Investigations into spray and gas entrainment characteristics of waste cooking oil biodiesel fuel using the LIF-PIV techniques

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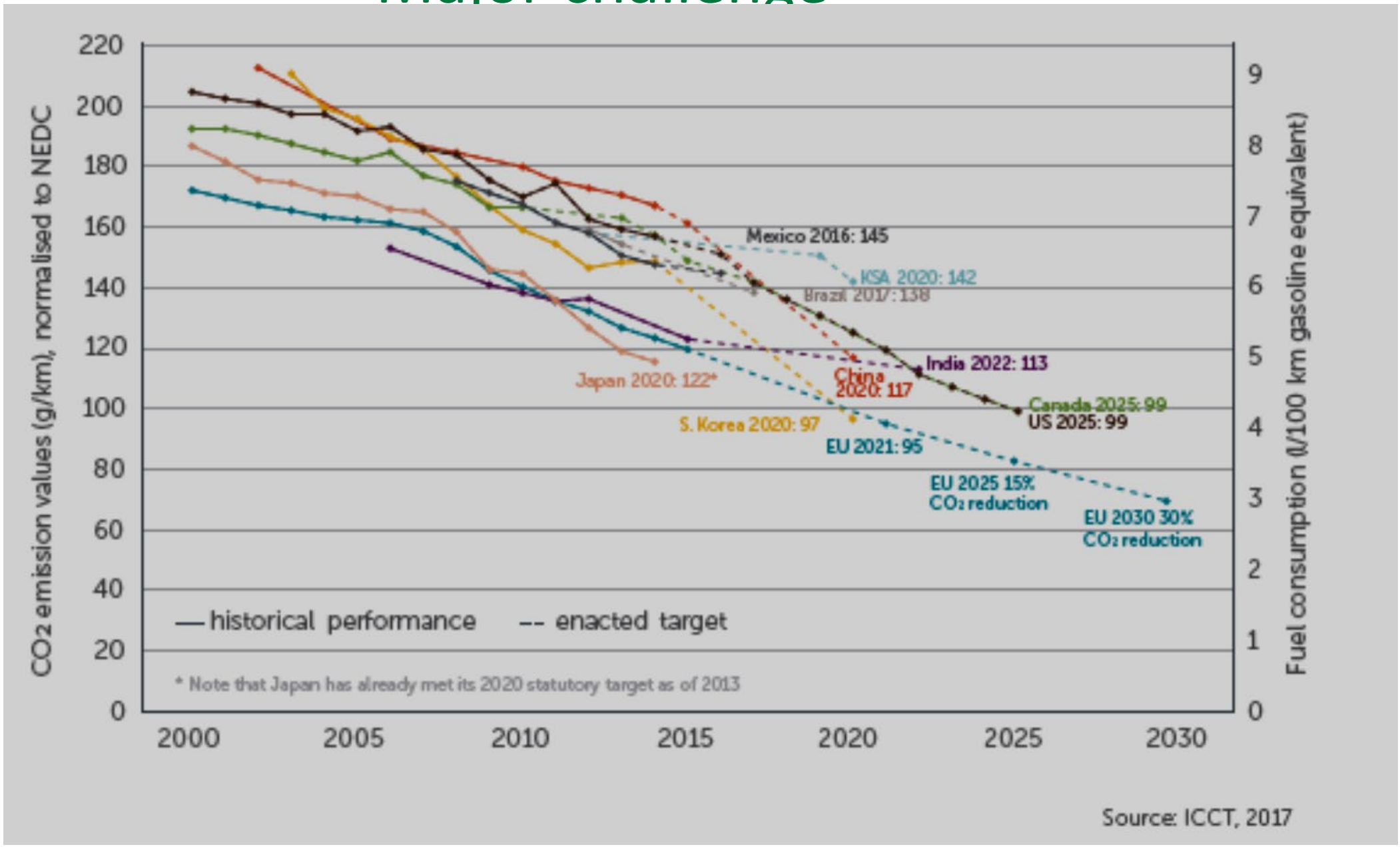
Outline of Talk

- ❑ Introduction
- ❑ Motivation
- ❑ Experimental Set-Up and Conditions
  - ✓ LIF-PIV methodology
- ❑ Results and Discussion
- ❑ Conclusions

Major Concerns

Major challenge



Will Electric drive be the solution?

While electricity promises to reduce emissions. There are major challenges such as;

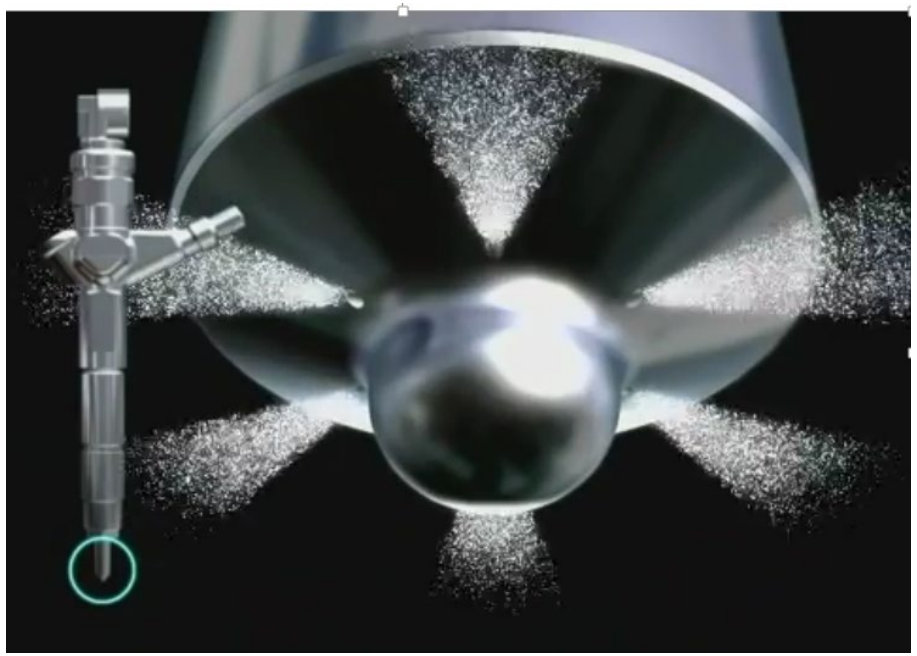
- ✓Charging points
- ✓Infrastructure Cost
- ✓Battery weight

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.

Manchester Metropolitan University

What is the way forward

- Fuel Injection Strategy
  - ✓High Injection Pressure up to ultra-high value of 300 MPa
  - ✓Nozzle hole size



- Fuel Formulation
  - ✓Alternative fuels i.e. Biofuels (Biodiesel)

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Motivation

- Spray characteristics of alternative fuel such as gas/air entrainment needs to be investigated. This could have effect on mixture formation and subsequently combustion (ignition, flame structure and emission) processes.

