Manchester Metropolitan University

Effects of Ultra-High Injection Pressure and Micro-hole Nozzle on Spray Formation and Combustion Characteristics of Waste Cooked Oil Biodiesel under Diesel Engine Conditions

Olawole Abiola KUTI

Manchester Metropolitan University

o.kuti@mmu.ac.uk

Manchester Metropolitan University

Outline

- Introduction
- Spray formation
- Combustion characteristics
- Conclusions

Manchester Metropolitan University

Outline

- Introduction
- Spray Formation
- Combustion
- Conclusions

Manchester Metropolitan University

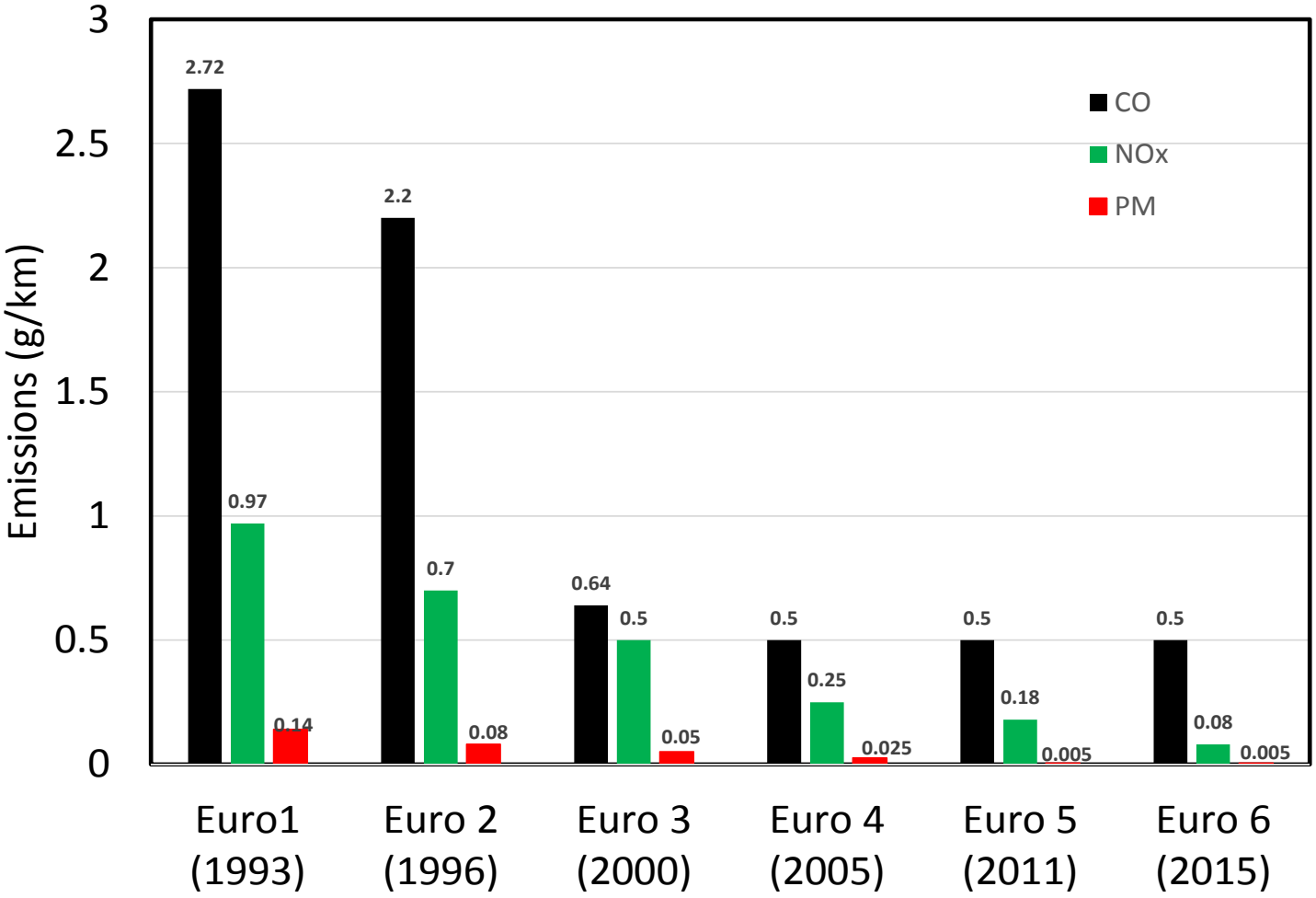
Role of advanced combustion systems in transportation

Manchester Metropolitan University

Major Concerns

Manchester Metropolitan University

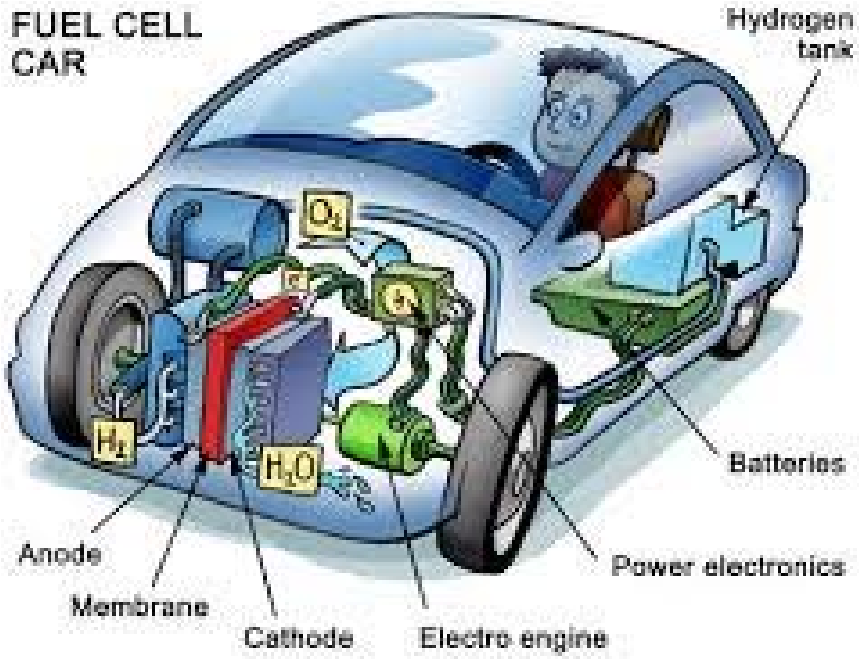
Major challenge



Source: https://www.theaa.com/motoring_advice/fuels-and-environment/euro-emissions-standards.html

Manchester Metropolitan University

Will fuel cell be the solution?



Manchester Metropolitan University

Will fuel cell be the solution?

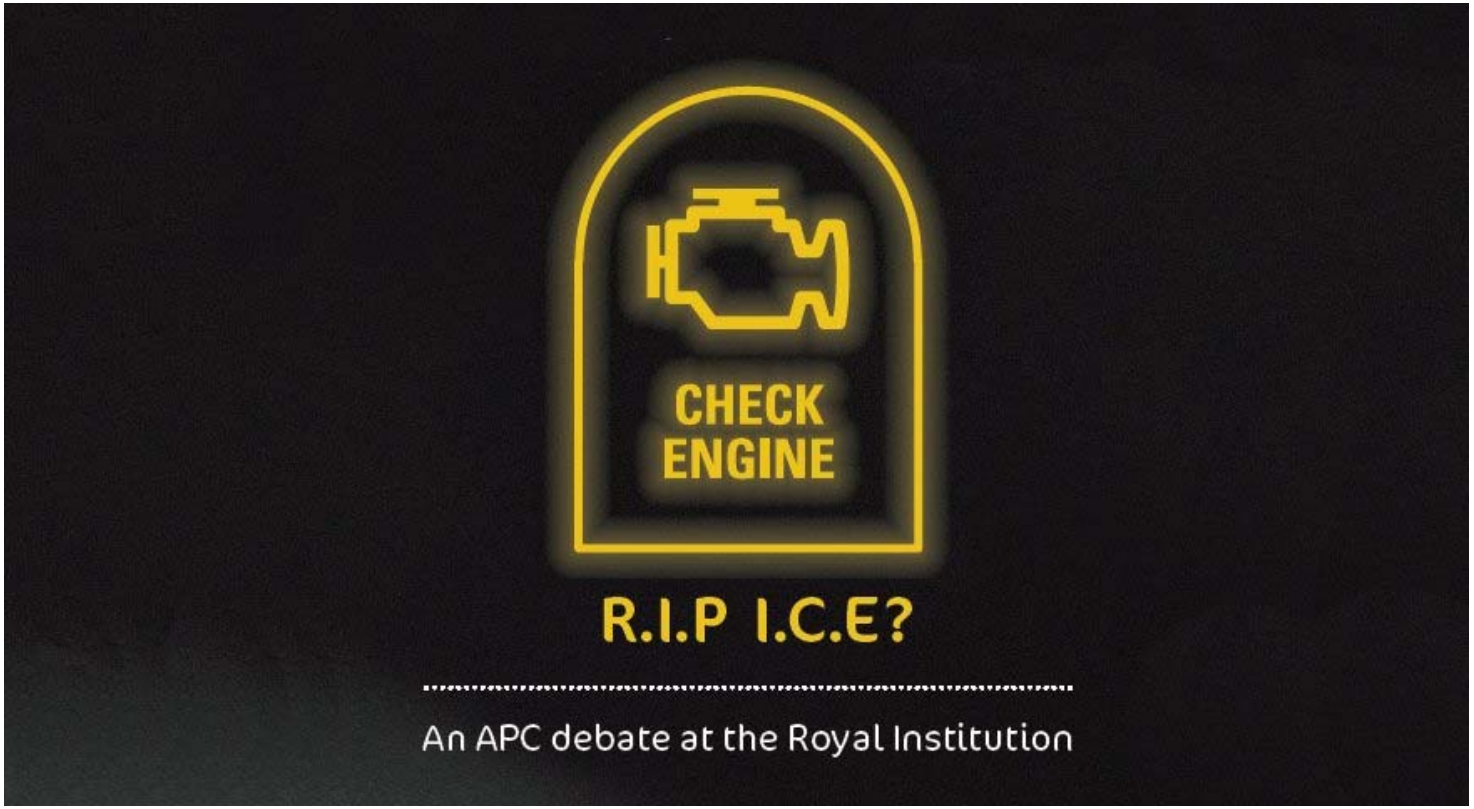
Electricity promises to reduce emissions. However for larger engines if electricity will be used there will still be the need to incorporate diesel engine to form an hybrid system in order to meet up with power demand

Also shortcomings could include

- ✓ Charging points
- ✓ Infrastructure Cost
- ✓ Battery weight

Manchester Metropolitan University

Excerpts from EPRSC and UK APC Report



"matching the range capability of a 44-tonne diesel lorry would require more than 30 tonnes of battery, leaving only about 12 tonnes for freight. **"EVs as HGVs are just not feasible"**
Addressing the central question of the debate – is it RIP for ICE? ....."I think probably not yet. Where we have to move large loads over long distances, **then electric isn't the right solution."**

Manchester Metropolitan University

What is the way forward?

❑Fuel Injection Strategy

- ✓High Injection Pressure
- ✓Nozzle hole size

❑Fuel Formulation

- ✓Alternative fuels i.e Biofuels (Biodiesel)

Manchester Metropolitan University

Motivation

Spray characteristics, such as spray penetration length, spray angle, liquid phase penetration length and air entrainment, of biodiesel fuels whose viscosity is higher than the diesel fuel

Role of cetane number and fuel oxygen content on combustion flame and soot characteristics of biodiesel sprays.

