DEVELOPMENT OF A FAST-ACTING, TIME-RESOLVED GAS SAMPLING SYSTEM FOR COMBUSTION AND FUELS ANALYSIS

Midhat Talibi, Paul Hellier, Ramanarayanan Balachandran, Nicos Ladommatos

University College London

SAE INTERNATIONAL

UCL ENGINEERING
Change the world

CONTENTS

INTRODUCTION

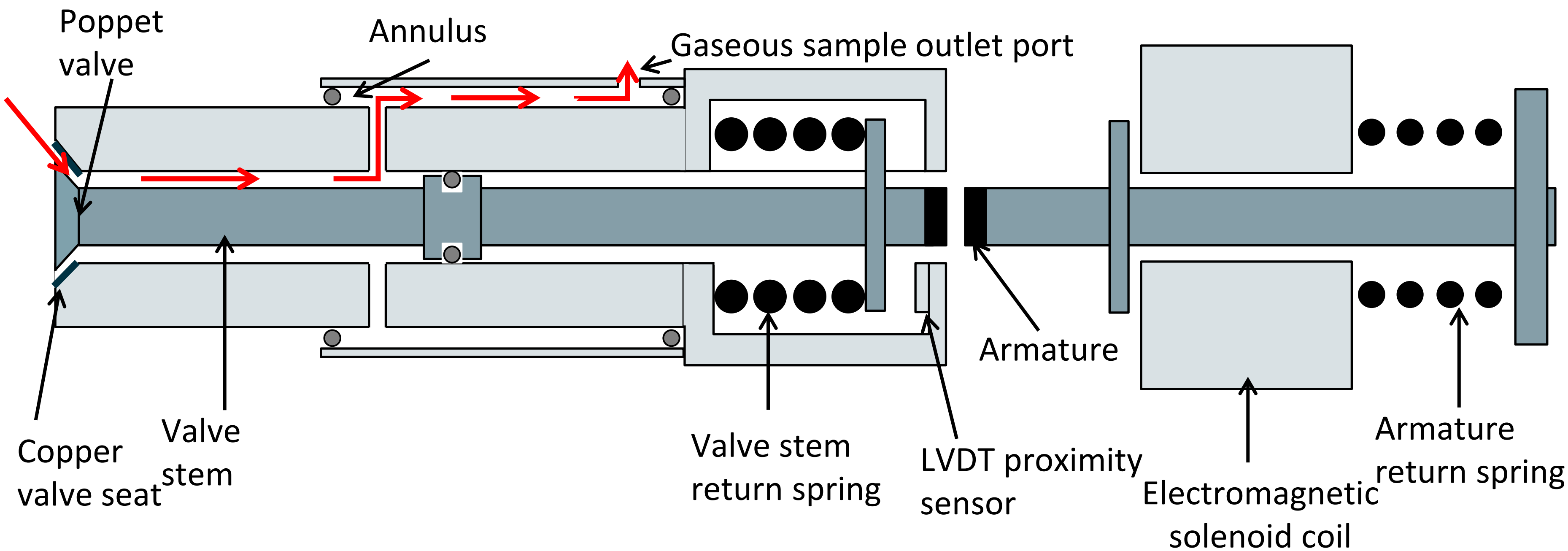
Rising concerns over the hazardous health effects of fossil fuel by-products, including poor air quality and rapid increase in GHG emissions.

Concentrated efforts towards greater fuel efficiency and producing 'cleaner' emissions by optimizing engine combustion behaviour.

Figure source : IFP Energies

Key to developing novel strategies for future combustion systems lies in comprehensively understanding the evolution of engine in-cylinder species and their reaction mechanisms.

IN-CYLINDER GAS SAMPLING VALVE

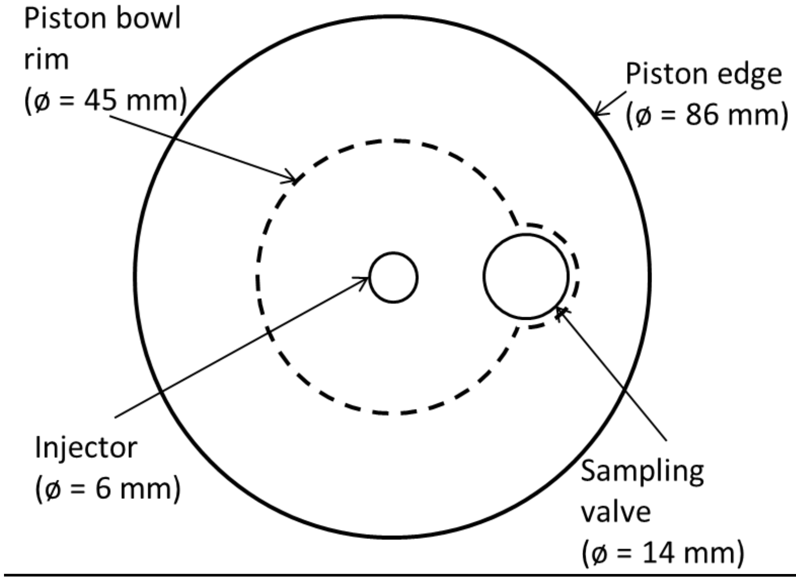


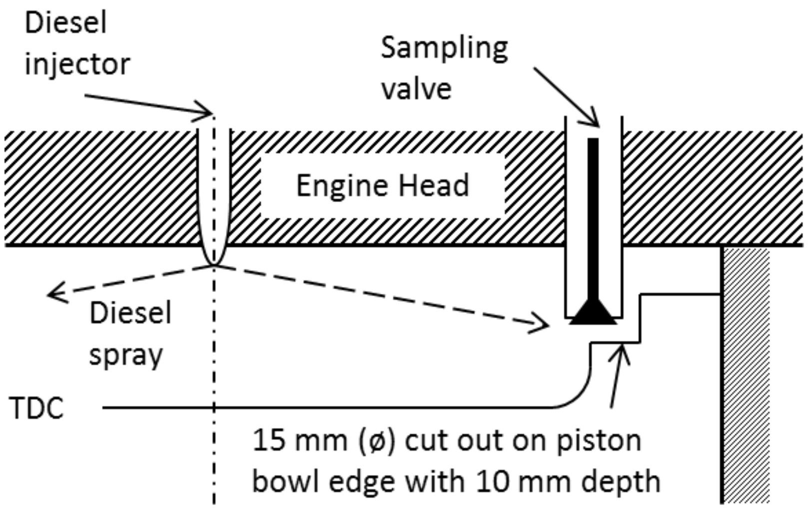
- Based on the ‘percussion’ principle
- Electromagnetic actuation
- Sensitive proximity sensor to measure valve lift
- Poppet valve sits in ‘soft’ copper valve seat