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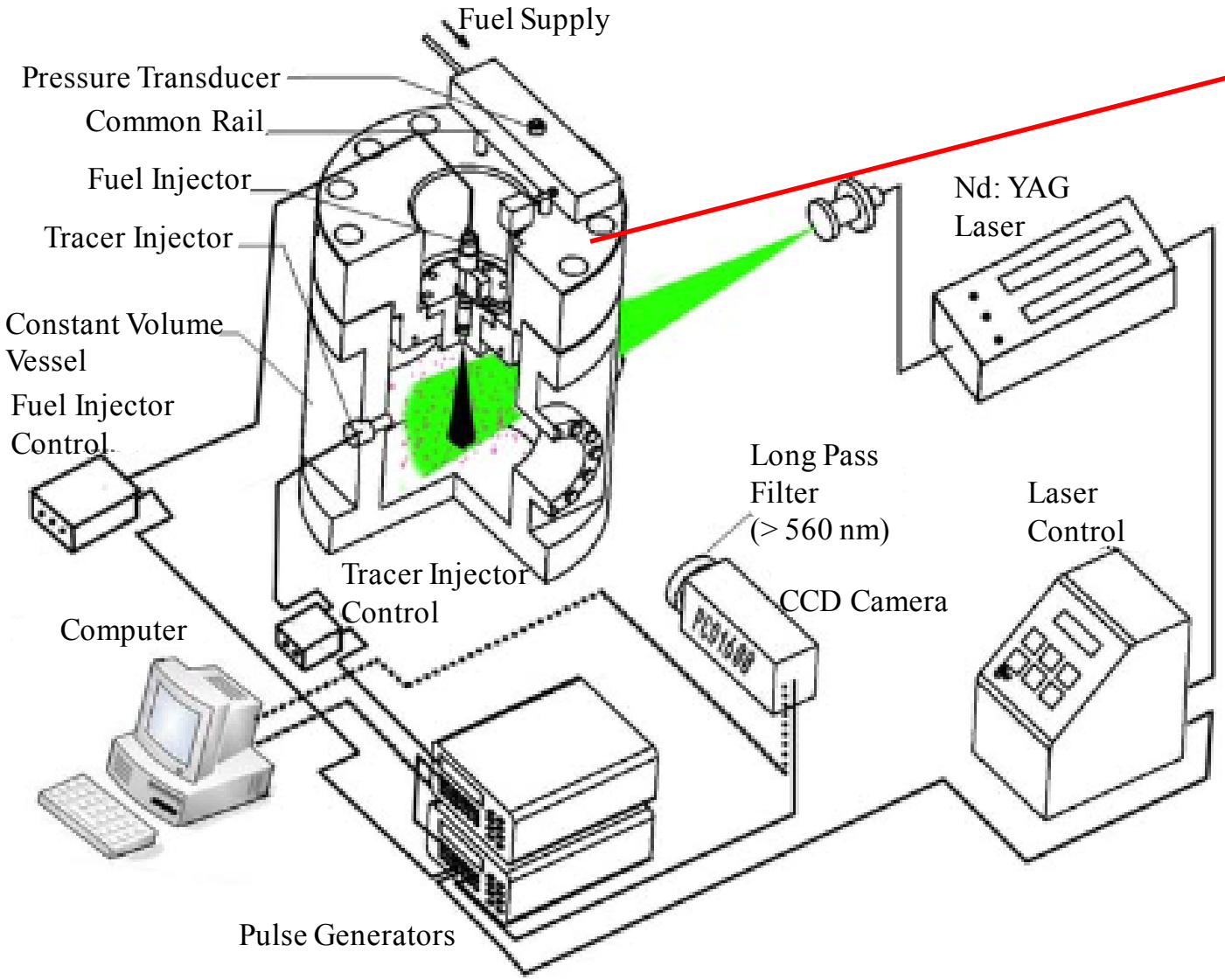
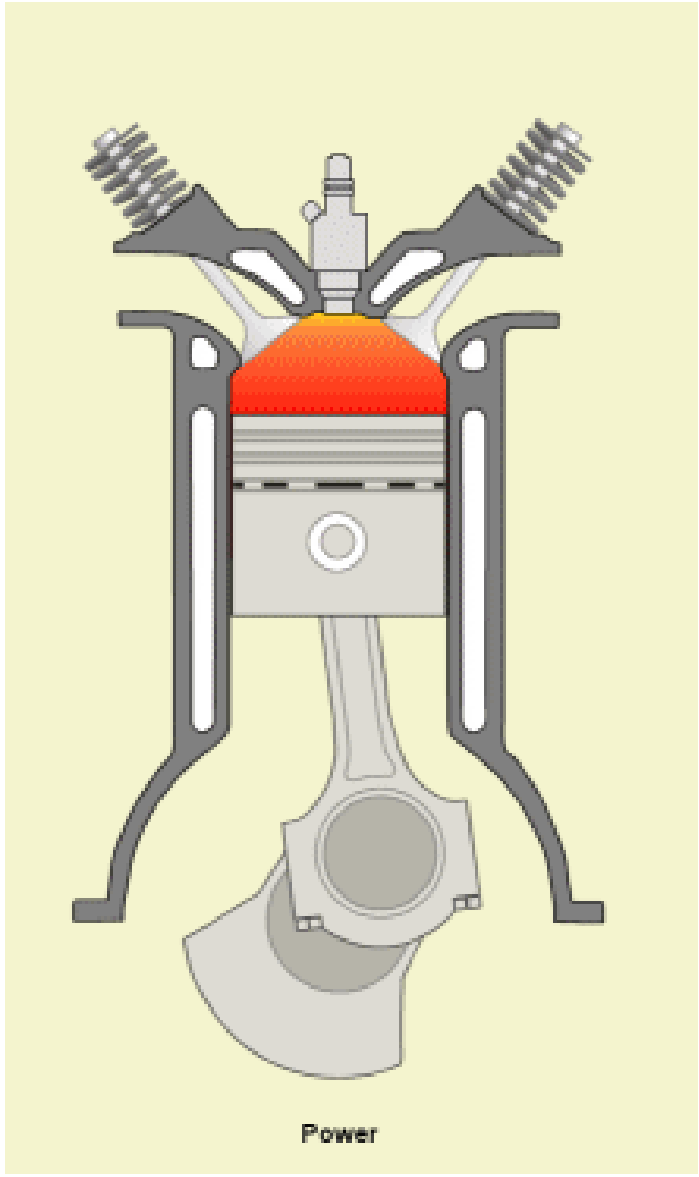
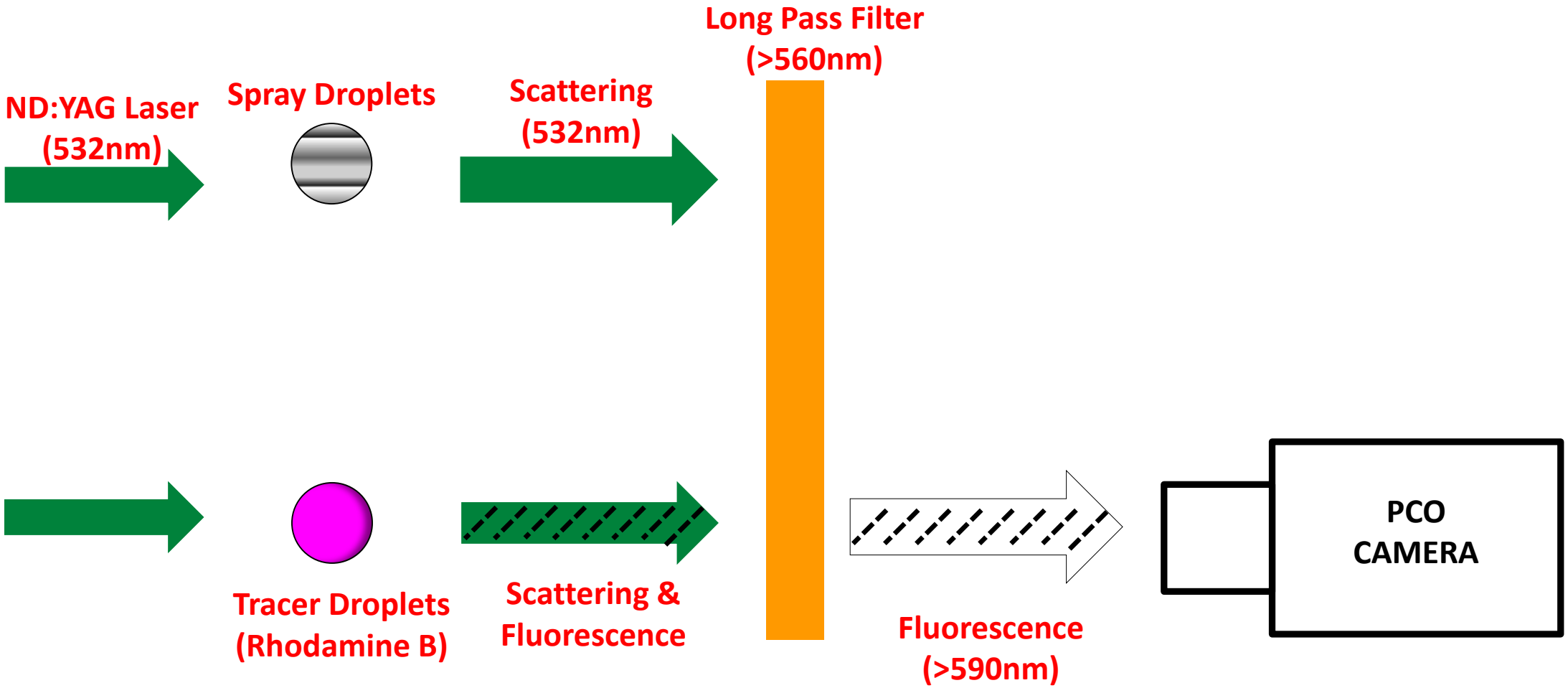
Experimental Set-Up