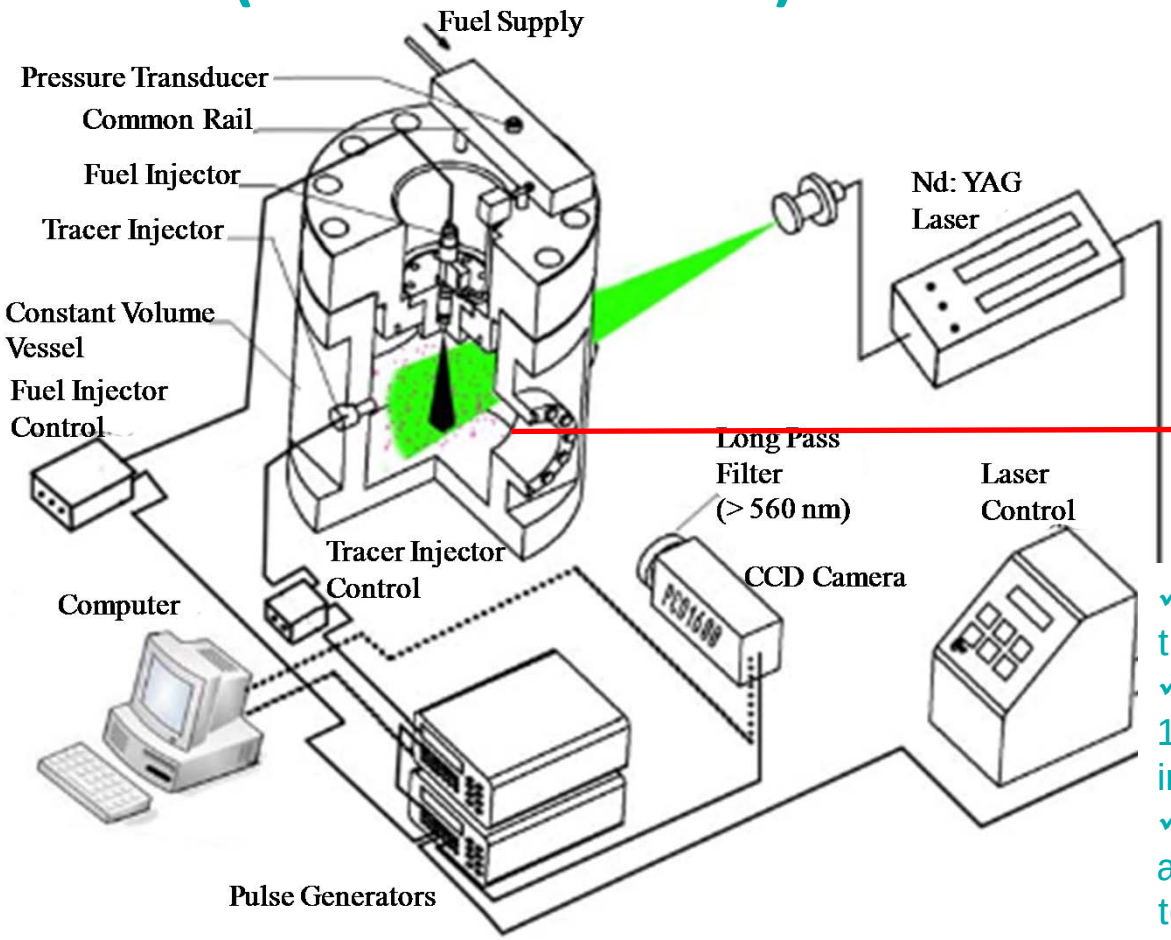
Manchester Metropolitan University

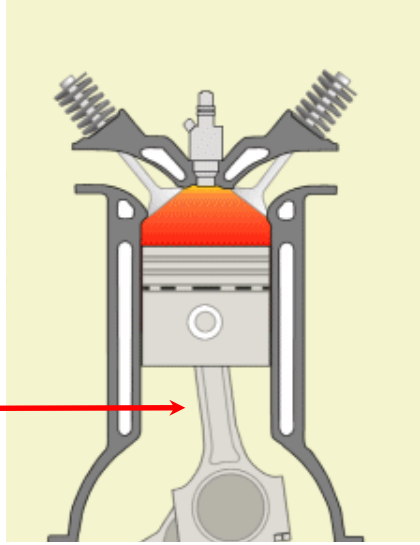
Outline

- Introduction
- Spray formation
- Combustion
- Conclusions

Manchester Metropolitan University

Non evaporating sprays
LIF-PIV (Gas entrainment) and Mie scattering

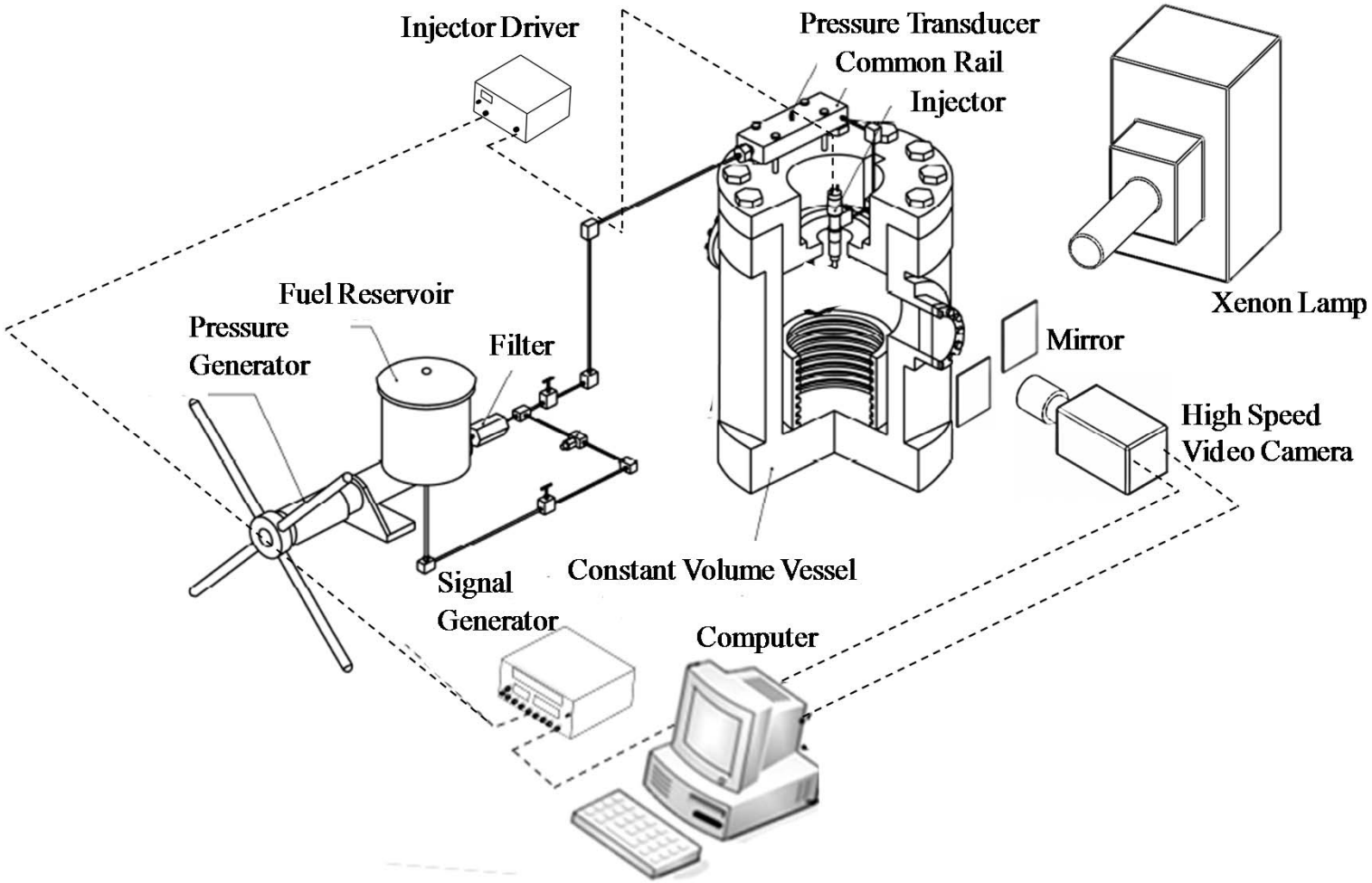




✓Constant volume vessel used to simulate the real production engine.
✓Conditions of what could be obtained at-10° ATDC in the engine was maintained inside the constant volume vessel.
✓Operating conditions of 40 bars ambient pressure and 900K ambient temperature

Manchester Metropolitan University

Evaporating sprays (Mie scattering)



Manchester Metropolitan University

Experimental conditions

	Spray		Combustion
Ambient gas	N_2		Air
Density (kg/m^3)	15 (-10° ATDC)		
Pressure (MPa)	1.36 (Non-evaporating) 4.0 (Evaporating)		4.0
Temperature	295 (Non-evaporating) 885 (Evaporating)		885
Nozzle	Single hole		
Diameter (mm)	0.08 and 0.16		
Injection	Common rail system		
Pressure (MPa)	100 and 300		
Fuel	Waste cooked oil biodiesel (WCO) and JIS#2 Diesel		
Quantity (g/s)	**d_o = 0.08mm**		**d_o = 0.16mm**
	100 MPa	**300 MPa**	**100 MPa**
WCO	1.65	2.8	9.4
Diesel	1.61	2.5	9.3
Injection duration (ms)	1.5 (Evaporating spray and combustion) 2.2 (LIF-PIV)		
Number of nozzle holes for 55mg/stroke (1.5 ms) 80mg/stroke (2.2 ms)	22	14	4

Manchester Metropolitan University

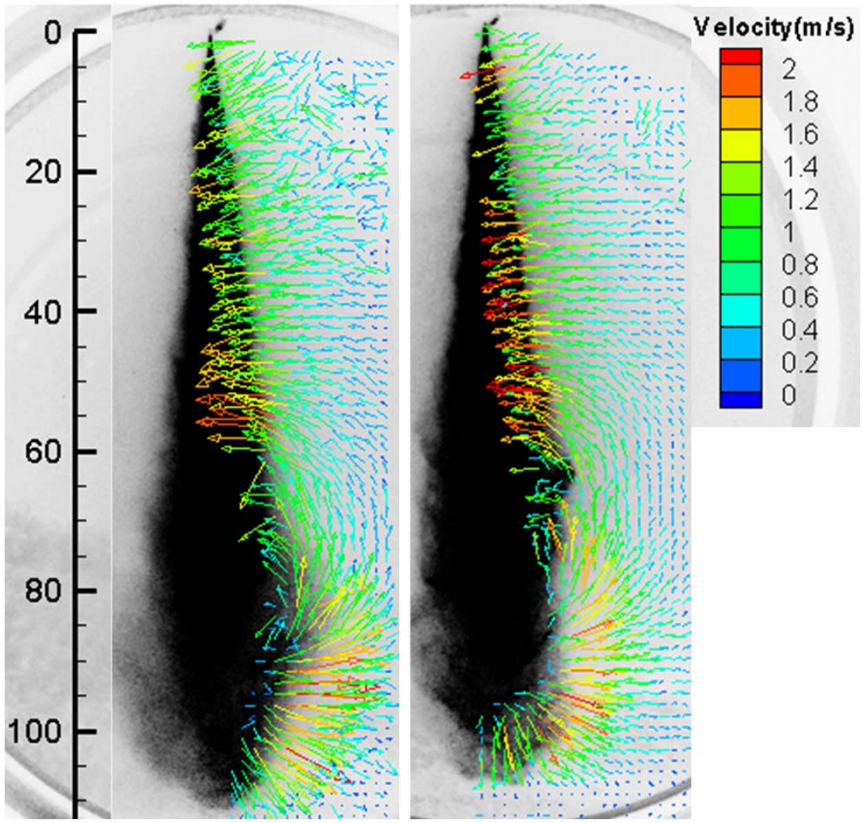
Experimental conditions

Fuel Property	WCO biodiesel	JIS#2 Diesel
Density @ 15°C (kg/m^3)	885	830
Viscosity @ 40°C (mm^2/s)	4.45	3.36
Surface tension @ 20°C (mN/m)	33.1	30.6
Cetane number	51	45
Distillation temperature (°C)	360	320
Flash point (°C)	>180.5	>60
Flow point (°C)	-5	4
Heating value (MJ/kg)	39.03	43.1
Sulphur content (ppm)	<3	<19
Carbon content (wt. %)	77.9	86.1
Hydrogen content (wt. %)	12.0	13.8
Oxygen content (wt. %)	10.1	<1