IN-CYLINDER GAS SAMPLING VALVE

- Sampling valve installed in place of one of the inlet valves.
- Valve penetration up to 9mm inside chamber

Tip of the sampling valve in the engine head

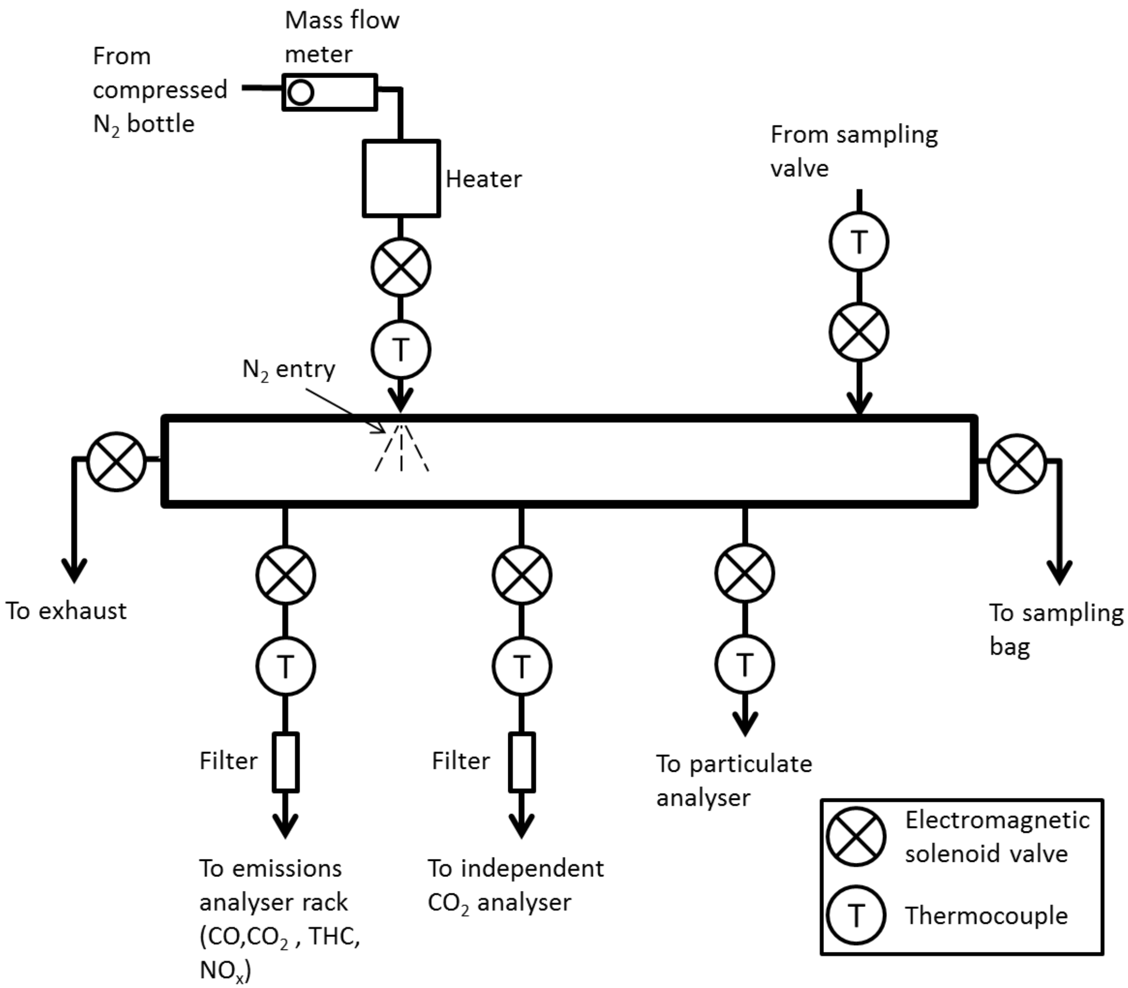




HEATED DILUTION TUNNEL

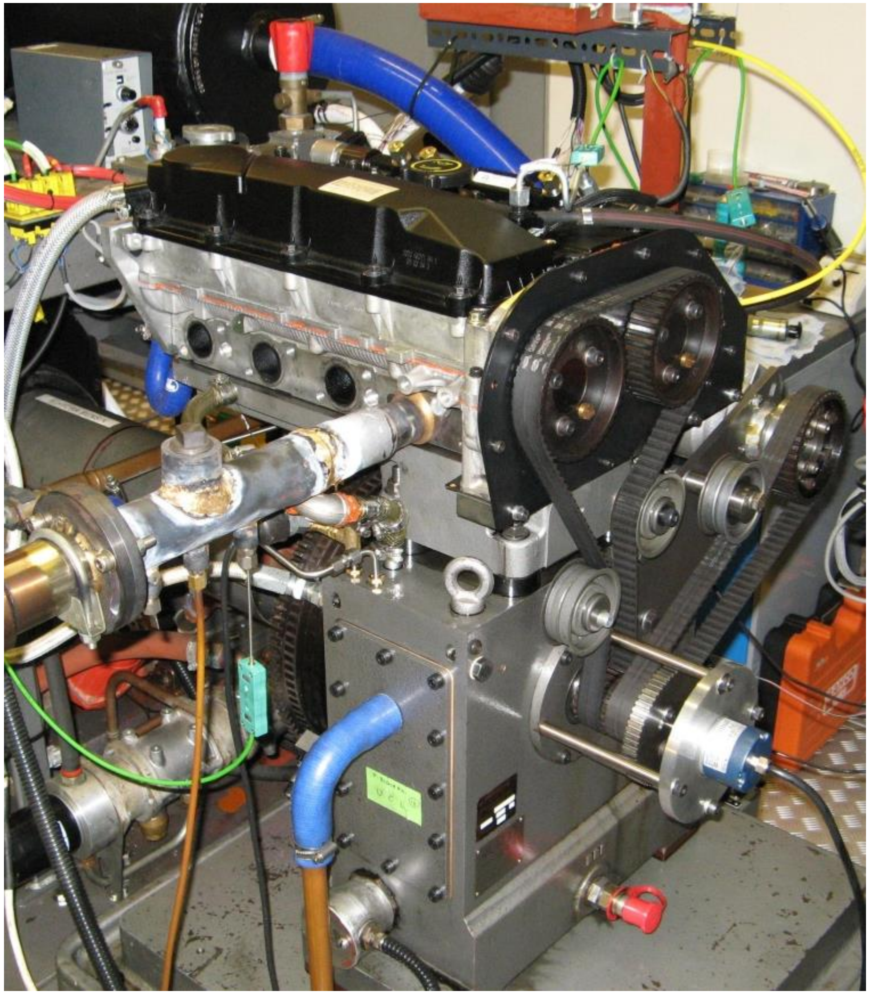
- Buffer the gas samples and mix them with heated N_2 to increase the sample volume