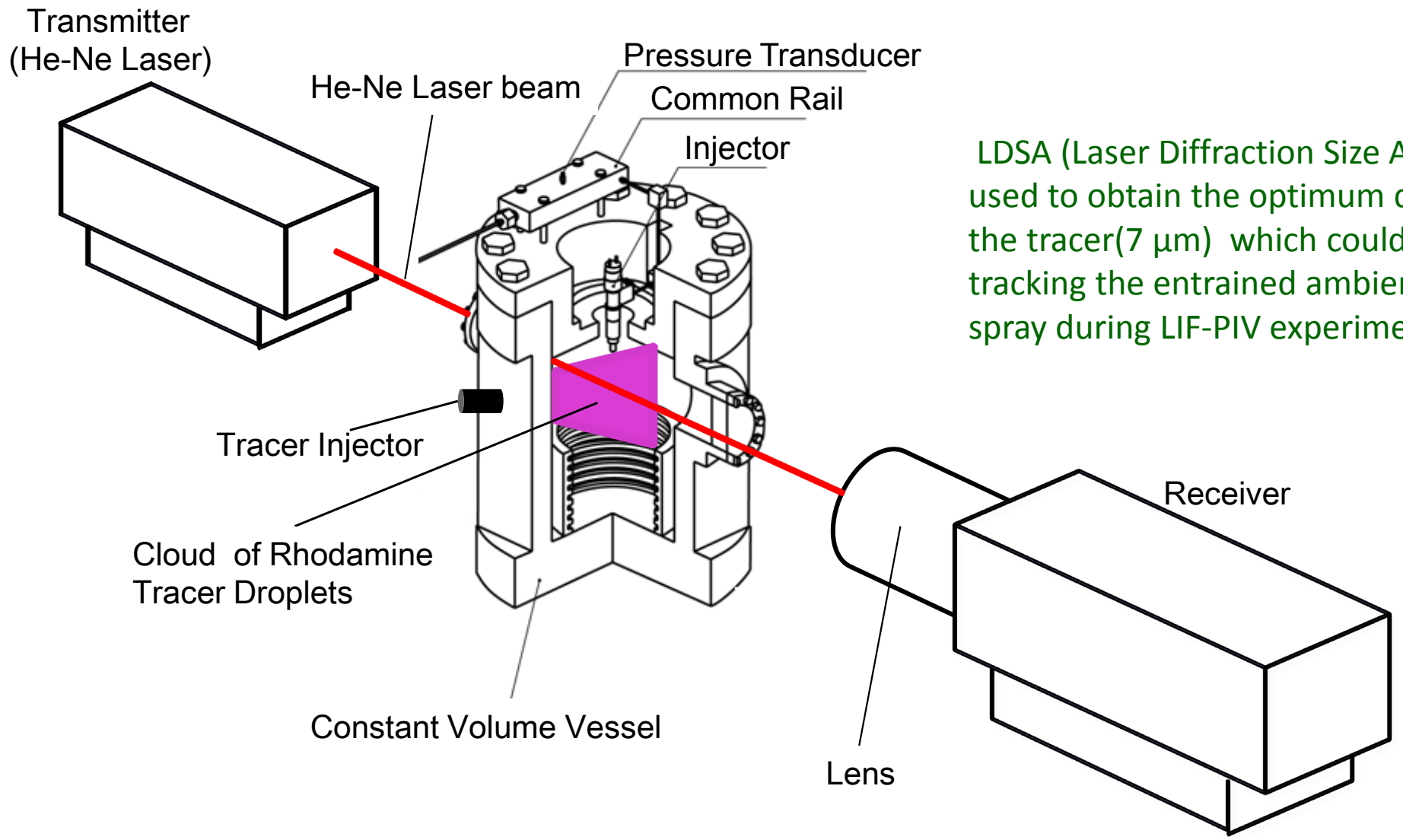




LIF-PIF methodology

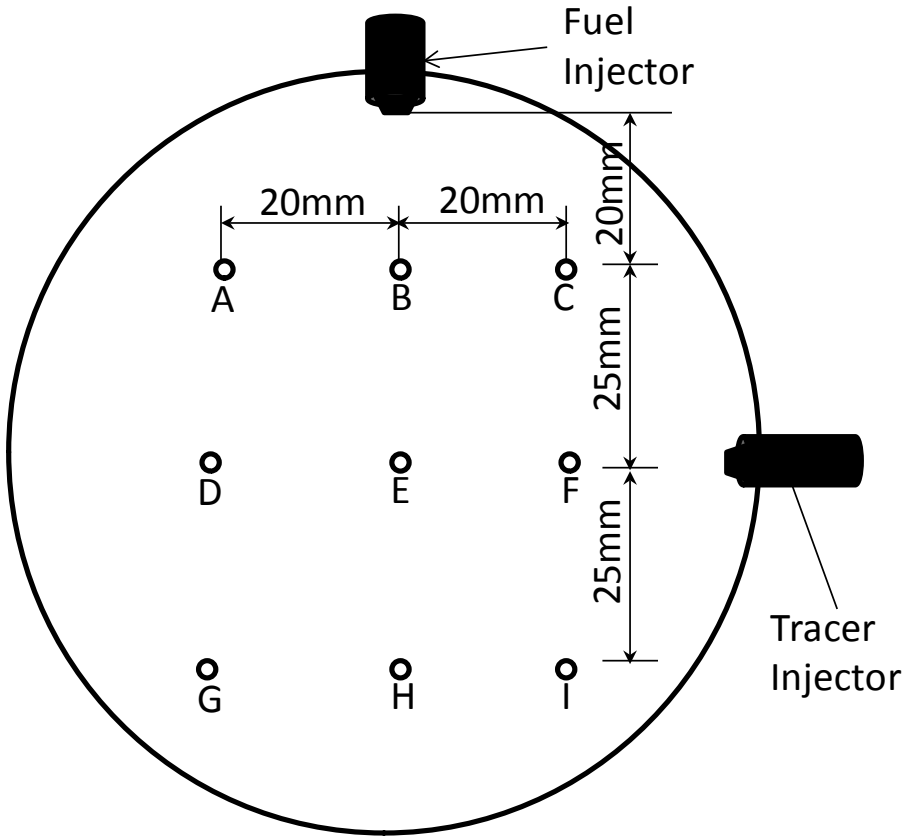


Optimum tracer size

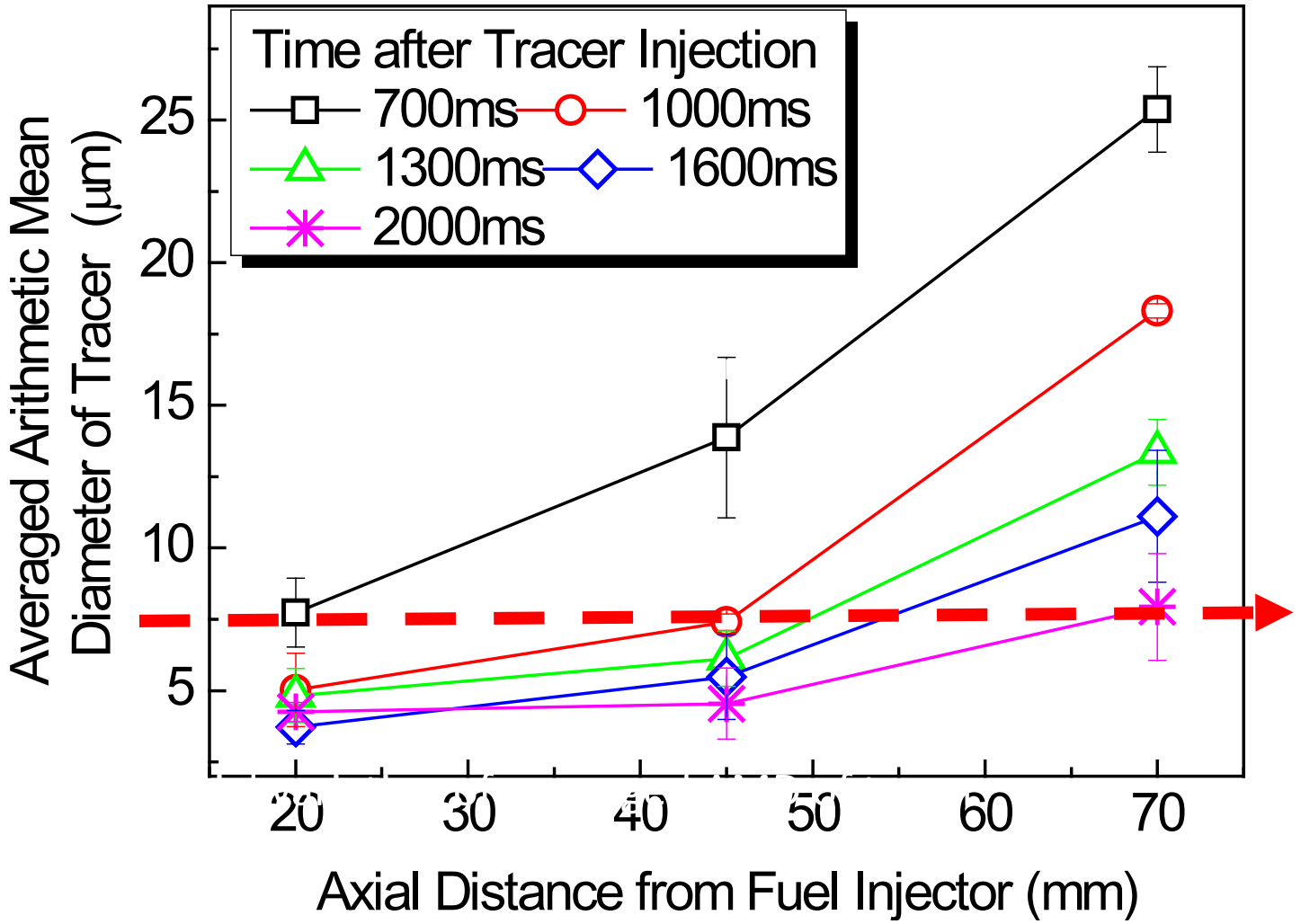


LDSA (Laser Diffraction Size Analyzer) was used to obtain the optimum droplet size of the tracer(7 µm) which could be used for tracking the entrained ambient gas in the spray during LIF-PIV experiments

Tracer Droplet Size Optimization



Tracer droplet size measurement locations