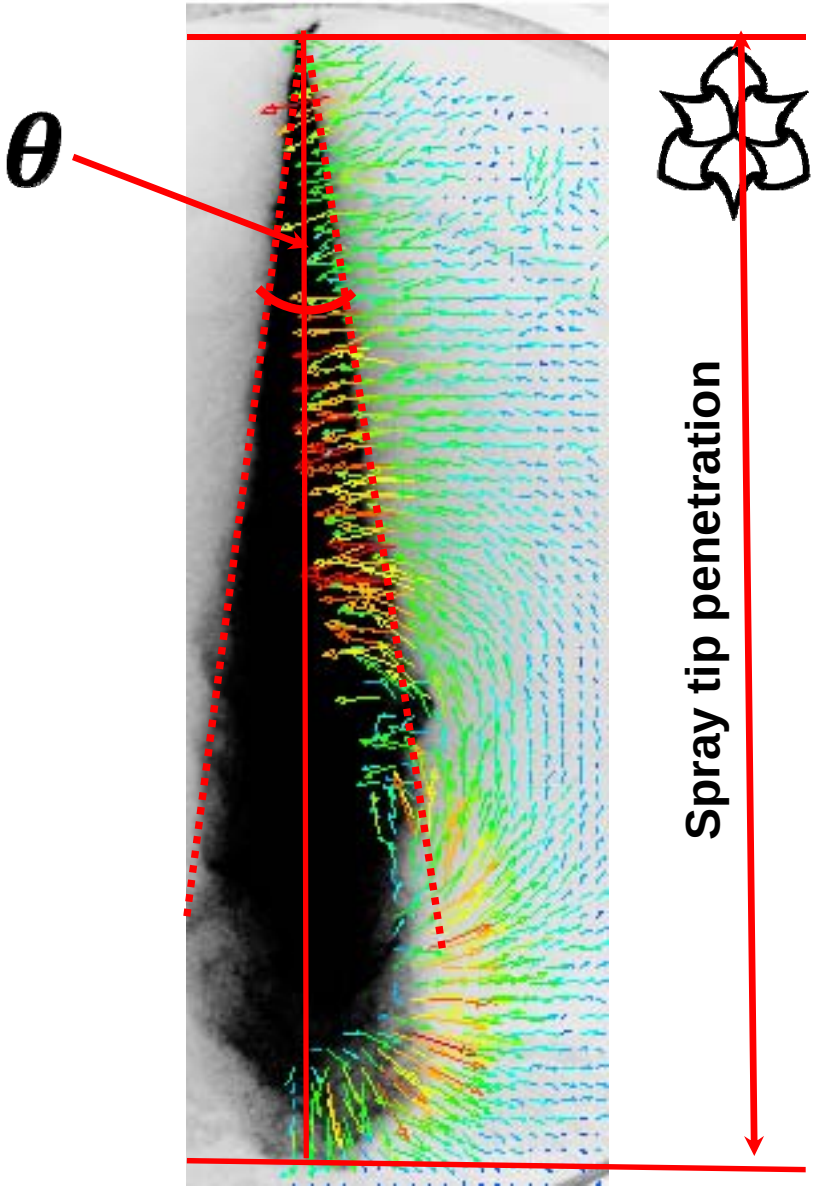
Manchester Metropolitan University

Results

P_{inj} = 100MPa, d_o=0.16mm, t_{inj}=2.0ms ASOI



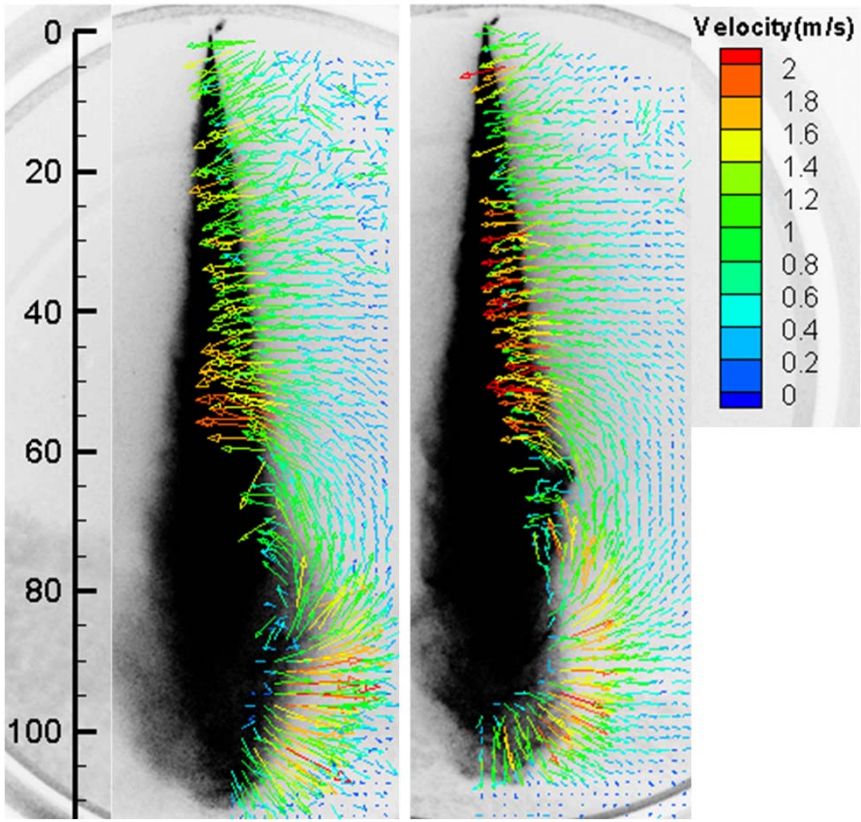
WCO Diesel



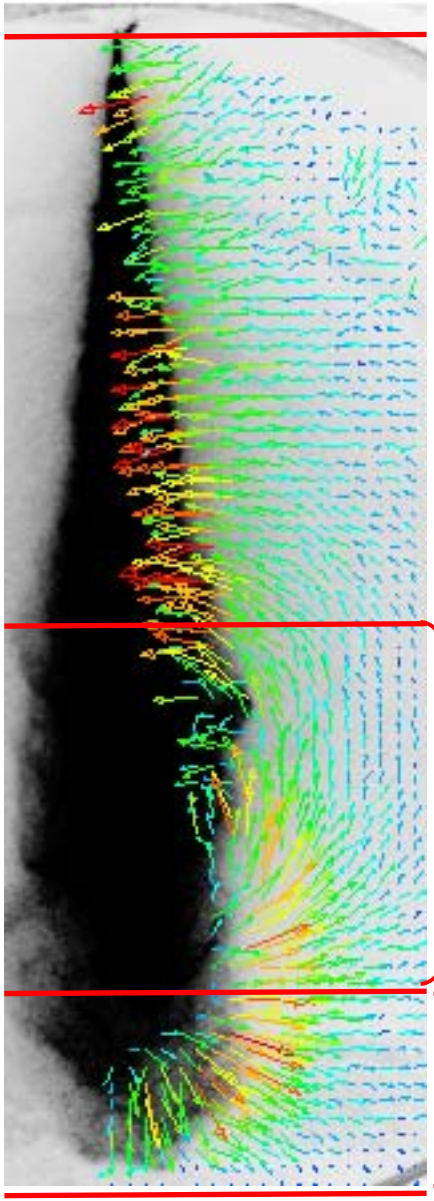
Manchester Metropolitan University

Results

P_{inj} = 100MPa, d_o=0.16mm, t_{inj}=2.0ms ASOI



WCO Diesel

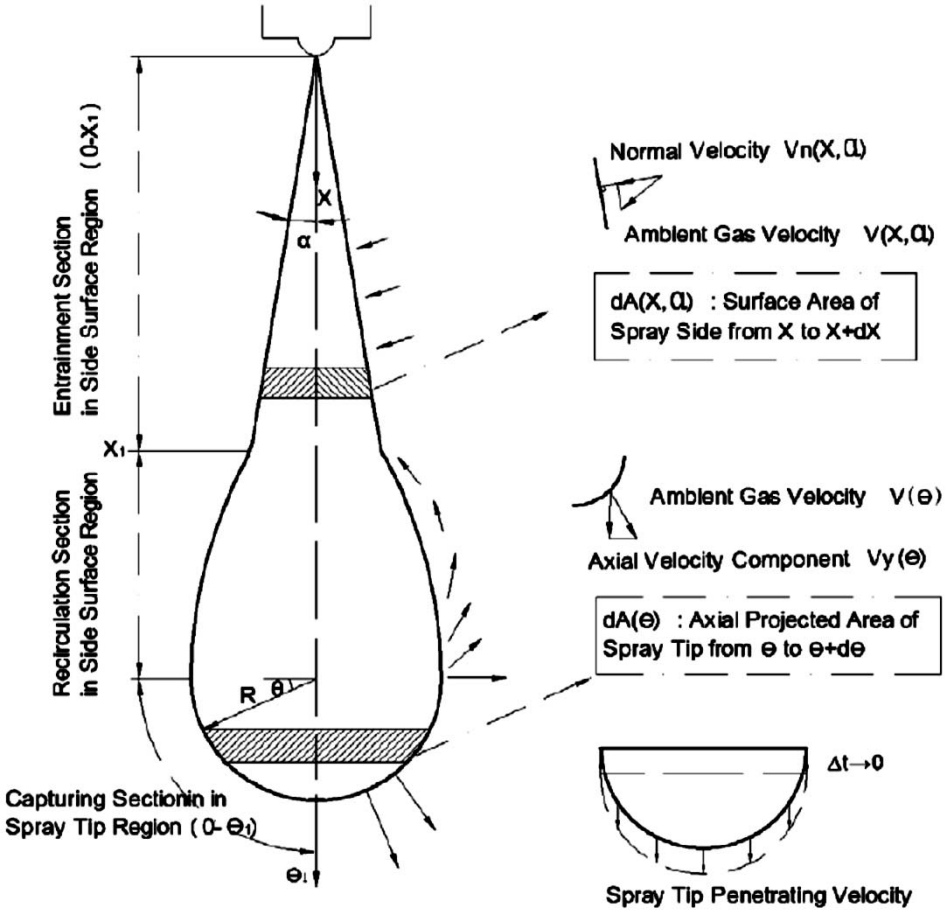


Lateral entrainment

Recirculation

Gas pushed out and captured

Manchester Metropolitan University



Spray side surface region:

$$\dot{m}_{a_{ent.}} = \int_0^{X_1} \rho_a . V_n(x,\theta) . dA(x,\theta)$$

Spray tip hemisphere region

$$\dot{m}_{a_{pushing}} = \int_0^{\theta_1} \rho_a . V_y(\theta) . dA(\theta)$$

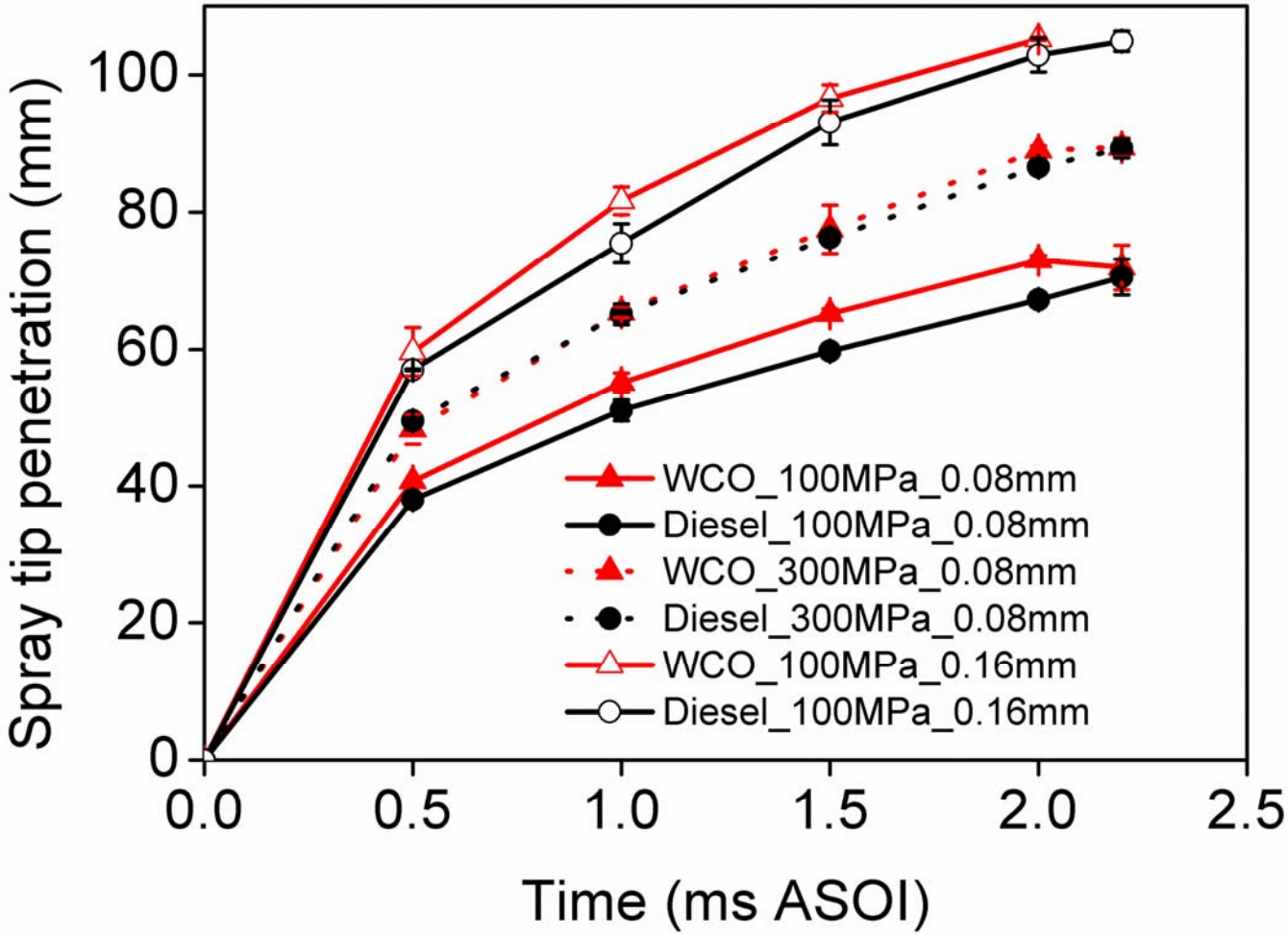
$$\dot{m}_{a_{cap}} = \dot{m}_{a_{penetrating}} - \dot{m}_{a_{pushing}}$$

$$= \rho_a . V_{sp} . \pi R^2 - \dot{m}_{a_{pushing}}$$

$$\dot{m}_{a_{total}} = \dot{m}_{a_{ent.}} + \dot{m}_{a_{cap}}$$

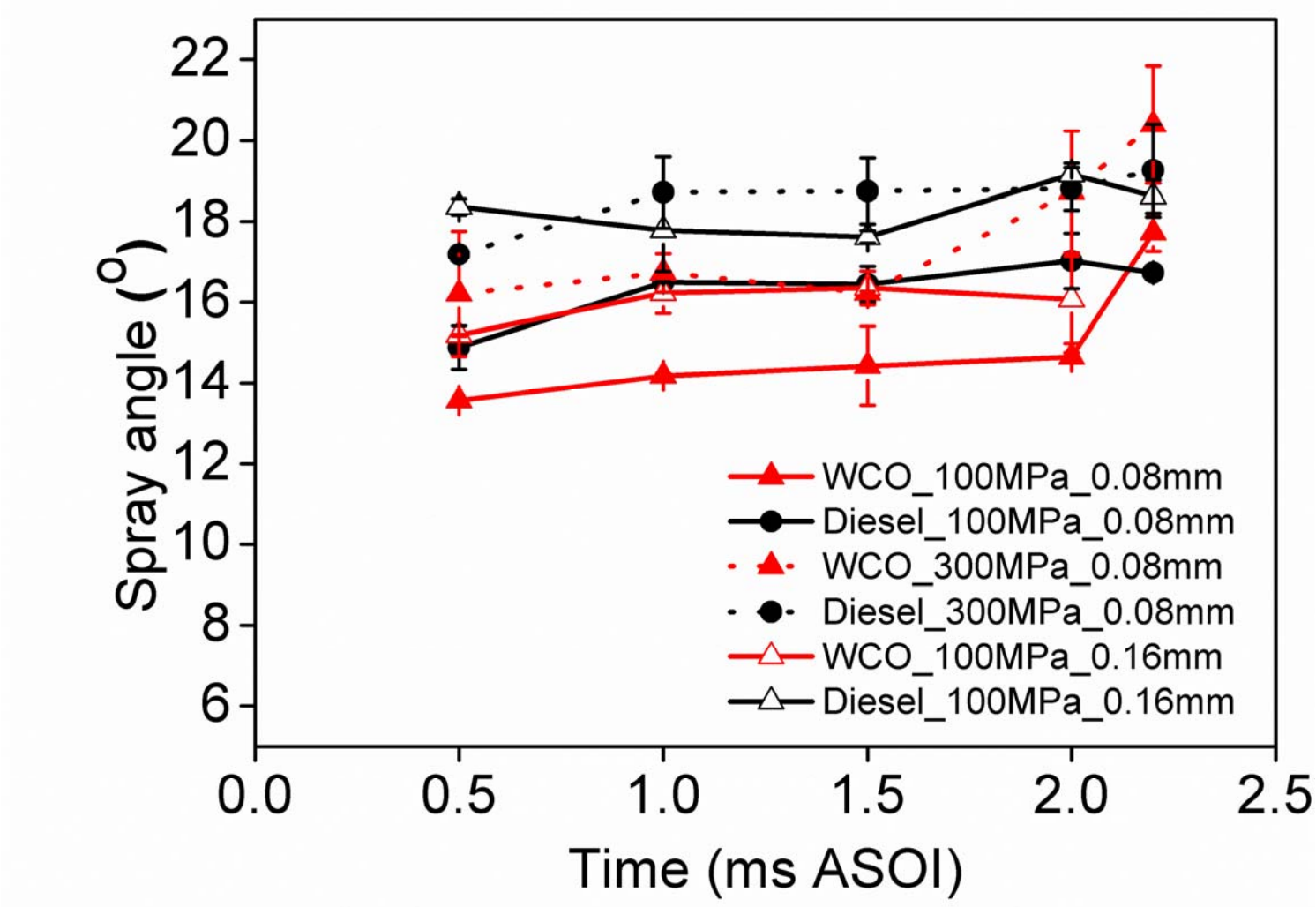
Manchester Metropolitan University

Results (Spray tip penetration)



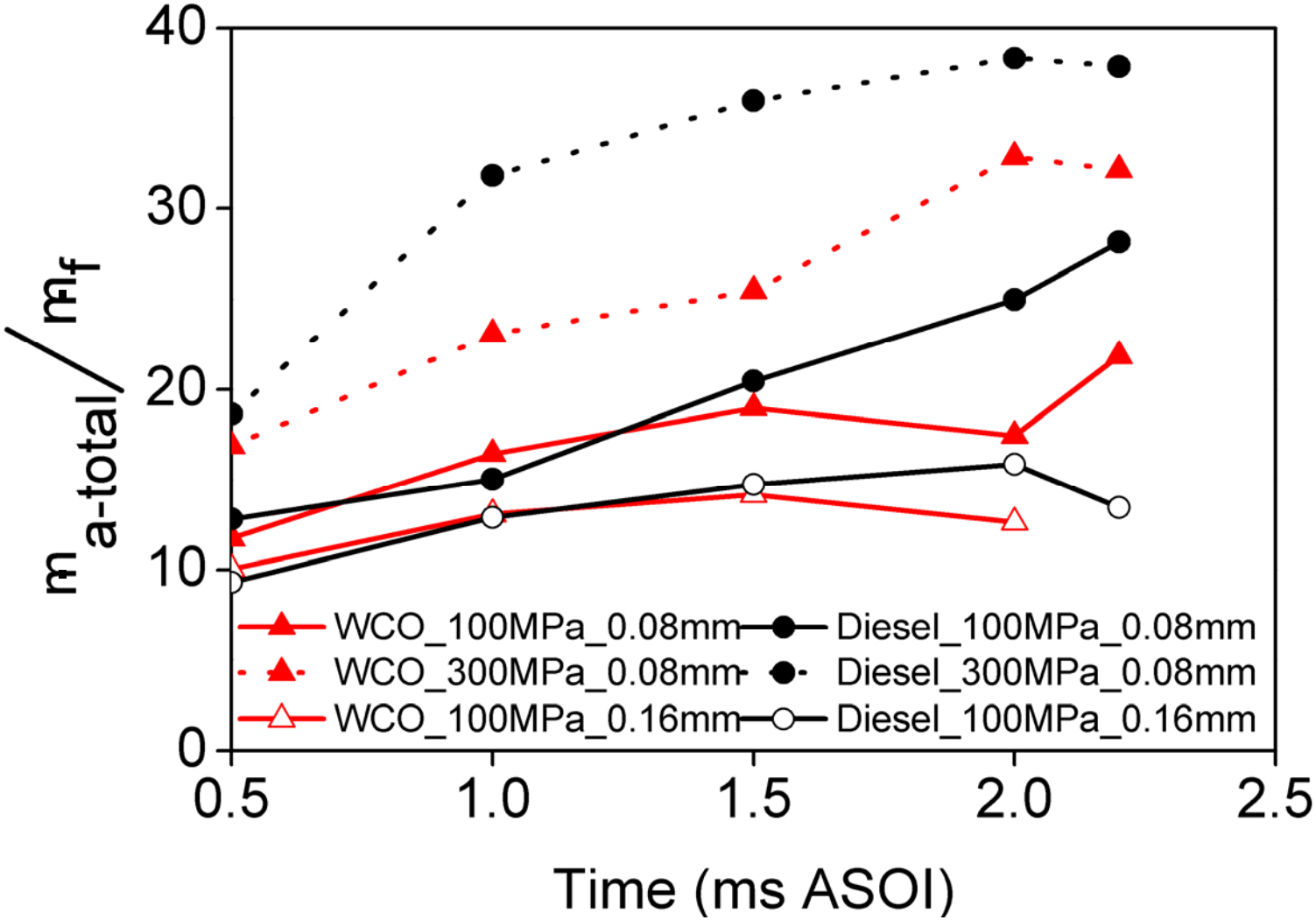
Manchester Metropolitan University

Results (Spray angle)



