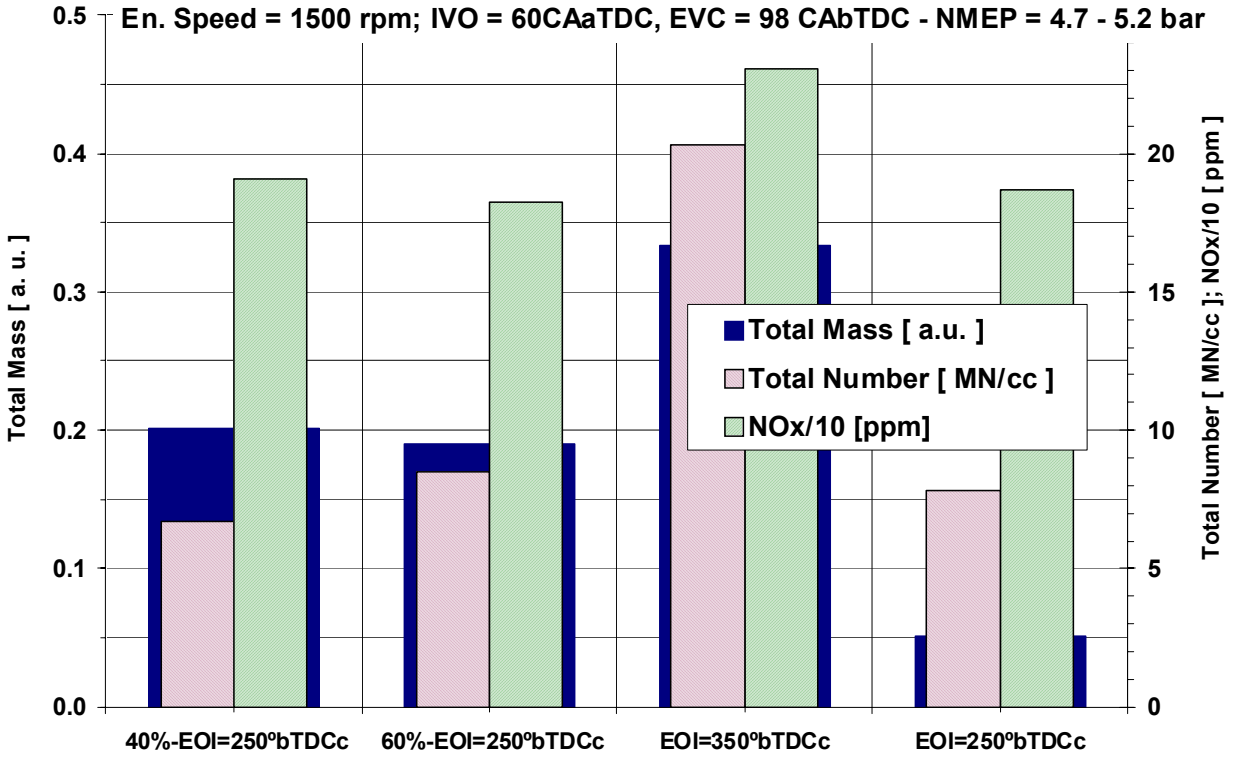
# PM with split injection




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

Xu *et al*, 2008 SAE HCCI Symposium

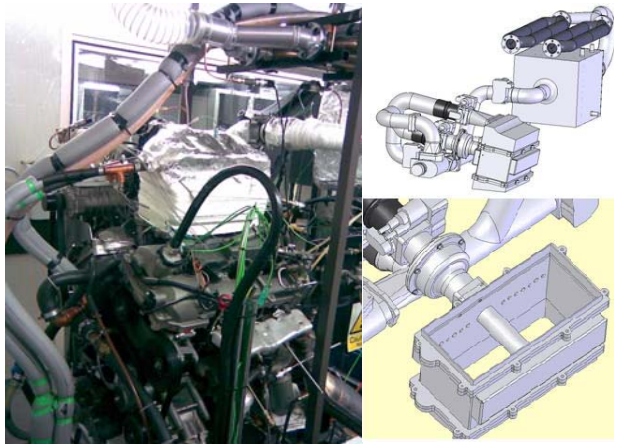
# PM with split injection




More pilot injection may increase PM

Xu *et al*, 2008 SAE HCCI Symposium

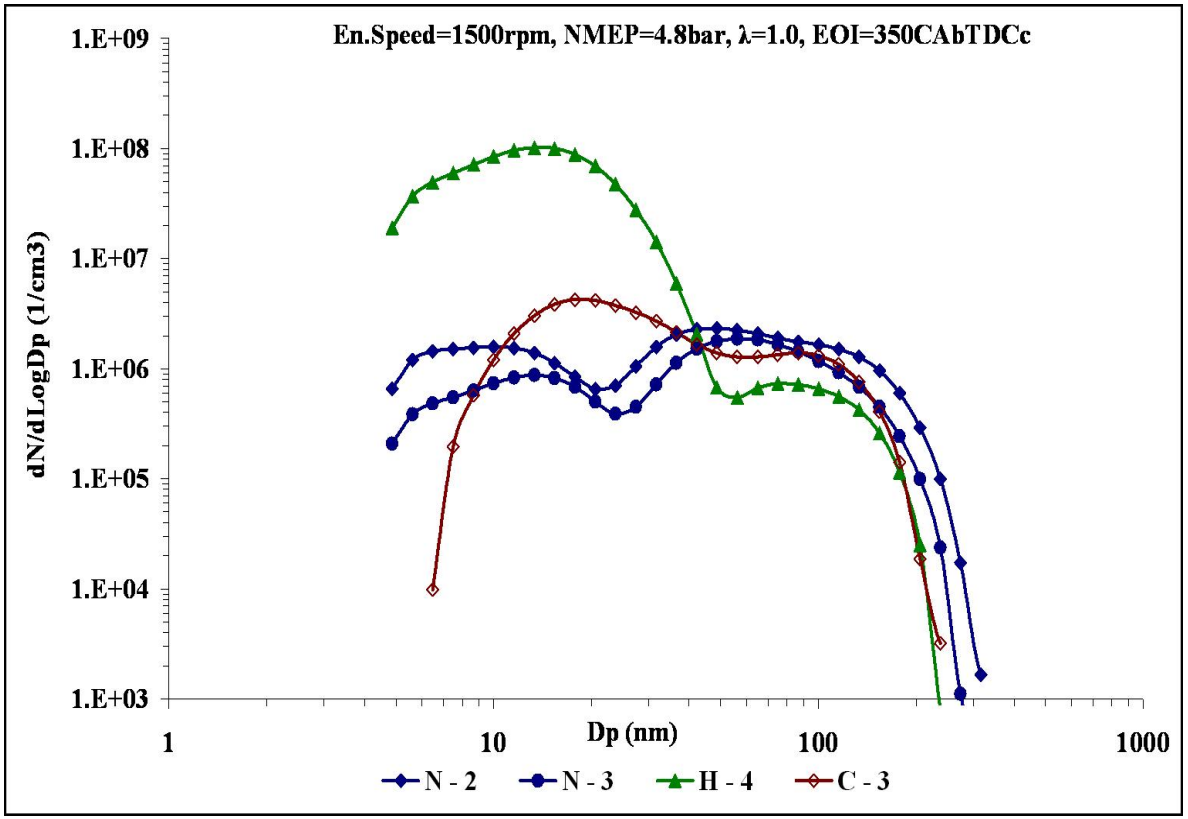
# Effect of intake air temperature



A thermal management system incorporating electrical heaters and an intercooler bypass was used to control the intake air temperature. Varied valve timings are used to regulate the engine load

| | TEST | NMEP | dp/Θ | IVO | EVC | T_In | T_Ex | PM No. 50-300nm | PM Mass 50-300nm | EGR | $\eta_{vol}$ | $\eta_{comb}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | bar | bar/deg. | °aTDC | °bTDC | ° C | ° C | MN/cc | a. u. | % | % | % |
| Ambient Charge Air | N - 2 | 4.8 | 6.0 | 60 | 86 | 56 | 412 | 0.90 | 0.69 | 41.3 | 60.9 | 93.6 |
| Ambient Charge Air | N - 3 | 4.8 | 4.2 | 80 | 81 | 61 | 430 | 0.65 | 0.36 | 40.5 | 60.3 | 93.5 |
| Heated Charge Air | H - 4 | 4.8 | 5.8 | 60 | 91 | 87 | 391 | 0.29 | 0.18 | 44.3 | 53.1 | 93.6 |
| Cooled Charge Air | C - 3 | 4.8 | 2.4 | 80 | 86 | 45 | 438 | 0.57 | 0.31 | 50.3 | 56.0 | 92.7 |