An optimum timing of 1400ms was selected as the time interval between the tracer injection and fuel injection. This is able to produce a tracer of about 7μm size

Tracer Tracking Ability

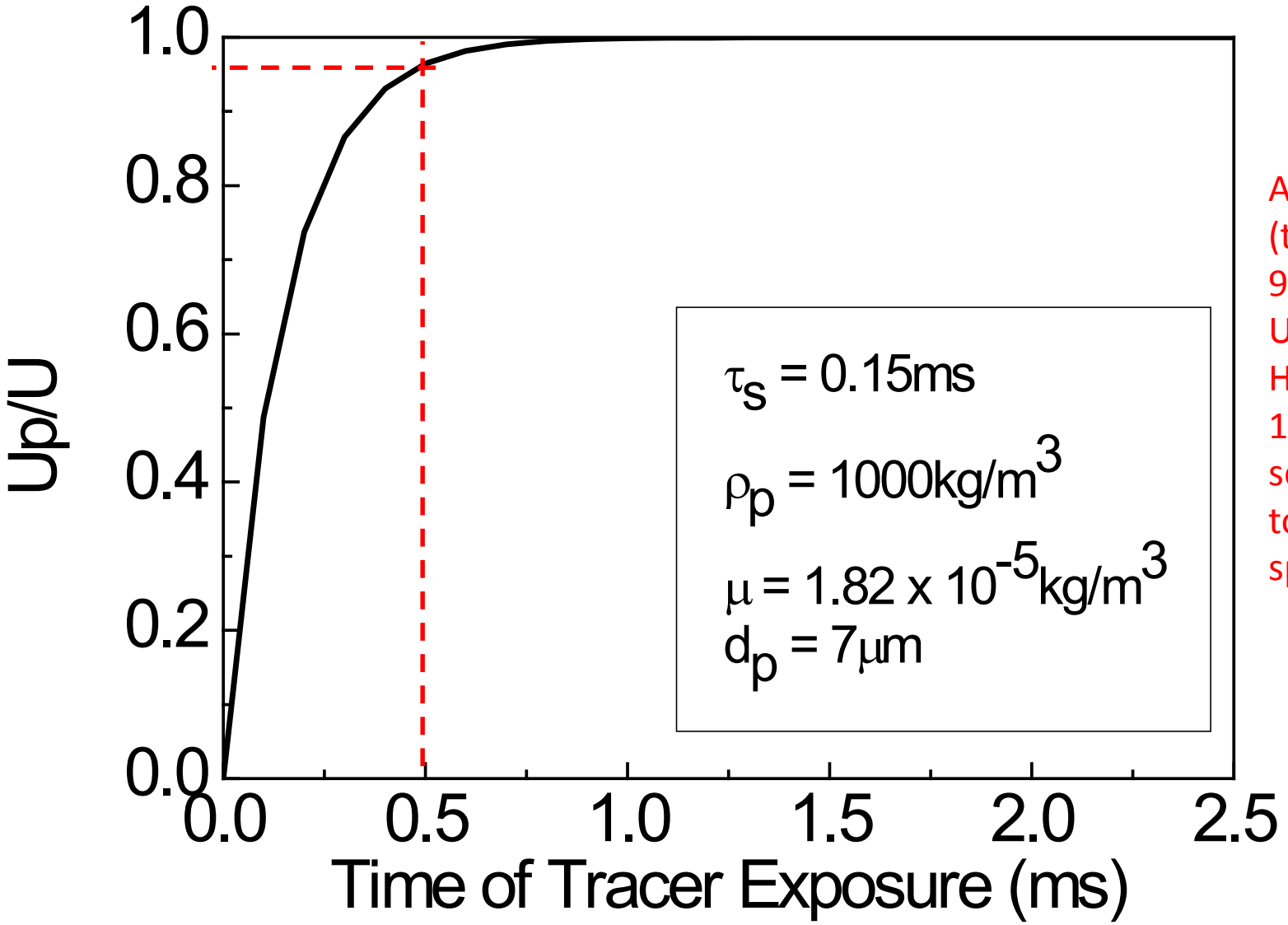
$$\tau_s = d_p^2 \frac{\rho_p}{18\mu} \qquad (1)$$

$$U_p = U\left[1 - exp\left(-\frac{t}{\tau_s}\right)\right] \qquad (2)$$

where τ_s : relaxation time [ms]
d_p : diameter of tracer particle [μm]
ρ_p : density of tracer [kg/m^3]
U_p : tracer particle velocity
U : ambient gas velocity
t : tracer particles exposed time to the surrounding flow