- Undiluted and diluted gas sample streams were fed to the standalone CO_2 analyser and to the emissions analyser rack and the mass ratio calculated



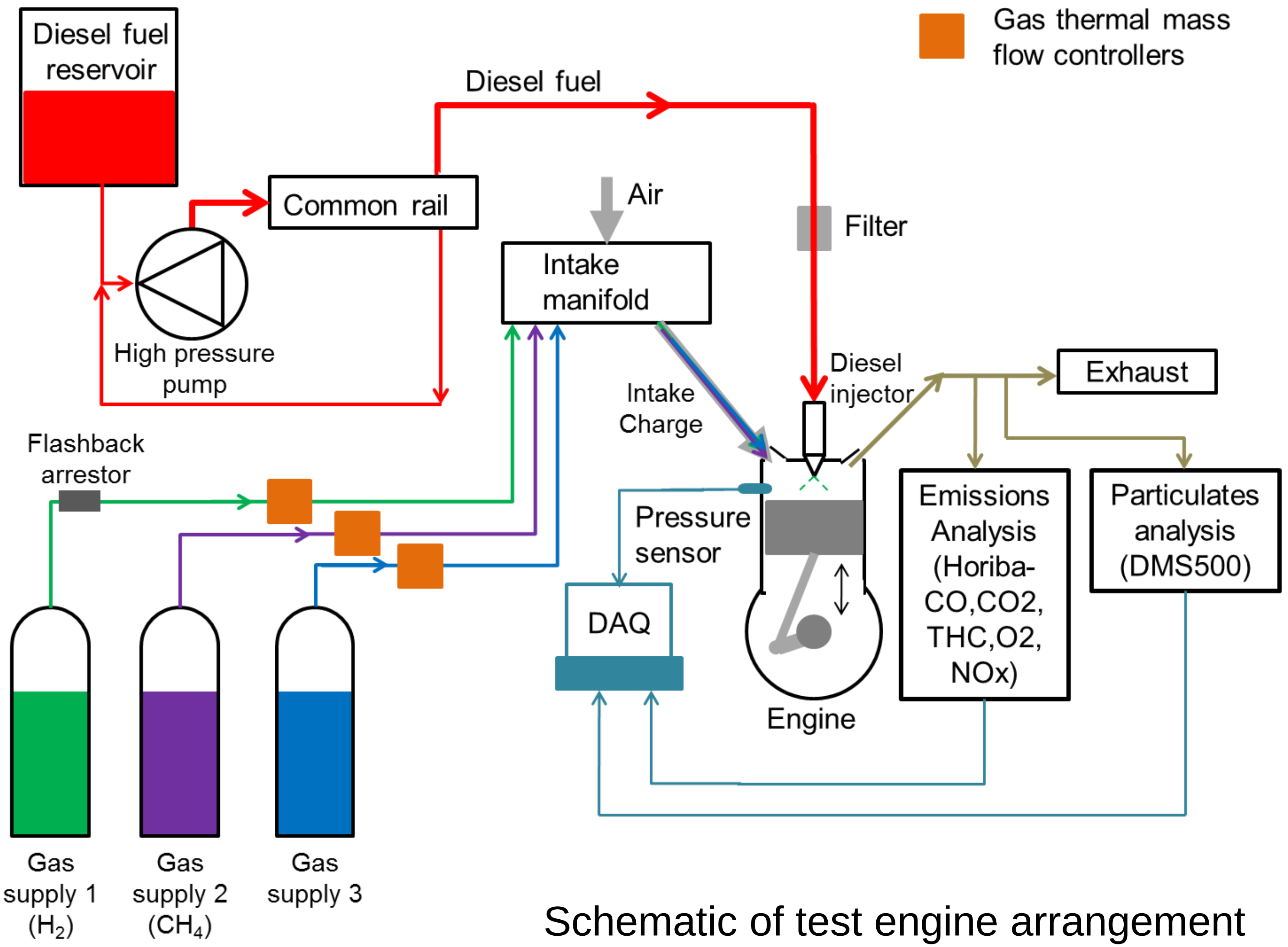
SINGLE CYLINDER TEST ENGINE

- Four-stroke, single cylinder, compression-ignition engine
- Naturally aspirated (capability for intake air boosting)
- Direct injection engine with a high pressure common rail – fuel injection pump system
- Compression ratio – 18.3:1
- Capability to measure in-cylinder gas pressure (to a resolution of 0.2 CAD)