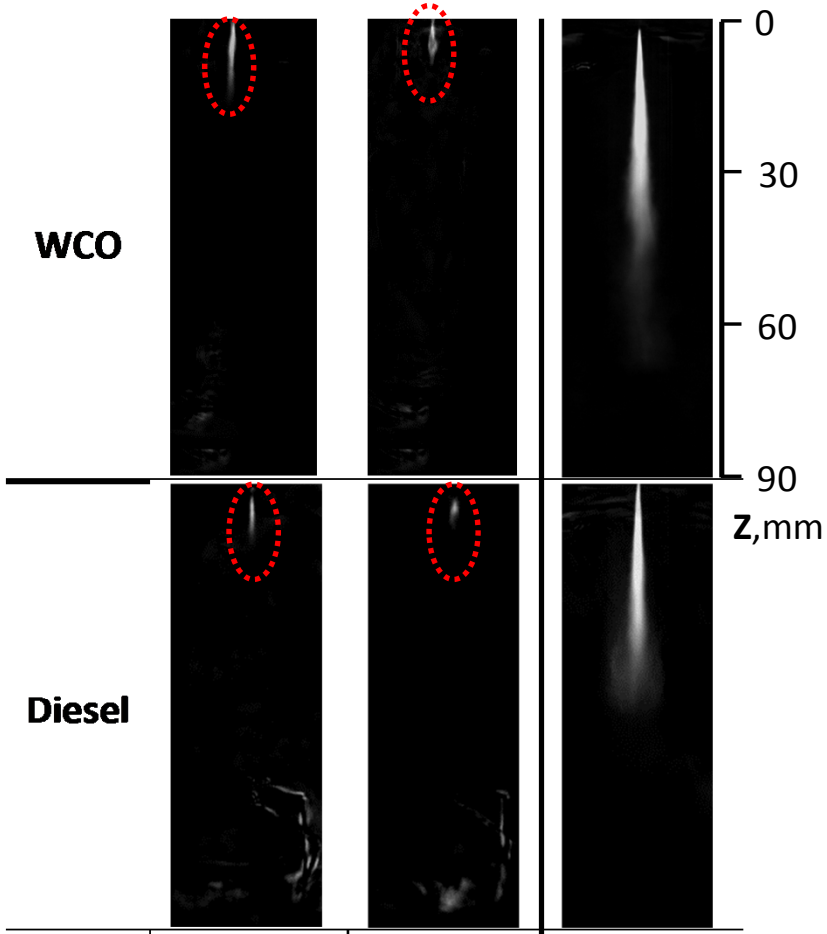
Mancl
Univer

Results (Rate of mixing)



Manchester Metropolitan University

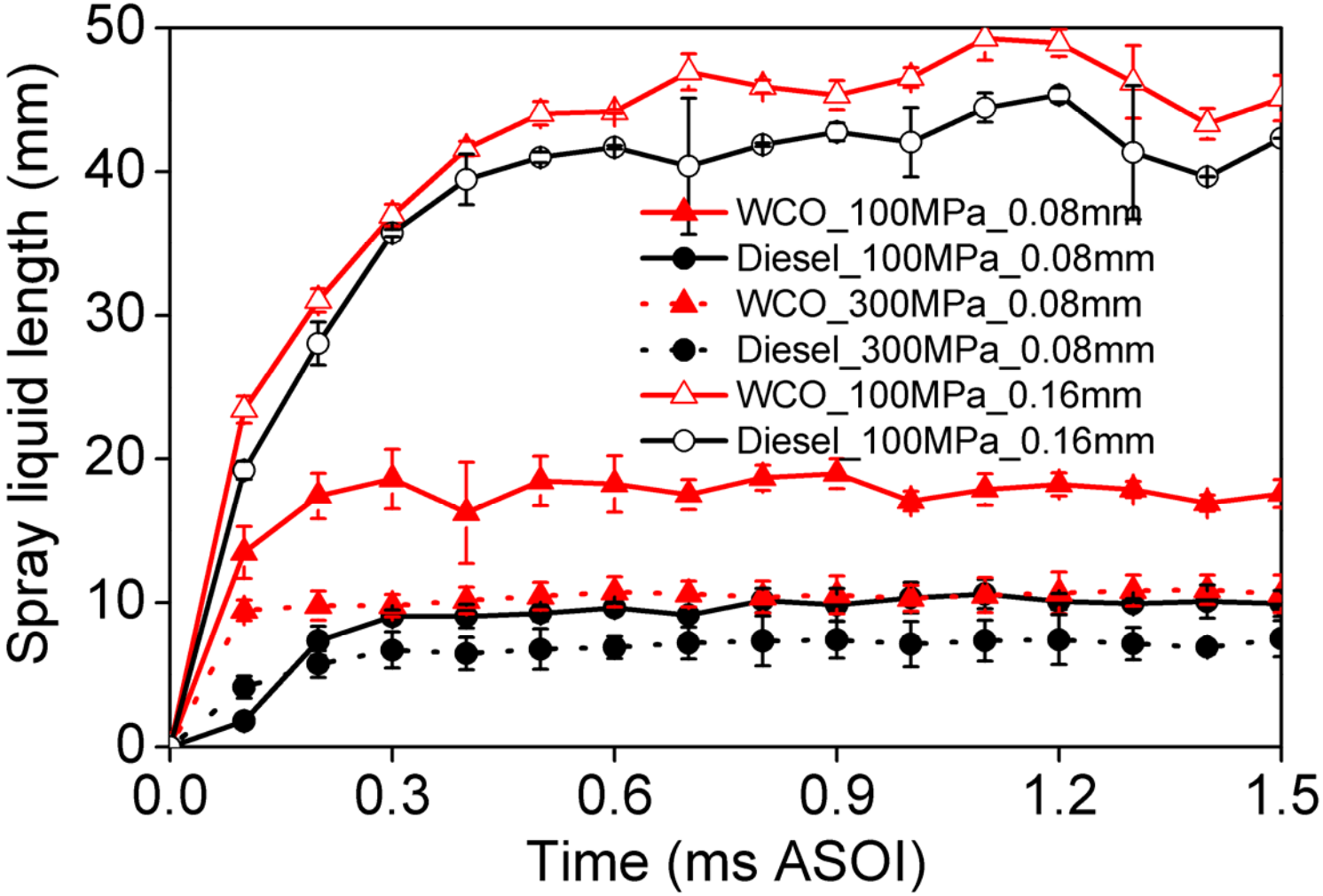
Evaporating spray at 1.4ms ASOI



P_{inj}	100 MPa	300 MPa	100 MPa
d_o	0.08 mm		0.16 mm

Manchester Metropolitan University

Results (Liquid length)



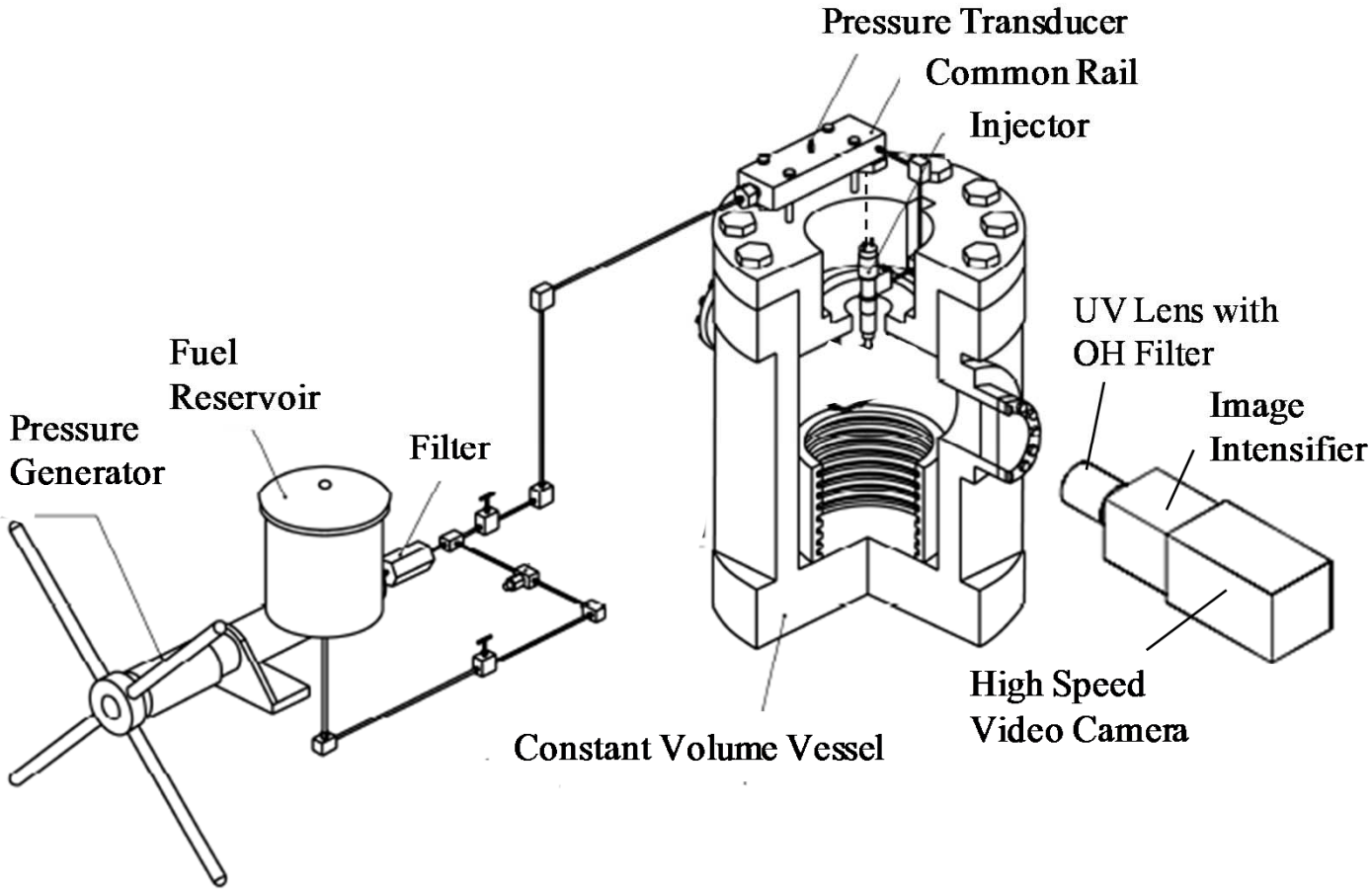
Manchester Metropolitan University

Outline

- Introduction
- Spray Formation
- Combustion characteristics
- Conclusions

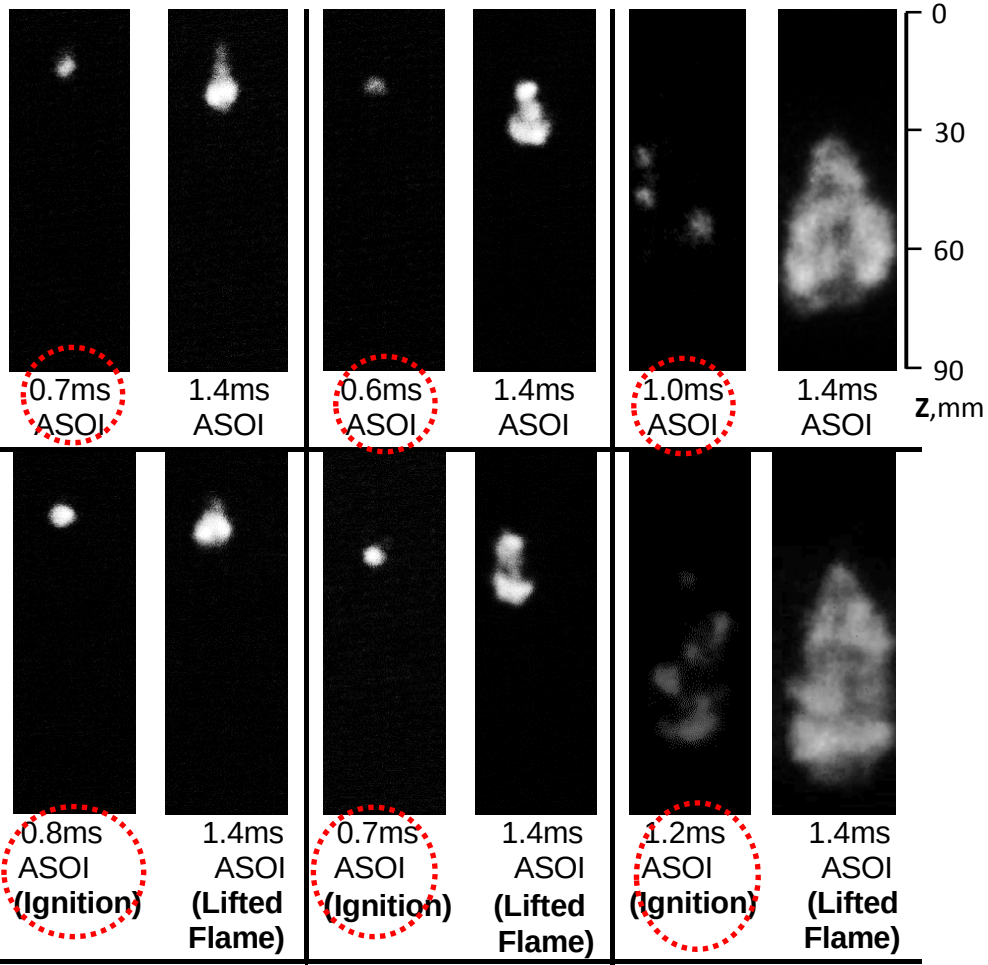
Manchester Metropolitan University

Autoignition and Flame Structure (OH chemiluminescence)