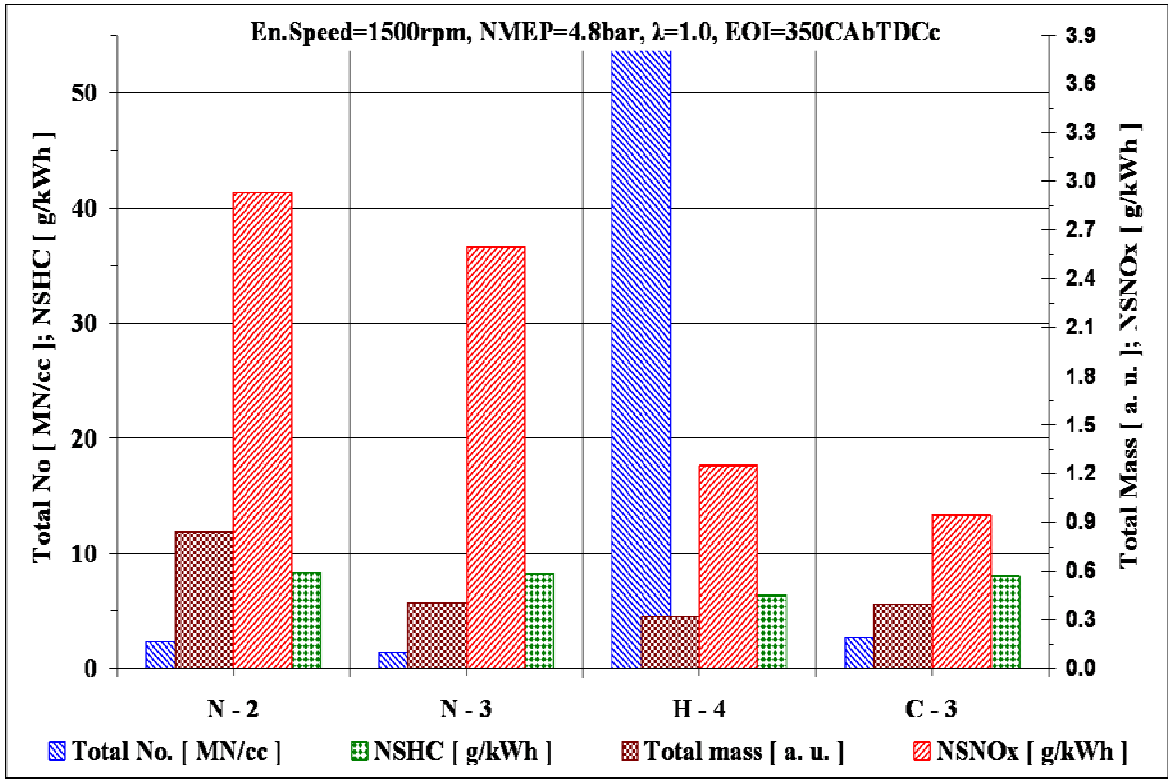
# Effect of intake air temperature (1)




N – normal, H – heated, C – cooled inlet air

Higher intake temperature seems to increase the number of PM in nuclei mode

# Effect of intake air temperature (2)




The effect of intake temperature on the mass of PM is limited, but apparently more on the number

# Summary and conclusions

1. Particulate emissions from HCCI engines are not negligible, especially when taking the number of smaller sized particulates into consideration.
2. 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 valve overlap is reduced, both NOx and PM levels increase with engine load..
3. 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, while pilot injection with impingement may increase PM.
4. Particulate emissions from HCCI engines are affected by air-fuel ratio and intake temperature, while the number of smaller sized particulates is more sensitive to engine conditions.