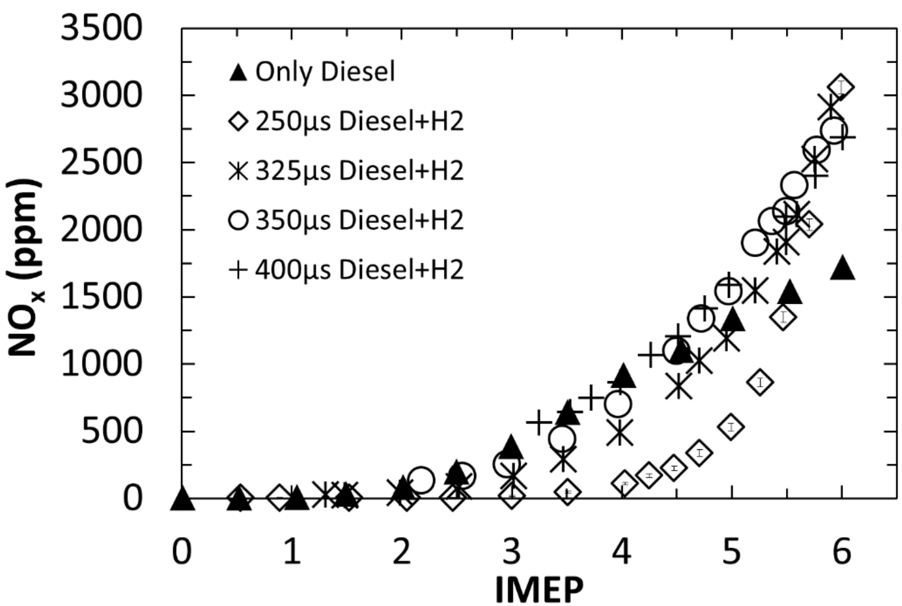
Ford 2.0l single cylinder diesel engine assembly