Manchester Metropolitan University

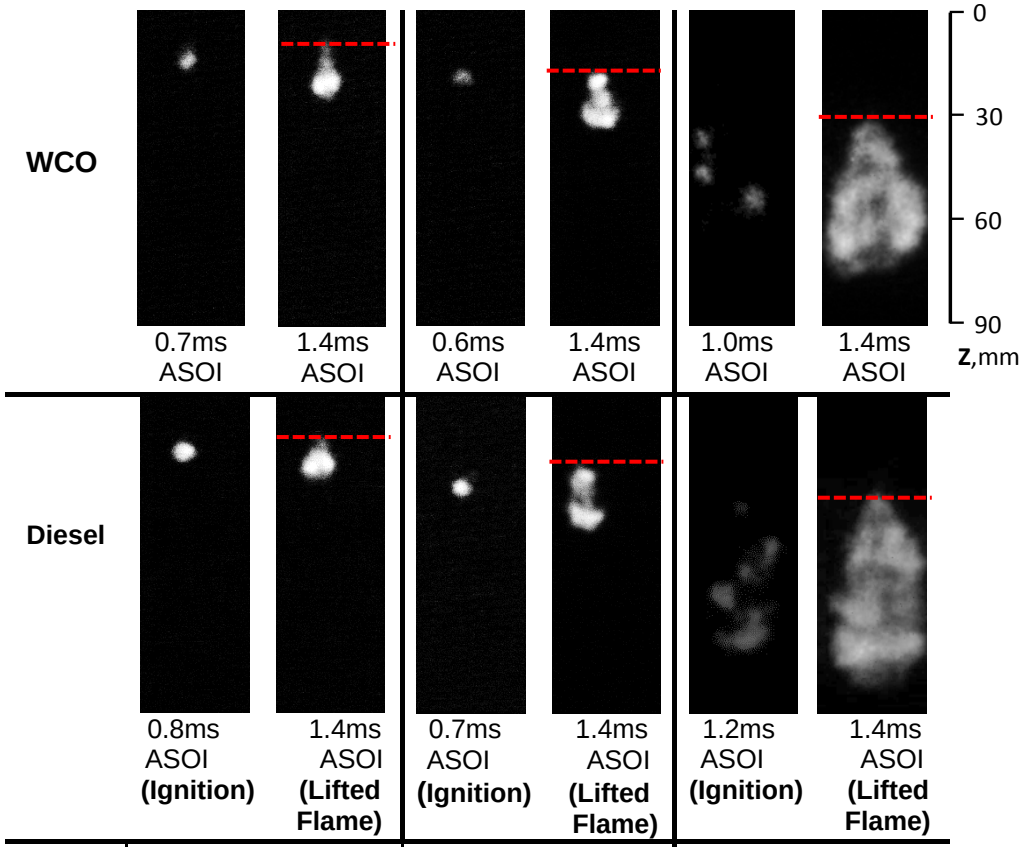
Autoignition and Flame Structure



P_{inj}	100 MPa	300 MPa	100 MPa
d_o	0.08 mm		0.16 mm

Manchester Metropolitan University

Flame lift-off length



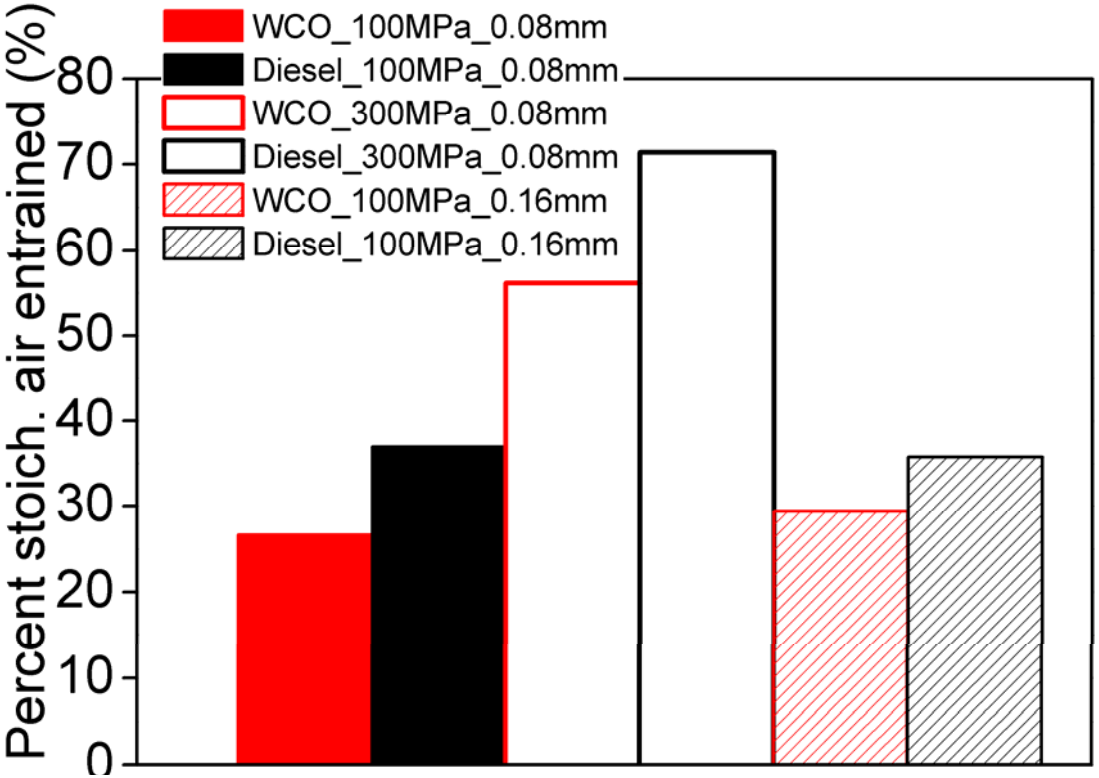
P_{inj}	100 MPa	300 MPa	100 MPa
d_o	0.08 mm		0.16 mm

Manchester Metropolitan University

Flame lift-off length (Air entrained upstream)

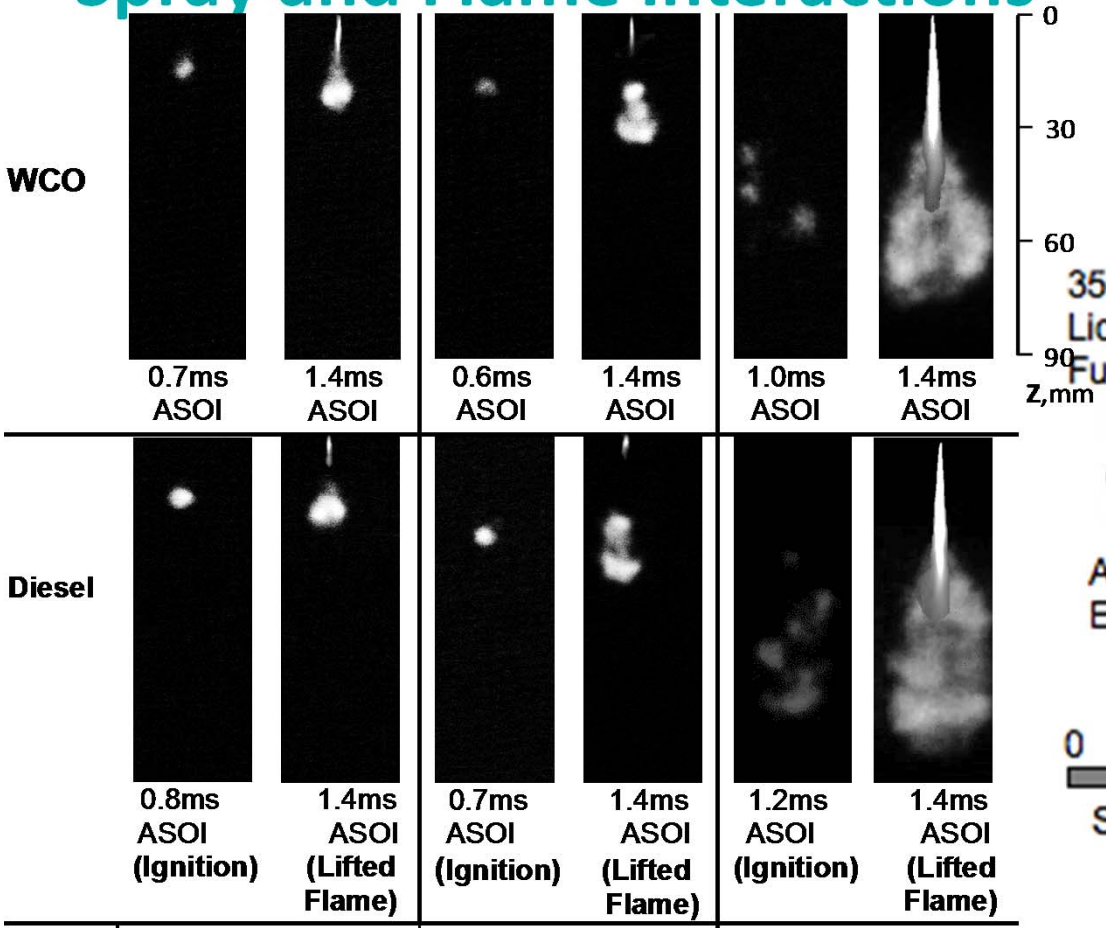
$$\zeta_{st}(\%) = \frac{10}{3}\left[\left(\sqrt{1 + 16\left(\frac{L_o}{x^+}\right)^2} - 1\right)\right]$$