# Acknowledgement

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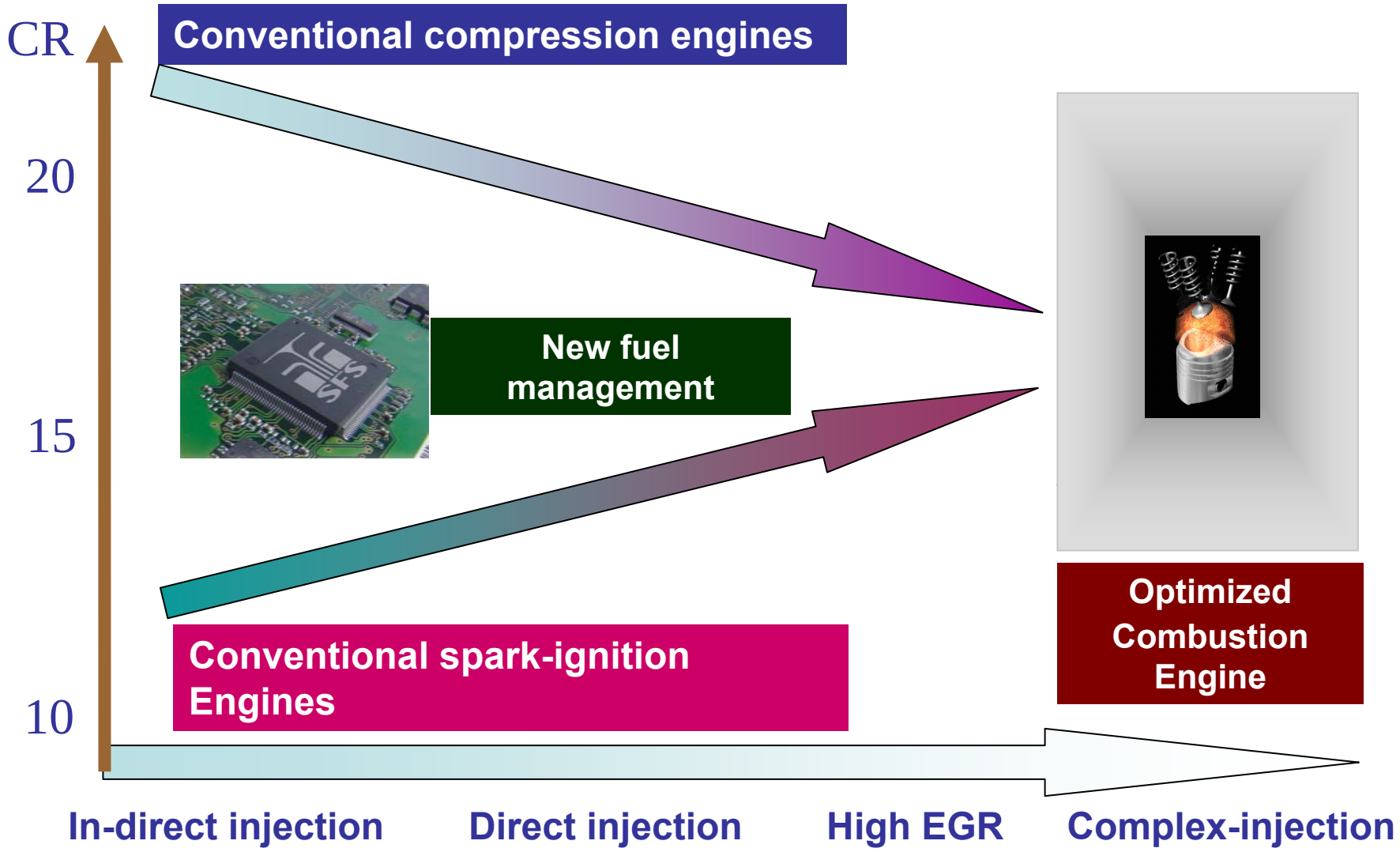
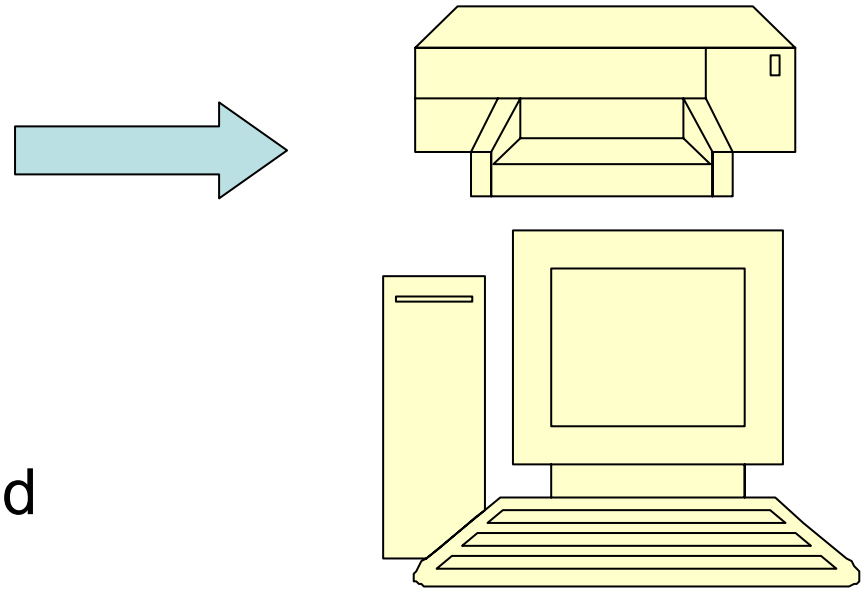
# Gasoline and Diesel Engine Technologies are merging



# 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 cant' 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!