TEST FACILITY SCHEMATIC

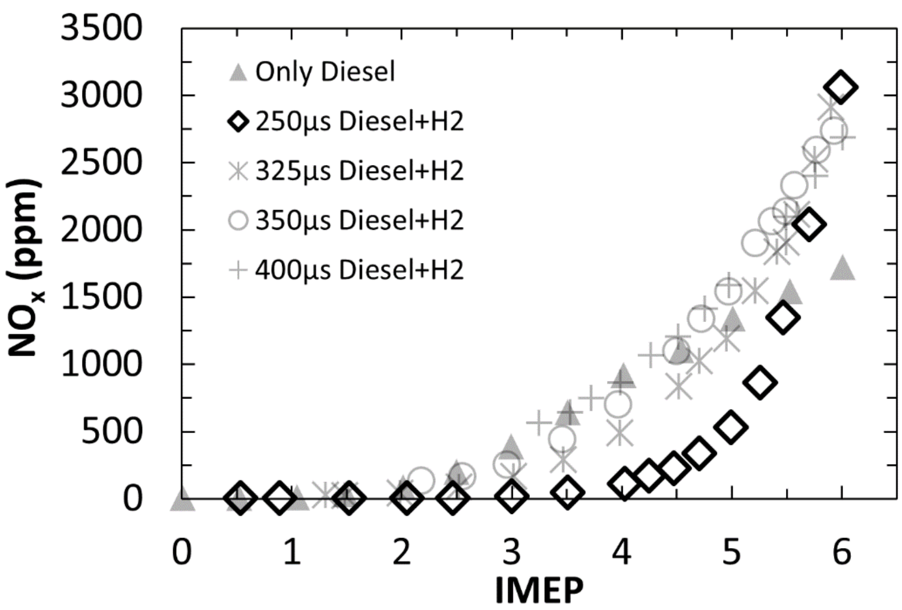


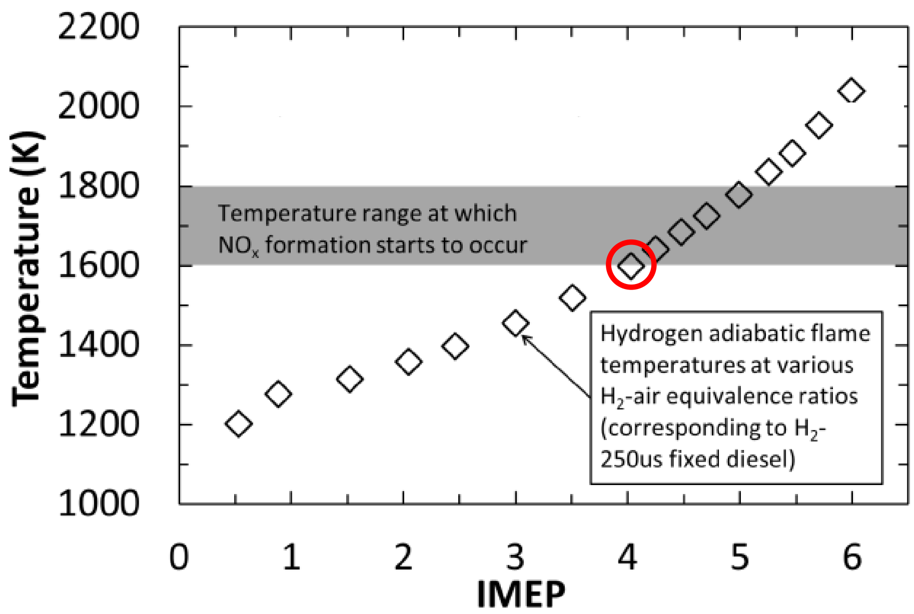
Schematic of test engine arrangement

H_2-DIESEL FUEL, EXHAUST NO_X EMISSIONS



H_2-DIESEL FUEL, EXHAUST NO_X EMISSIONS

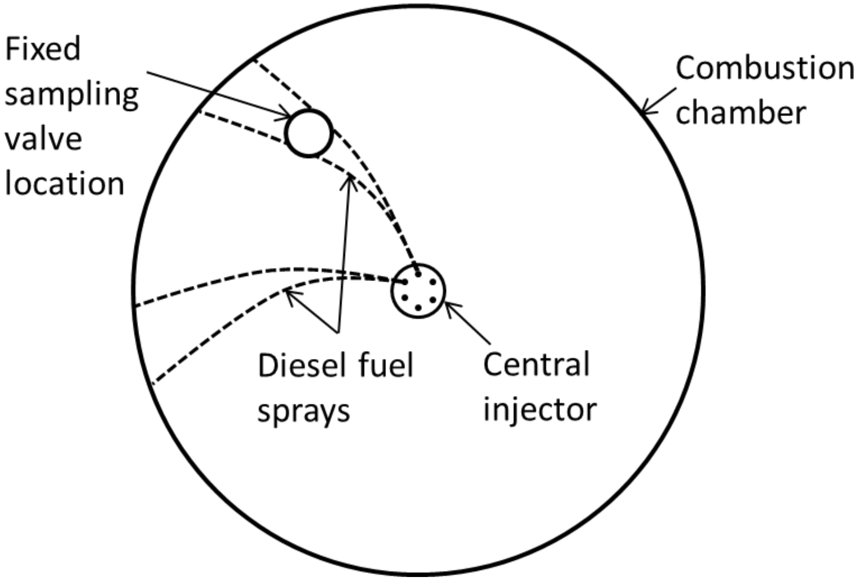


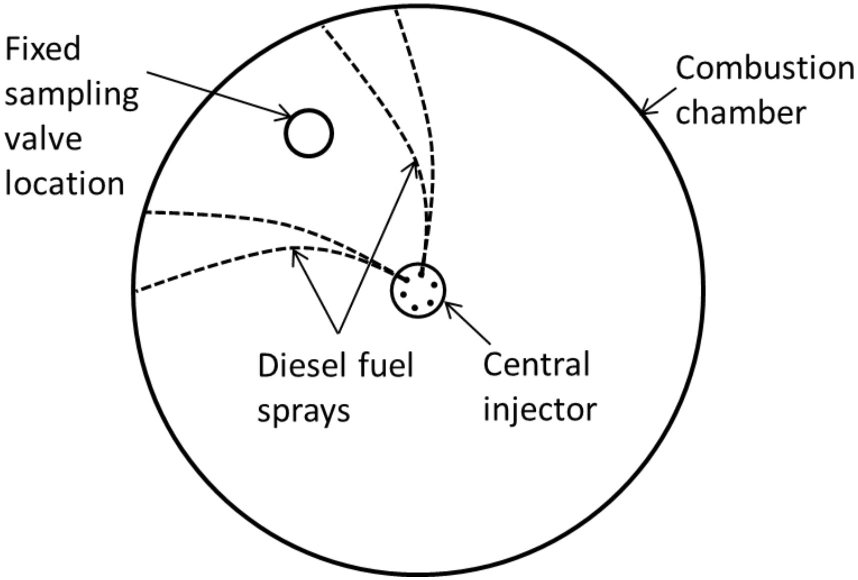


- For loads below 4 bar, negligible levels of NO_x formed
- Above 4 bar, NO_x formation rates accelerated significantly
- Suggests thermal synergy of H_2-diesel co-combustion
- Sharp increase in NO_x coincides with H_2 flame temperatures reaching NO_x formation temperatures

IN-CYLINDER GAS SAMPLING TESTS

- Gas samples extracted with two different sampling arrangements relative to the fuel spray; in the core of the diesel fuel spray and between two spray cones.
- Change in sampling arrangement achieved through rotation of the centrally-located injector





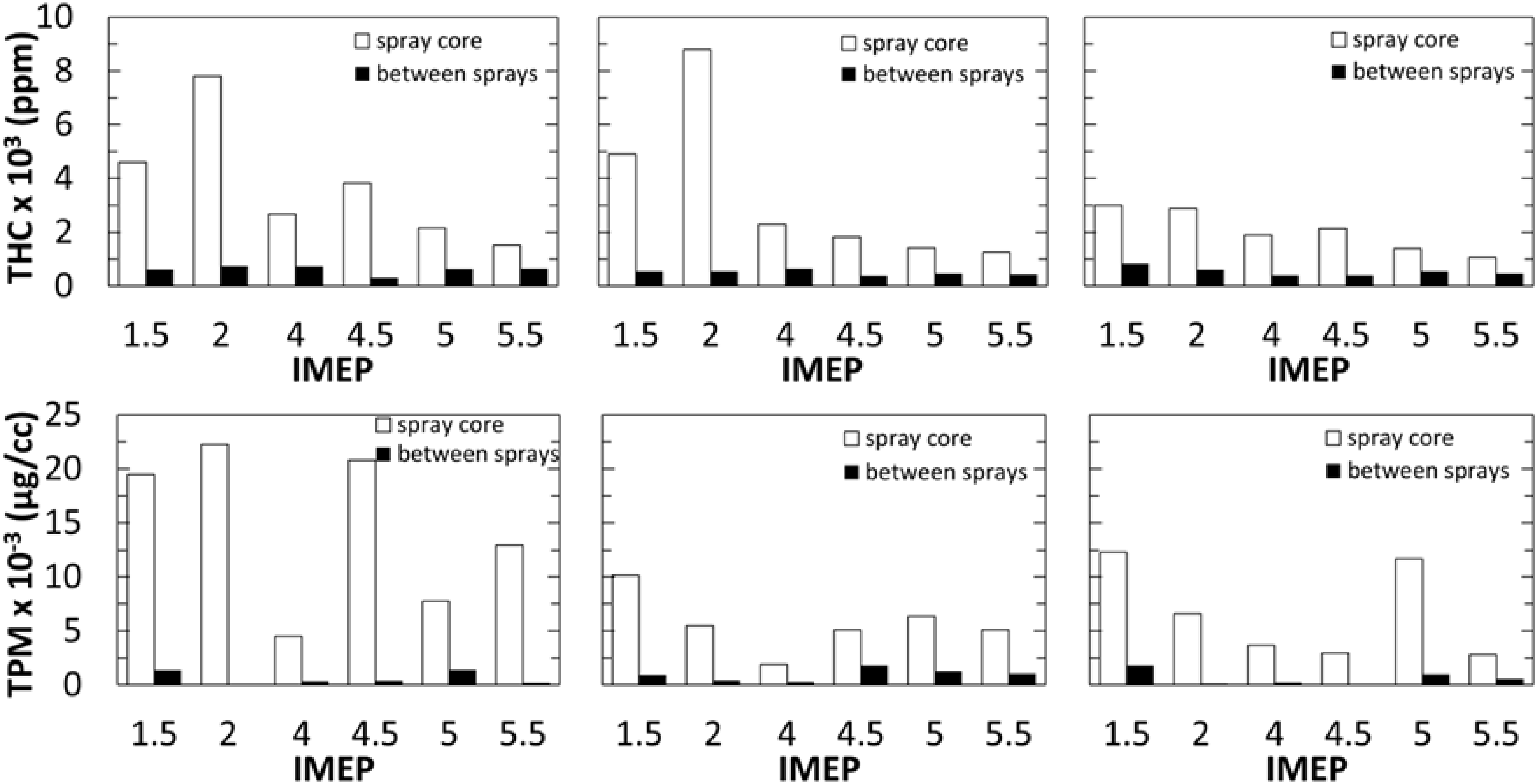
IN-CYLINDER GAS SAMPLING TESTS

- For each of the two relative sampling arrangements, gas samples were extracted at three sampling instants within the engine cycles.