Source: Pickett, LM and Siebers, DL *Int.J.Eng.Res.*, 7(2) 103-129, 2006



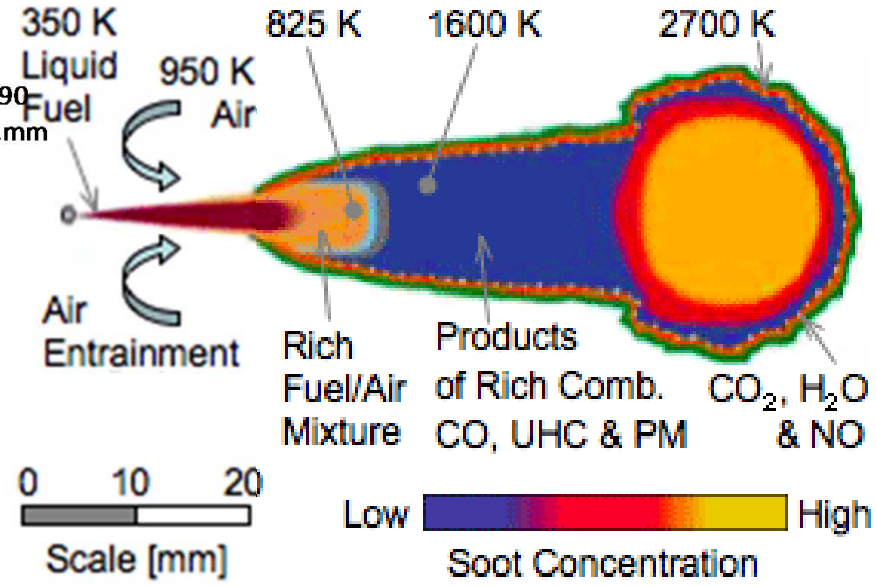
Manchester Metropolitan University

Spray and Flame Interactions



P_{inj}	100 MPa	300 MPa	100 MPa
d_o	0.08 mm		0.16 mm

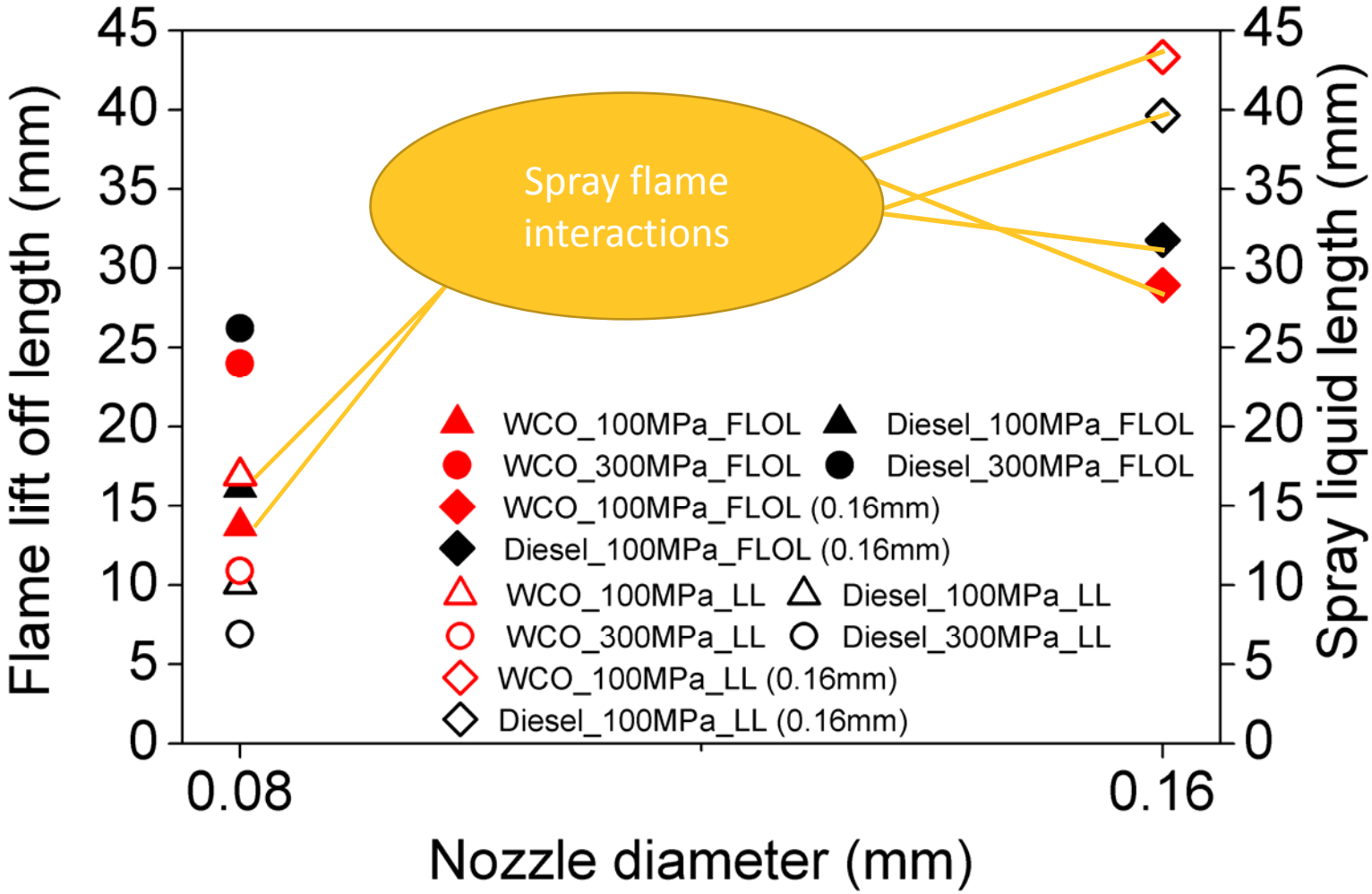
Dec's conceptual model



Source: SAE Paper 970973, (1997)

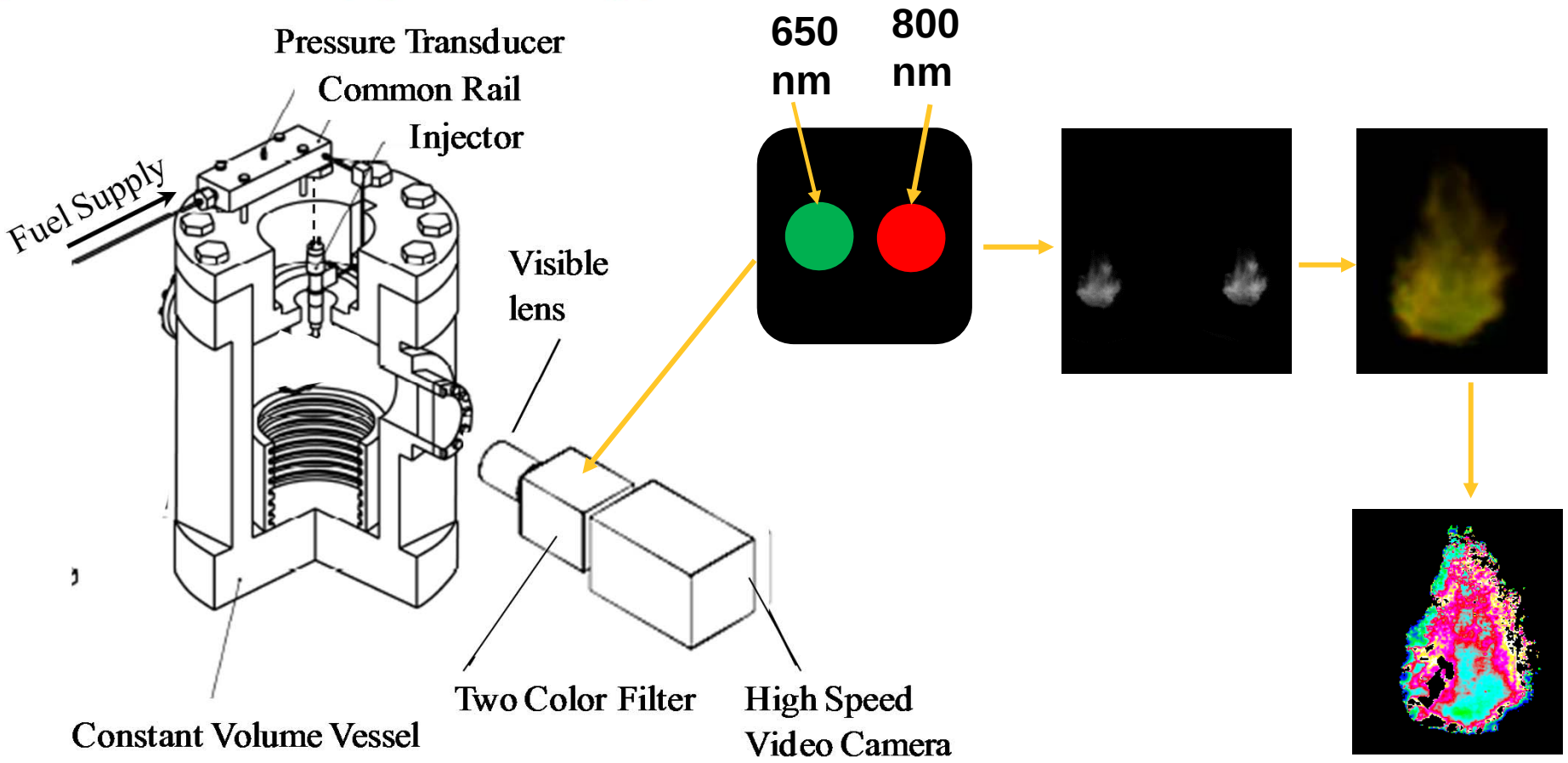
Manchester Metropolitan University

Spray and Flame Interactions



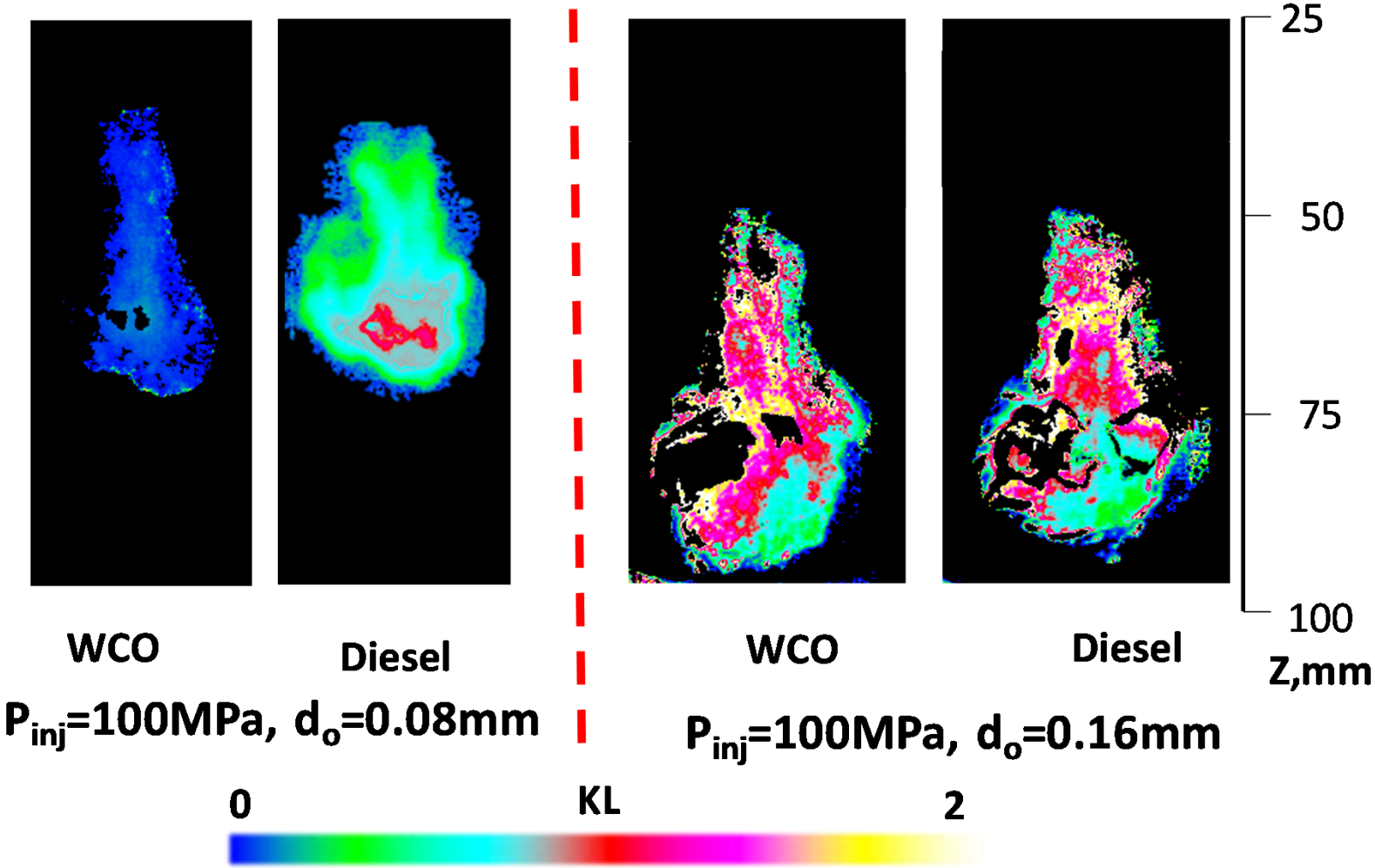
Manchester Metropolitan University

Soot Formation (Two colour pyrometry)