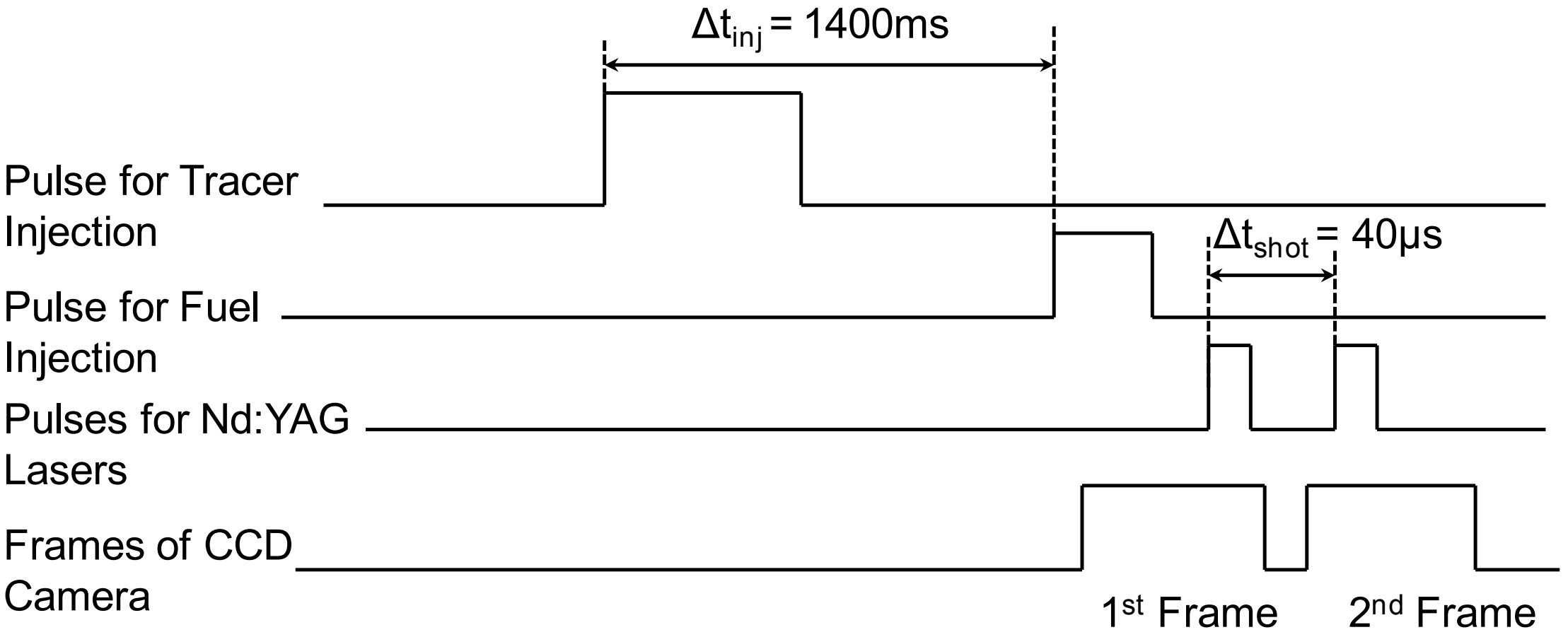
Source: Raffel et.al, 2000

Tracer Tracking Ability



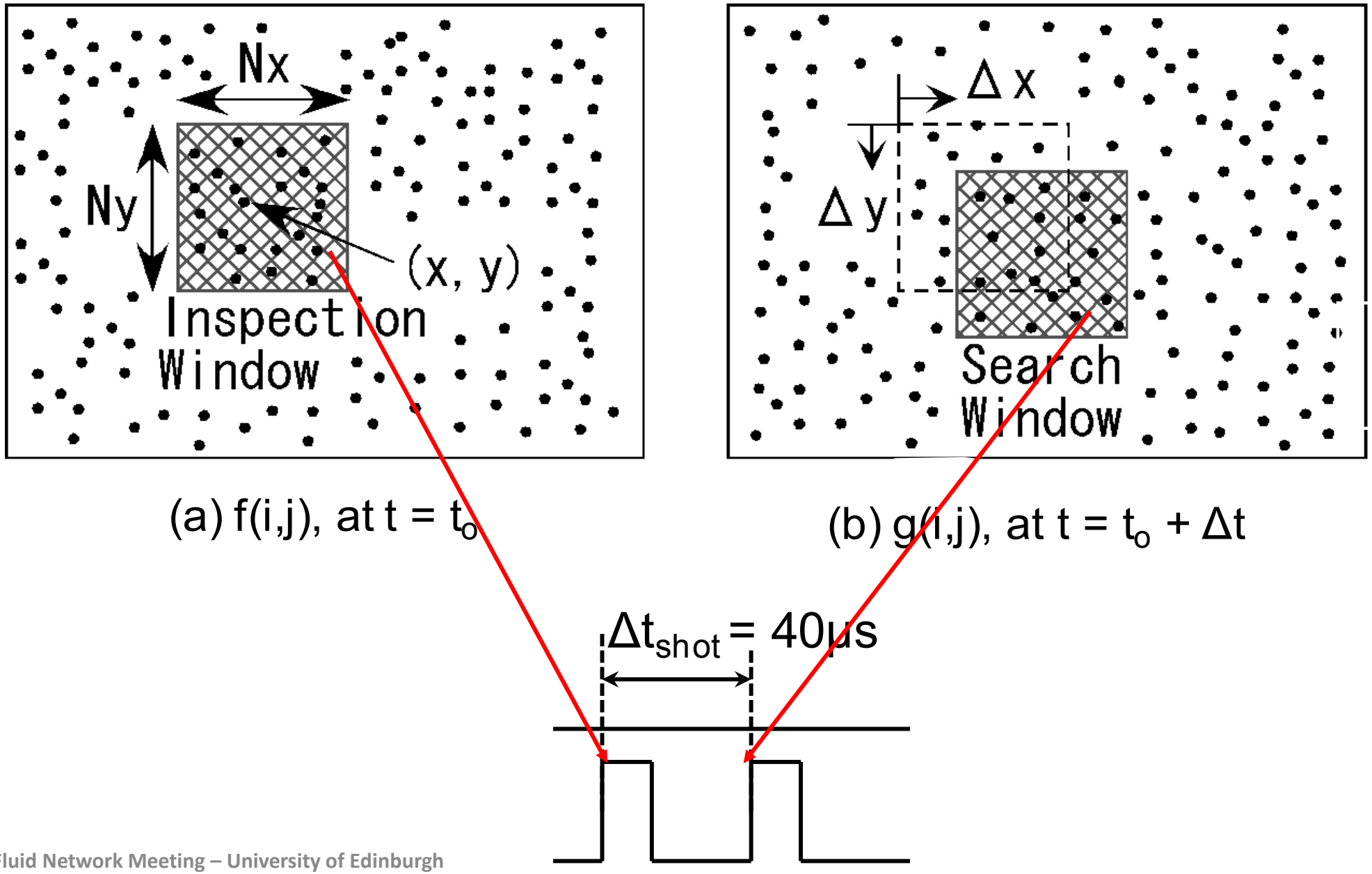
At t = 0.5 ms after exposure (tracer pulse), U_p is more than 90% of the ambient gas velocity, U induced by the fuel spray. Hence the optimum timing i.e. 1400ms (7µm tracer particle) selected is enough for the tracer to track the gas entrained in the spray

Timing Chart of LIF-PIV Measurement



Δt_{inj} = 1400ms was adopted in order to obtain the fine tracer droplet diameter around 7μm and the uniform tracer droplet distribution in the constant volume vessel.

Cross-correlation algorithm for the velocity vector analyses



Experimental conditions

Ambient gas	N_2		
Density (kg/m^3)	15 (-10° ATDC)		
Pressure (MPa)	1.4		
Temperature	295		
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)	2.2		
Number of nozzle holes for 80mg/stroke (2.2 ms)	22	14	4

Fuel properties

Fuel Property	WCO biodiesel	JIS#2 Diesel
Density @ 15ºC (kg/m^3)	885	830
Viscosity @ 40ºC (mm^2/s)	4.45	3.36
Surface tension @ 20ºC (mN/m)	33.1	30.6
Cetane number	51	45
Distillation temperature (ºC)	360	320
Flash point (ºC)	>180.5	>60
Flow point (ºC)	-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
Carbon content (wt. %)	10.1	<1