Sampling instant (middle of sampling window) (CAD ATDC)	Duration of sampling window (CAD)	Diesel fuel injection period (μs)
10 (premixed combustion)	6	325
25 (early diffusion combustion)	10	325
40 (late burning stage)	15	325

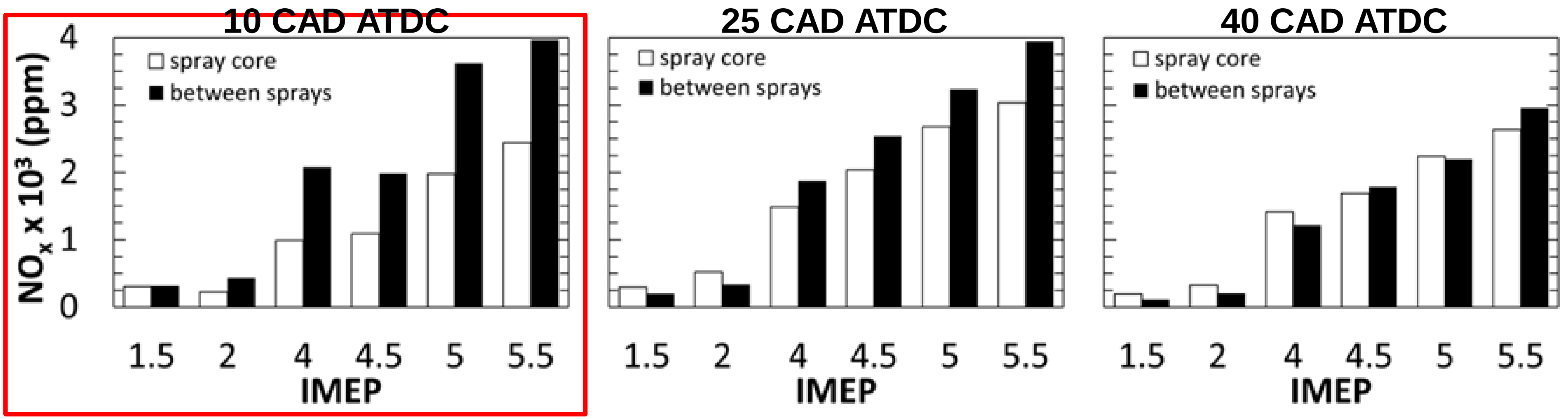
Gaseous sample extraction time CAD ATDC during the engine cycle and the corresponding sampling window in CAD

IN-CYLINDER GAS SAMPLING WITH H_2 – THC AND PM



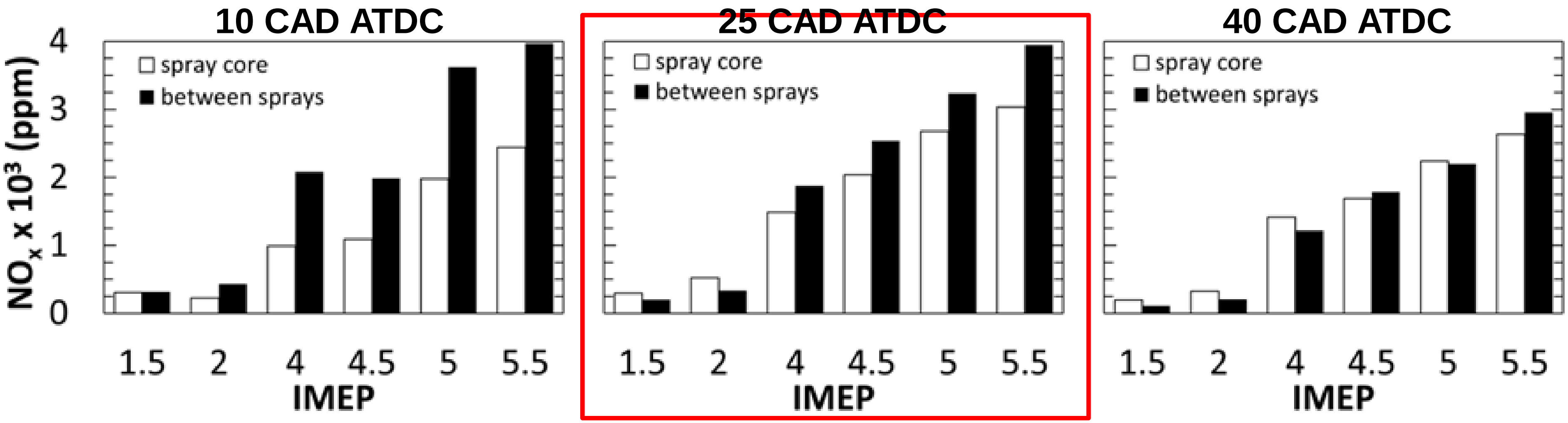
10 CAD ATDC	25 CAD ATDC	40 CAD ATDC
Premixed combustion	Early diffusion	Late burning