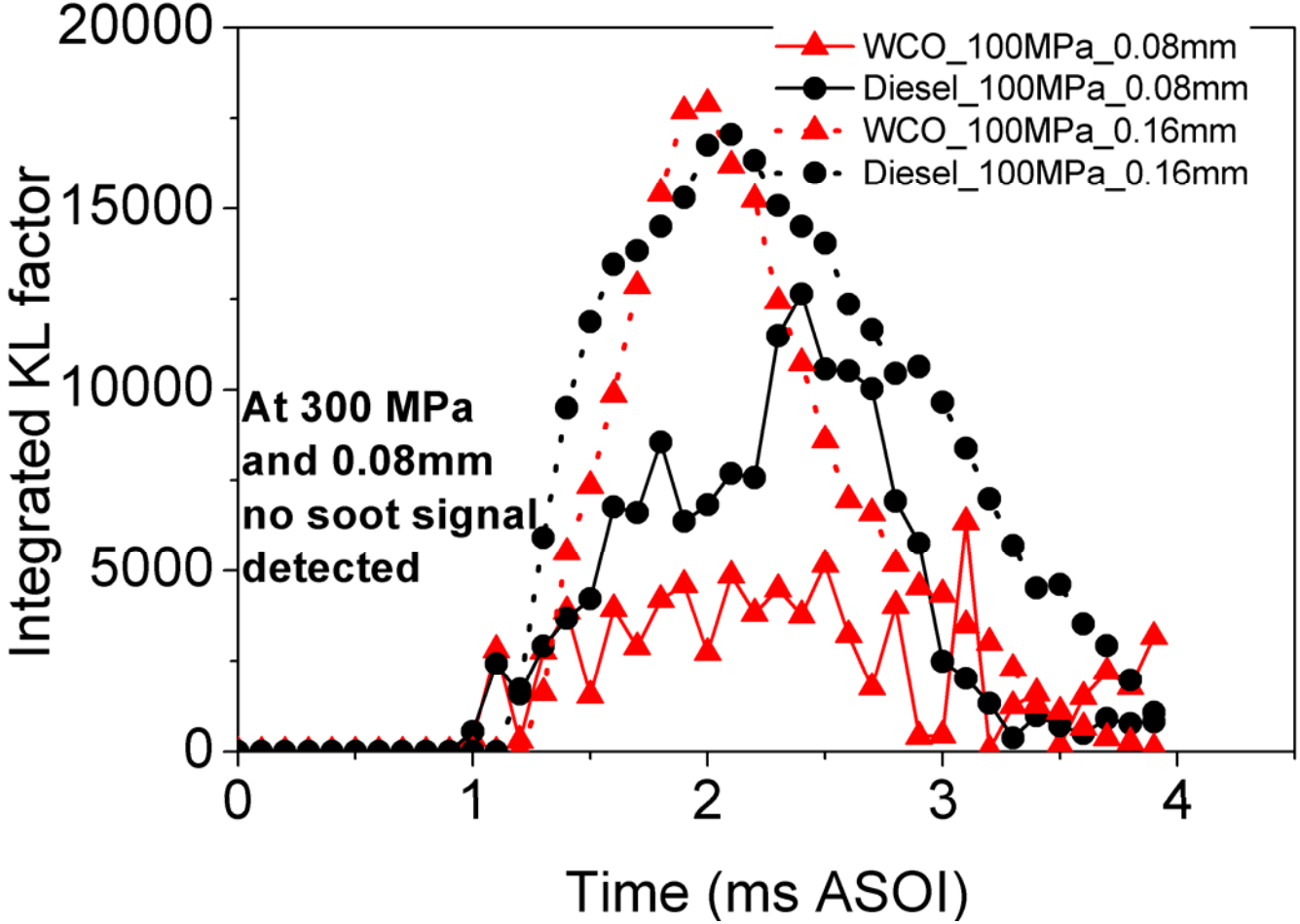
Manchester Metropolitan University

Soot Formation at 0.5ms AEOI



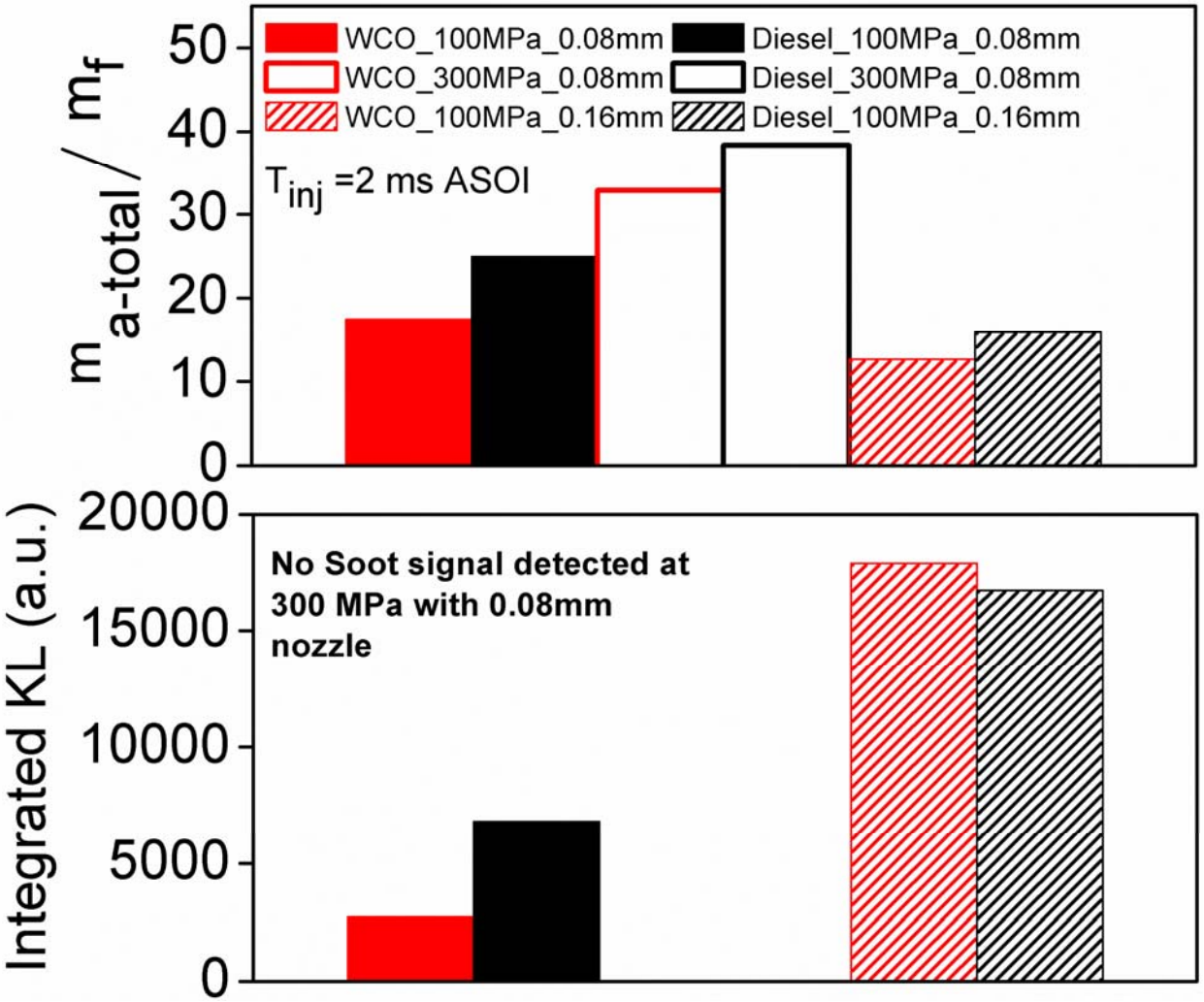
Manchester Metropolitan University

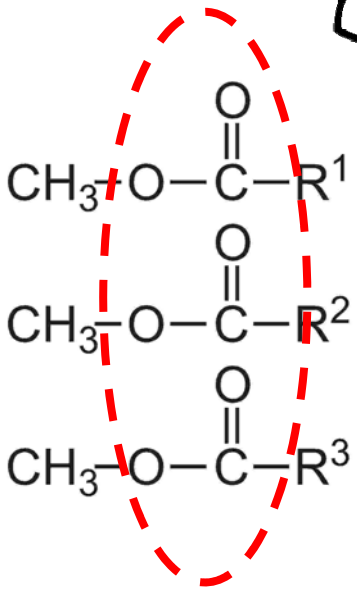
Soot Formation



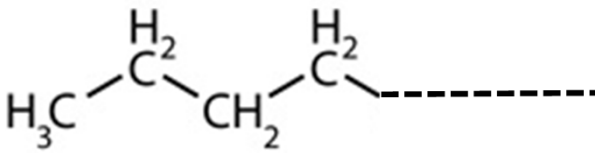
Manchester Metropolitan University

Implications of molecular oxygen content





Biodiesel Structure



Diesel structure

Manchester Metropolitan University

Outline

- Introduction
- Spray Formation
- Conclusions
- Conclusions

Manchester Metropolitan University

Conclusions

Spray

- The combined 300 MPa ultra high injection pressure with 0.08 mm micro-hole nozzle led to shorter spray penetration with wider spray dispersion angle when compared to the baseline condition (100 MPa injection pressure and 0.16 mm nozzle hole diameter).

- The combined effect of ultra high injection pressure with micro-hole nozzle enhanced mixing with larger ratio of gas flow rate to fuel rate

- As a result of wider spray dispersion with much air entrained liquid length produced by the ultra high injection pressure and micro hole nozzle was shorter compared to the baseline condition.

- As a result of higher viscosity, higher surface tension, higher distillation temperature WCO spray penetrated more with less spray dispersion and produced longer spray tip penetration and liquid length compared to diesel.

Manchester Metropolitan University

Conclusions

Ignition and flame development

- As a result of enhancement in mixing, shorter ignition delay was attained by combination of ultra high injection pressure and micro-hole nozzle. WCO ignited faster compared to diesel due to higher cetane number.

- As injection pressure and nozzle diameter increased to 300 MPa and 0.16mm respectively, flame lift off length (FLOL) increased. However the combined effect of the 300MPa and 0.08mm nozzle led to more air entrained upstream of lifted flame.

- WCO FLOL was shorter than diesel with less quantity of air entrained upstream of its flame.

Soot Formation

- Soot reduced to minimum through the combined ultra-high injection pressure and micro-hole nozzle with signal undetected optically.

- Through the 300MPa and 0.08mm nozzle WCO produced less soot with the molecular oxygen content playing a vital role.

Manchester Metropolitan University

Acknowledgement

This work was done at the University of Hiroshima at Prof. Keiya Nishida's Fluid and Spray Engineering Laboratory.

THANK YOU FOR YOUR LISTENING