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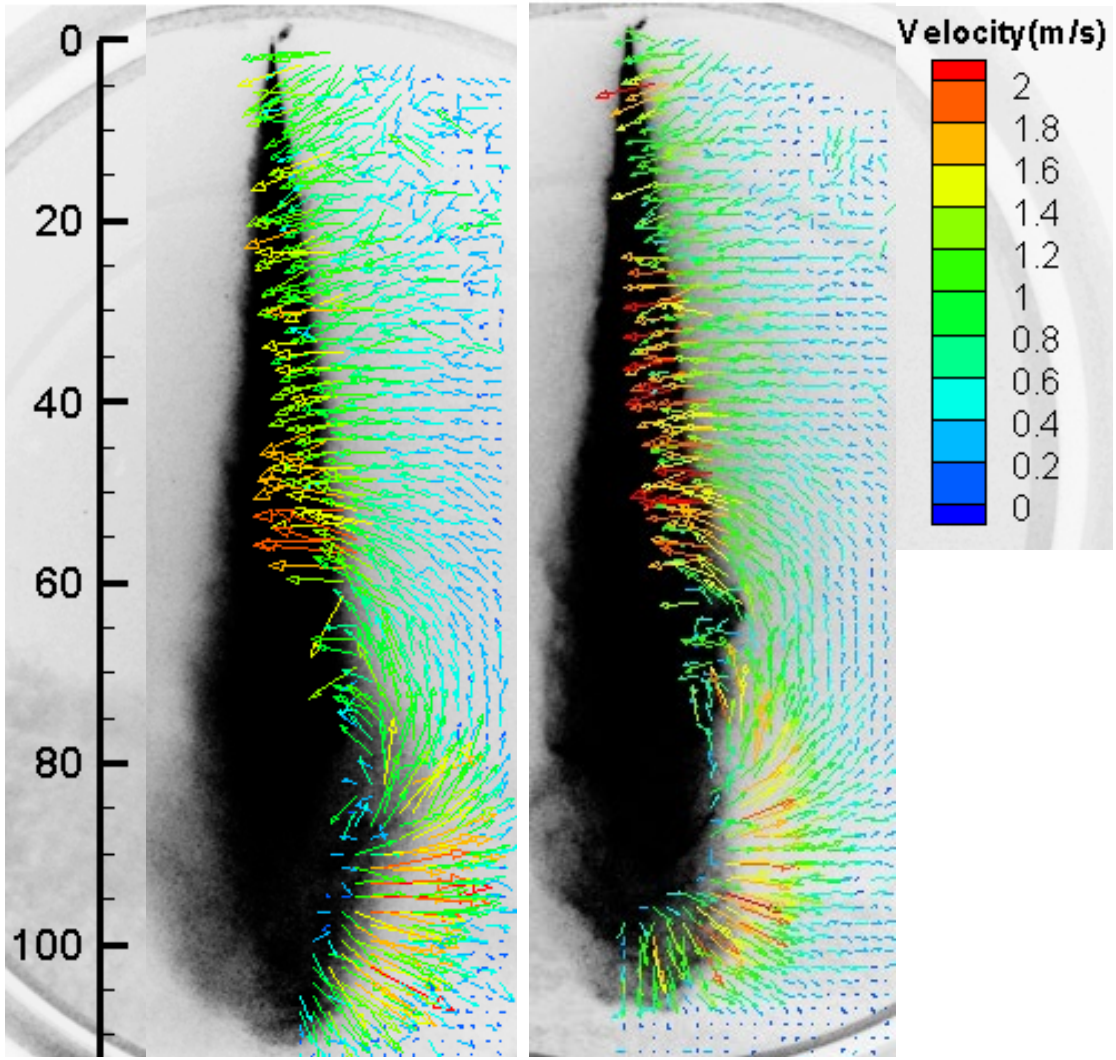
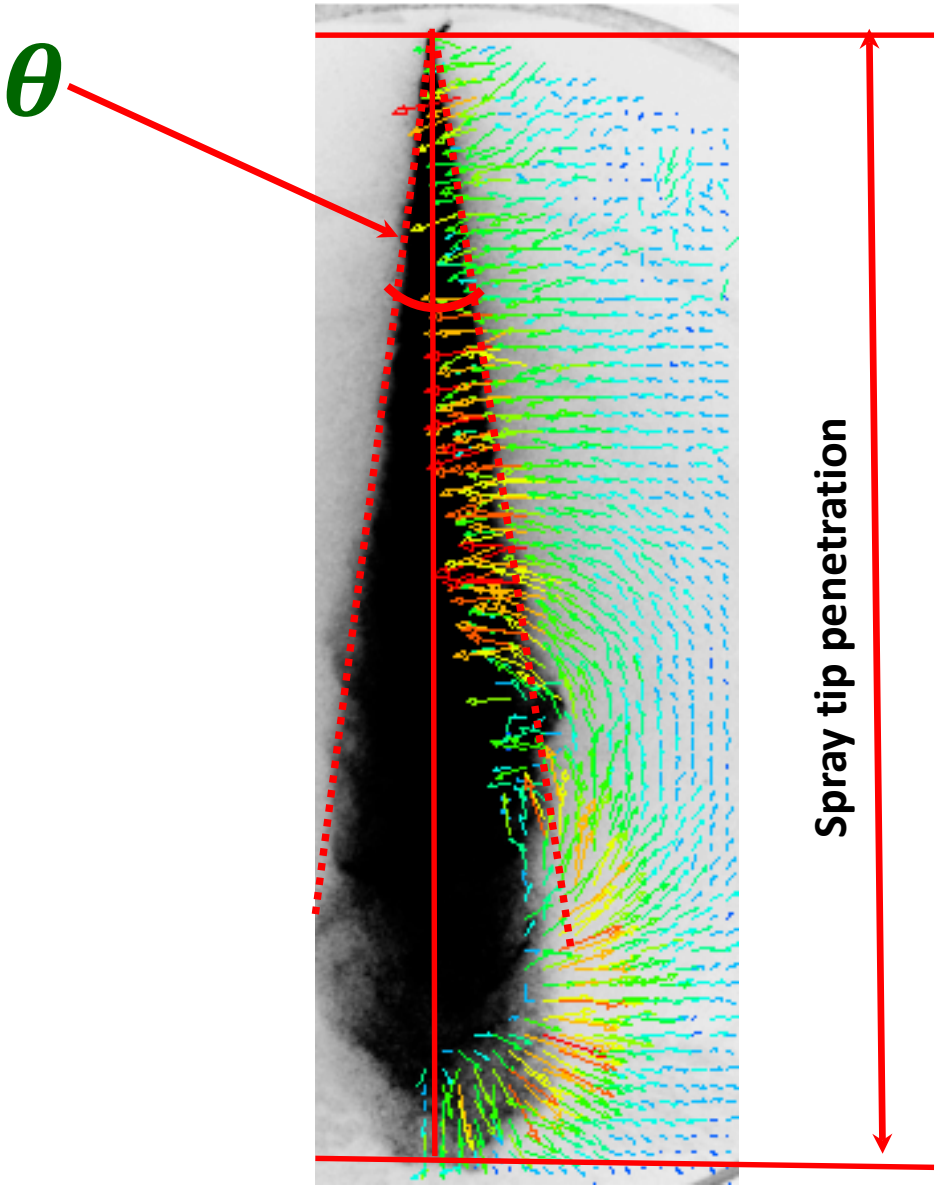
Spray evolution