IN-CYLINDER GAS SAMPLING WITH H_2 – NO_X



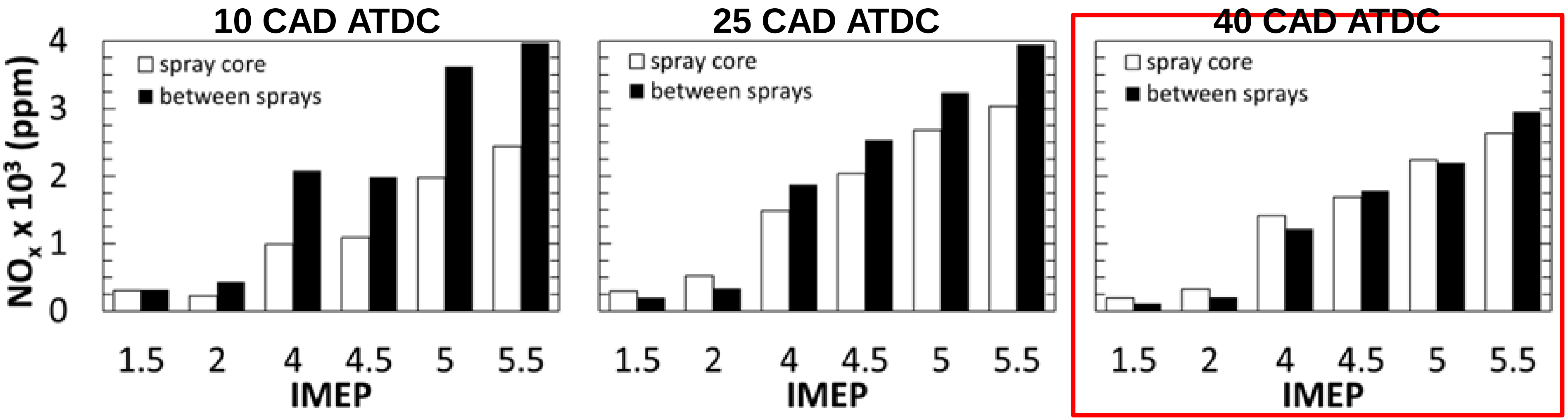
- At 10 CAD, NO_x levels significantly higher between sprays.
- Due to H_2 combustion adding to diesel flame temperatures, leading to high temperatures, hence greater NO_x production
- At 25 CAD, NO_x levels increase in spray core region
- At 40 CAD, redistribution of in-cylinder gases lowers NO_x levels

IN-CYLINDER GAS SAMPLING WITH H_2 – NO_X



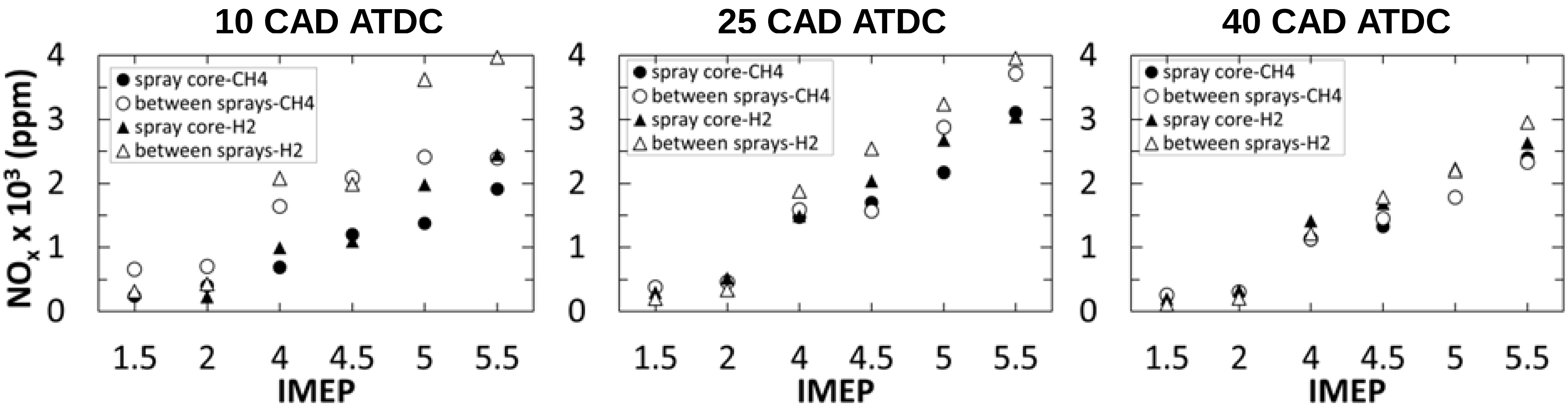
- At 10 CAD, NO_x levels significantly higher between sprays.
- Due to H_2 combustion adding to diesel flame temperatures, leading to high temperatures, hence greater NO_x production
- At 25 CAD, NO_x levels increase in spray core region
- At 40 CAD, redistribution of in-cylinder gases lowers NO_x levels

IN-CYLINDER GAS SAMPLING WITH H_2 – NO_X



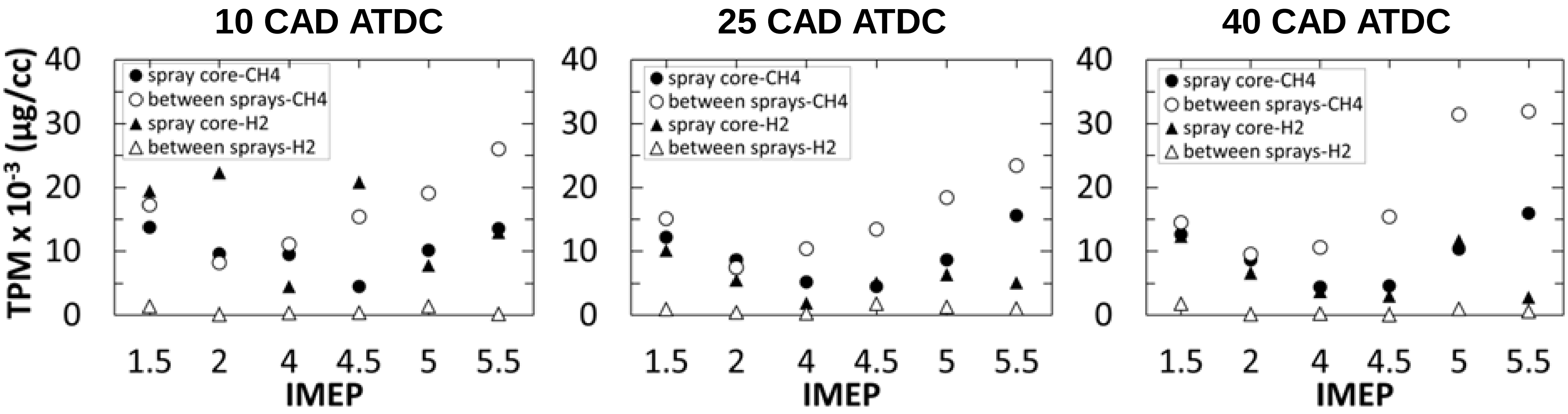
- At 10 CAD, NO_x levels significantly higher between sprays.
- Due to H_2 combustion adding to diesel flame temperatures, leading to high temperatures, hence greater NO_x production
- At 25 CAD, NO_x levels increase in spray core region
- At 40 CAD, redistribution of in-cylinder gases lowers NO_x levels

IN-CYLINDER GAS SAMPLING WITH H_2 and CH_4 – NO_X



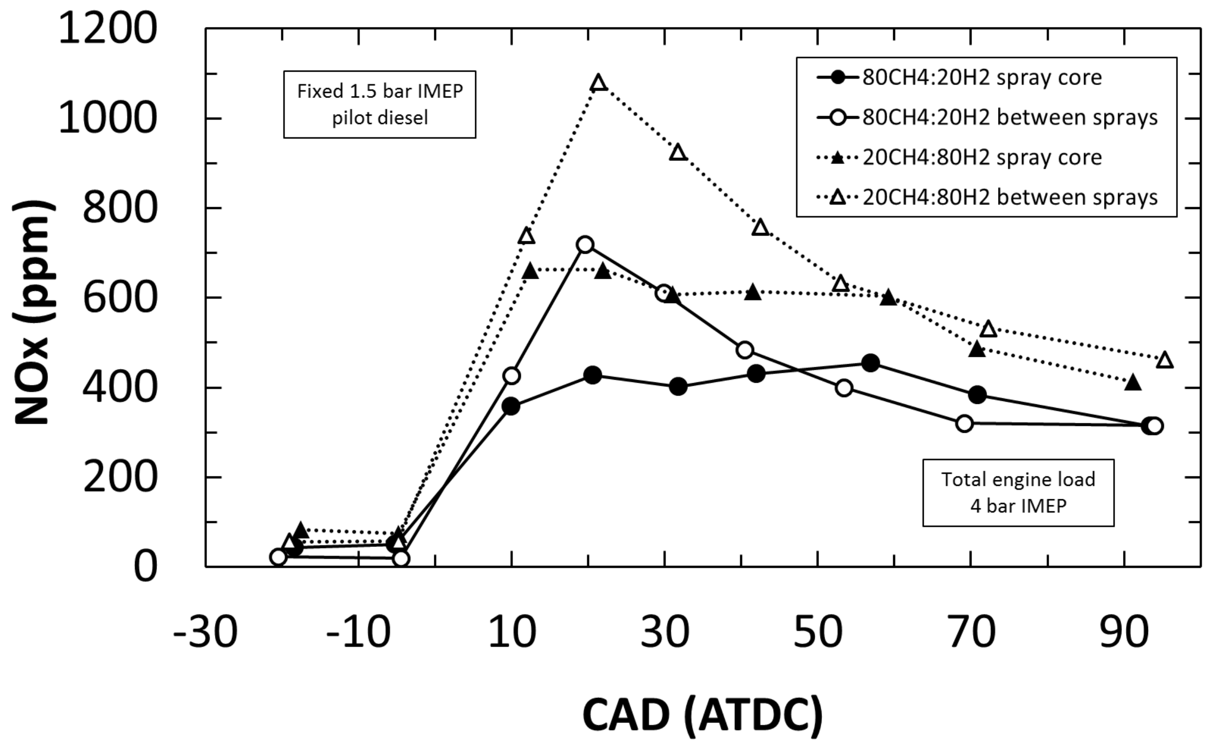
- For both CH_4 and H_2, NO_x levels higher between sprays as compared to within the spray core, suggesting higher gas temperatures in that region.
- NOx levels generally higher with H_2 than CH_4, as H_2 burns at a higher adiabatic flame temperature

IN-CYLINDER GAS SAMPLING WITH H_2 and CH_4 – PM



- PM higher in spray core than between sprays with H_2
- However, PM higher between sprays than in spray core with CH_4
- Suggests significant quantities of particulates being produced by CH_4, since CH_4 concentration higher in the region between sprays.

IN-CYLINDER GAS SAMPLING WITH H_2-CH_4 mixtures – NO_X



- NO_x levels highest when with $20CH_4$:$80H_2$ mixtures, and in the region between sprays.
- H_2 burns at higher temperatures compared to CH_4 and diesel fuel.
- After 40 CAD, NO_x levels similar between the two sampling arrangements.

CONCLUSIONS

- A novel gas sampling system was developed to analyse in- cylinder gas composition and particulate concentration.
- In-cylinder NO_x levels were higher between two diesel fuel sprays than in the spray core, in the case of both H_2-diesel fuel and CH_4-diesel fuel co-combustion, during the early stages of combustion.
- The contrast in species concentrations was significantly less after 40 CAD ATDC, due to effects of redistribution of in-cylinder gases during the expansion stroke.
- With H_2, PM levels were higher in diesel fuel spray compared to between sprays. On the other hand, with CH_4, PM levels were significantly higher between the two diesel fuel sprays.
- Exhaust NO_x emissions were observed to increase very rapidly with the addition of H_2 but only when the combined temperatures from H_2-diesel fuel co-combustion exceeded the NO_x formation temperature threshold.

Thank you

Midhat Talibi

m.talibi@ucl.ac.uk

UCL Mechanical Engineering, UK

- M. Talibi et al., “Effect of hydrogen-diesel fuel co-combustion on exhaust emissions with verification using an in–cylinder gas sampling technique,” *International Journal of Hydrogen Energy*, vol. 39, no. 27, pp. 15088–15102, Sep. 2014. http://dx.doi.org/10.1016/j.ijhydene.2014.07.039
- M. Talibi, “Co-combustion of diesel and gaseous fuels with exhaust emissions analysis and in-cylinder gas sampling,” University College London, 2015.
- M. Talibi et al., "Development of a Fast-Acting, Time-Resolved Gas Sampling System for Combustion and Fuels Analysis," SAE Int. J. Engines 9(2):2016, doi:10.4271/2016-01-0791