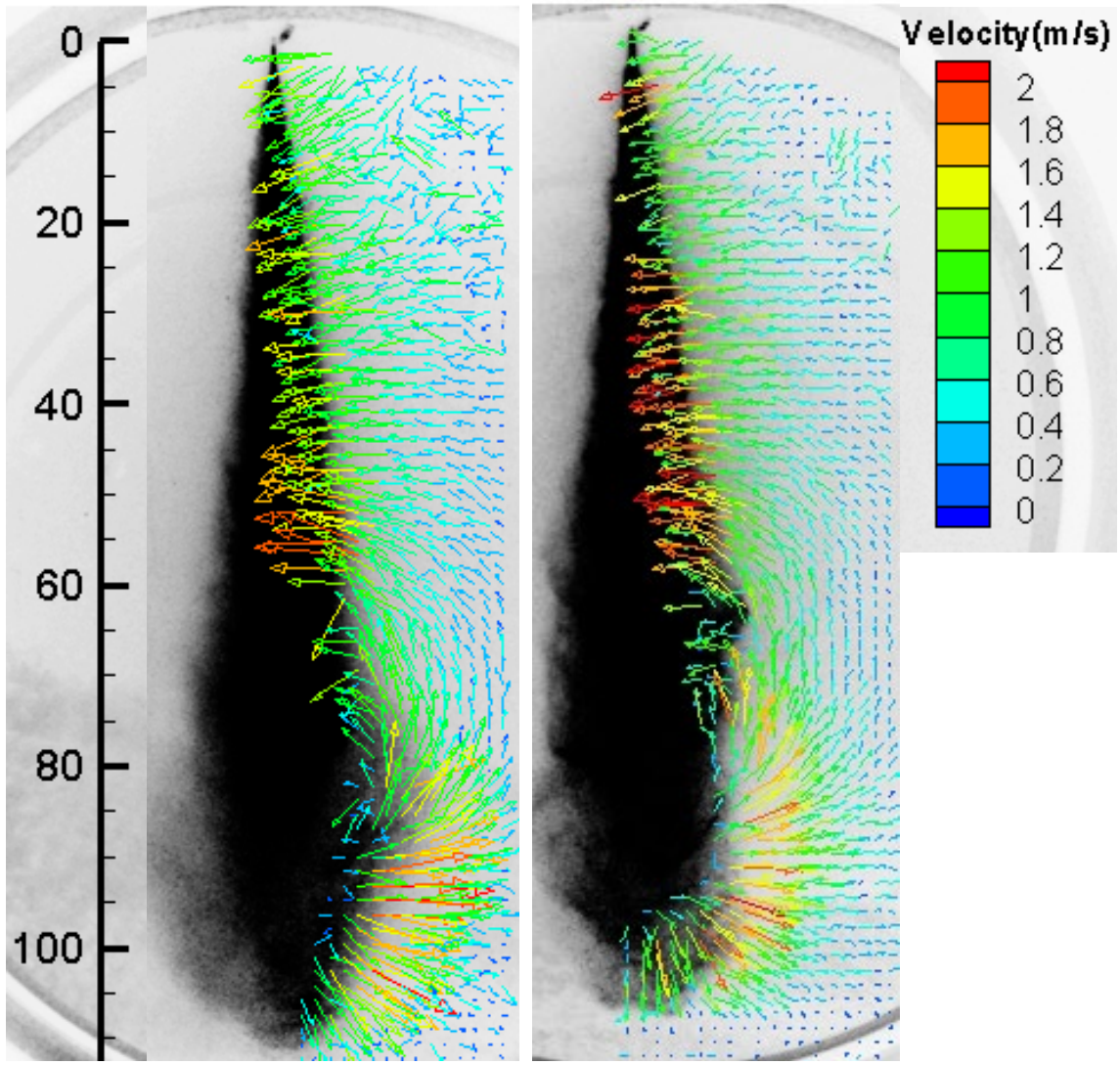
P_{inj} = 100MPa,d_o=0.16mm,t_{inj}=2.0ms ASOI



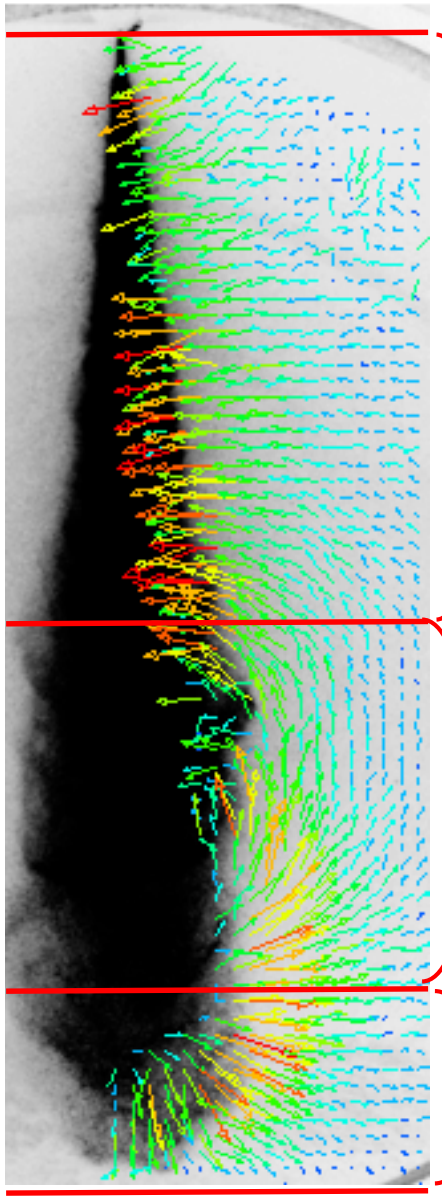


Terminologies

Pinj = 100MPa,do=0.16mm,tinj=2.0ms ASOI



WCO **Diesel**

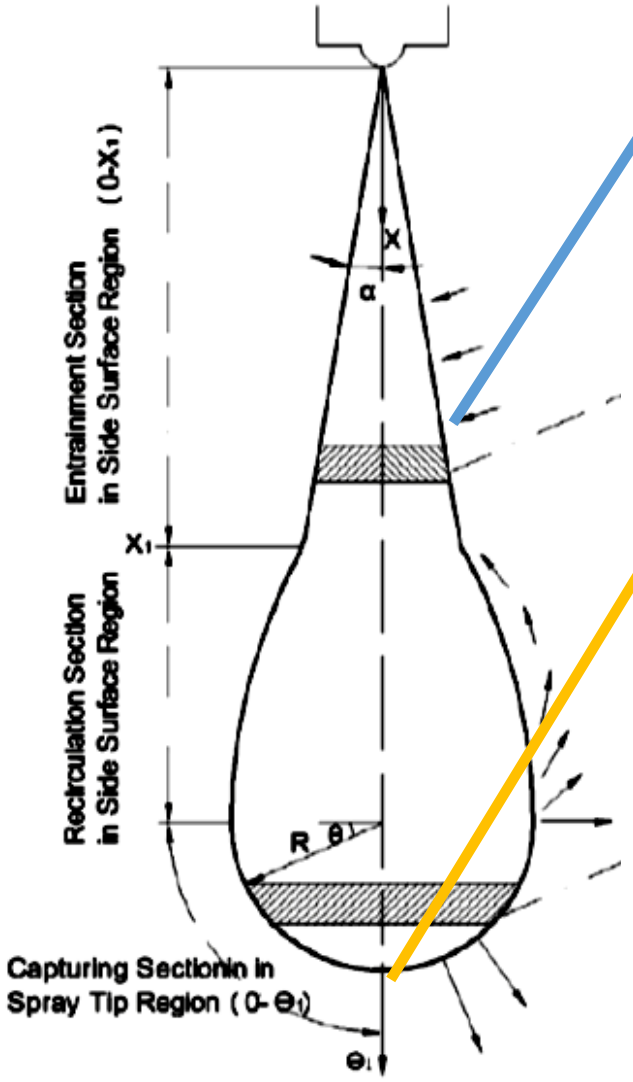


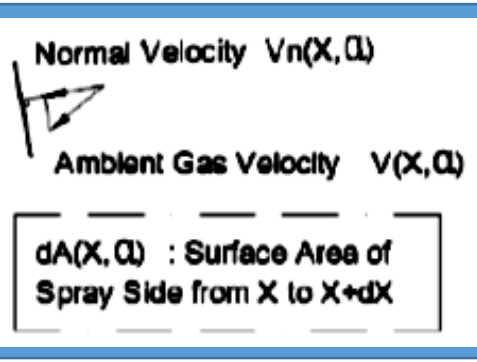
Lateral entrainment

Recirculation

Gas pushed out and captured

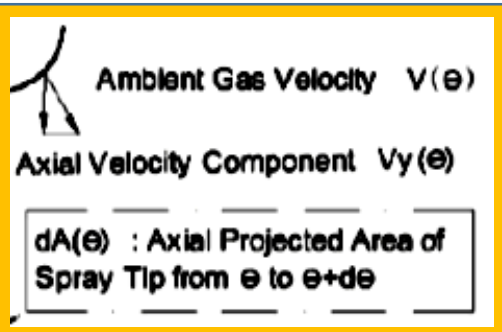
Terminologies





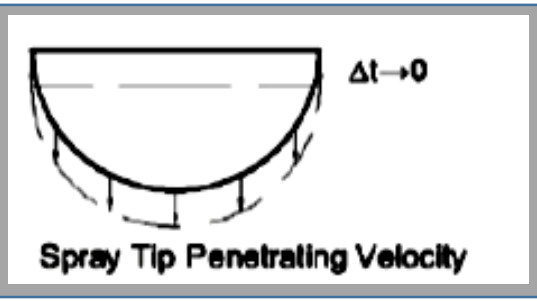
Spray side surface region:

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



Spray tip hemisphere region:

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



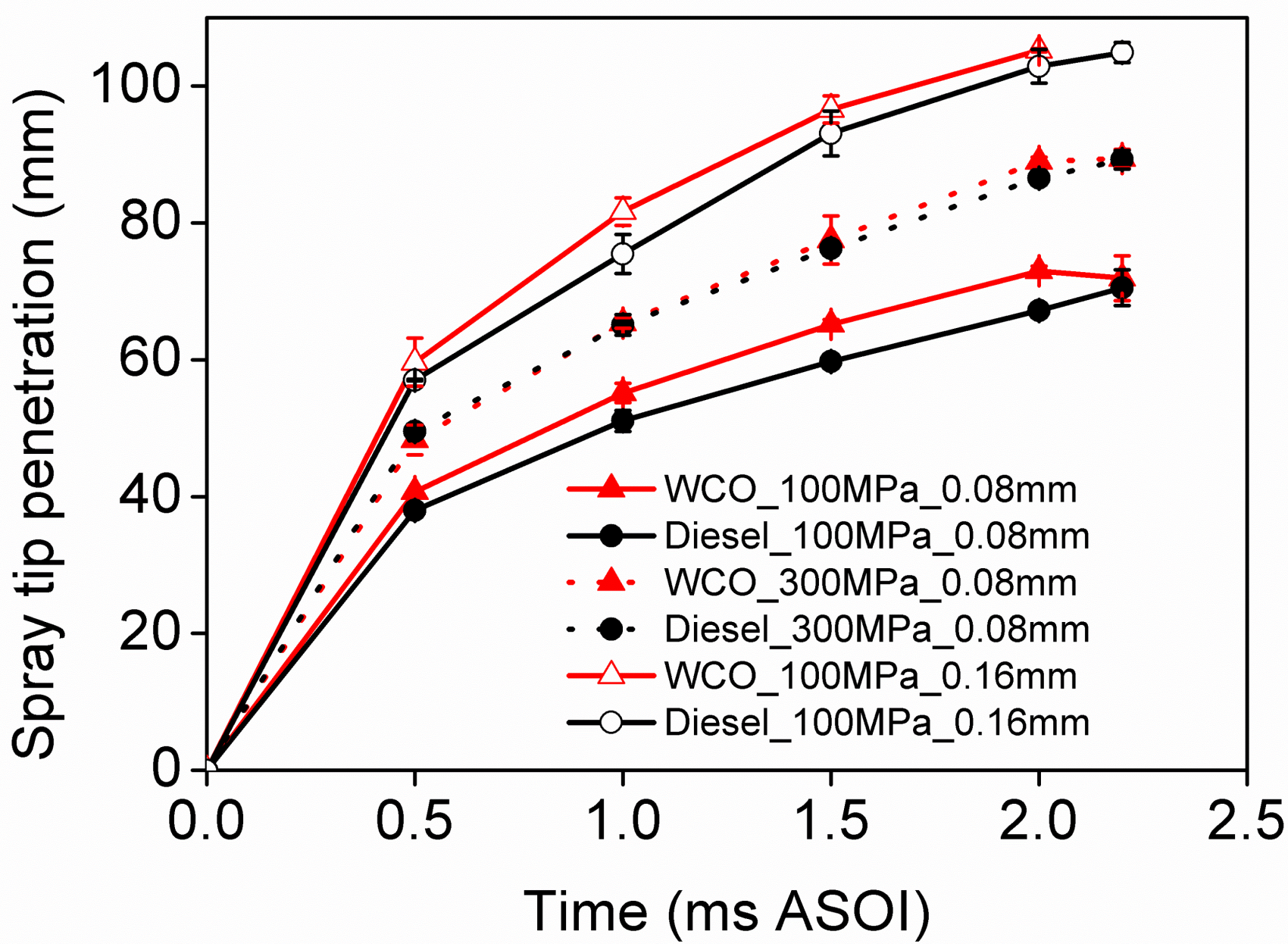
Spray Penetration

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

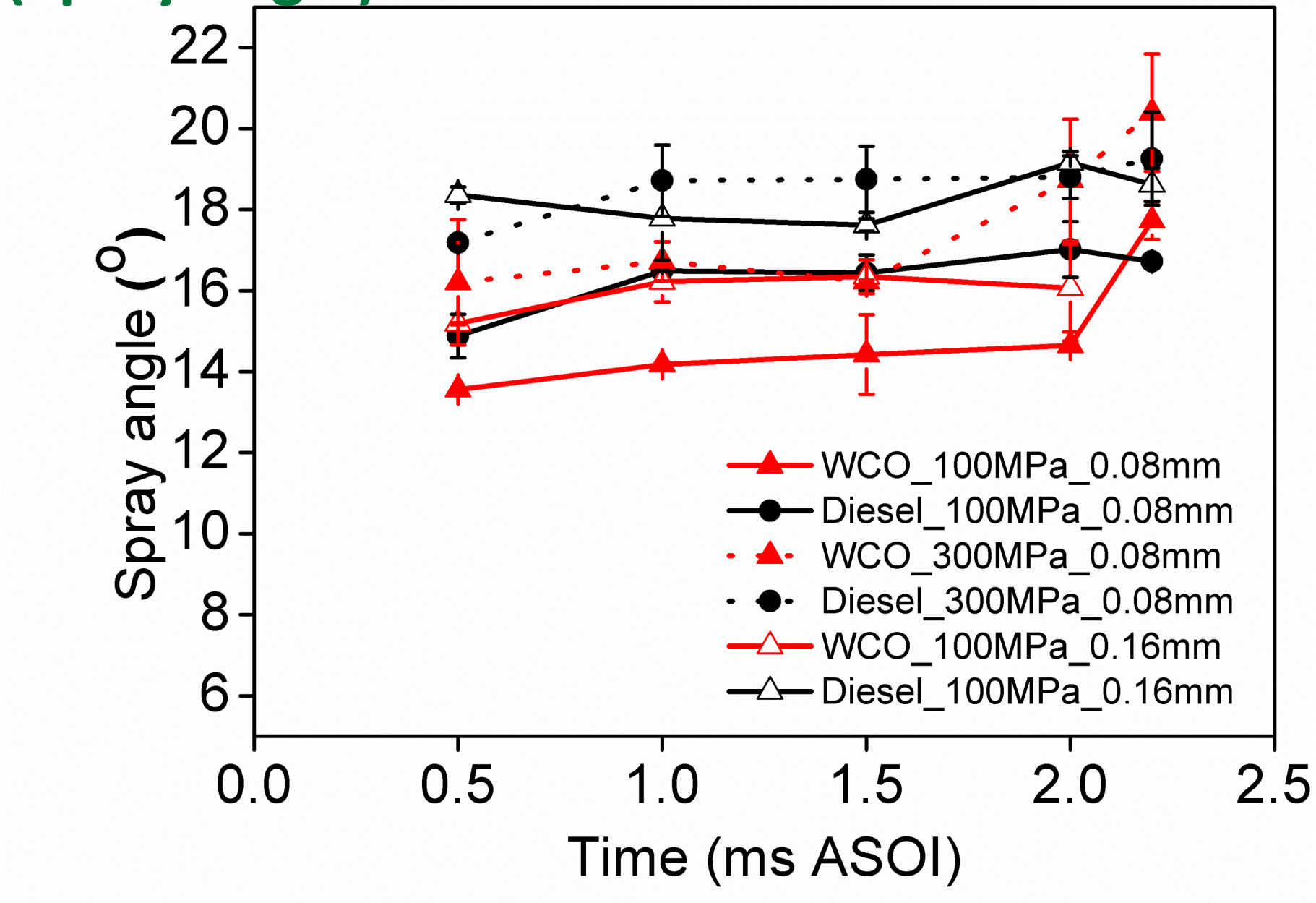
$$\dot{m}_{a_{cap}} = \dot{m}_{a_{penetrating}} - \dot{m}_{a_{pushing}}$$

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

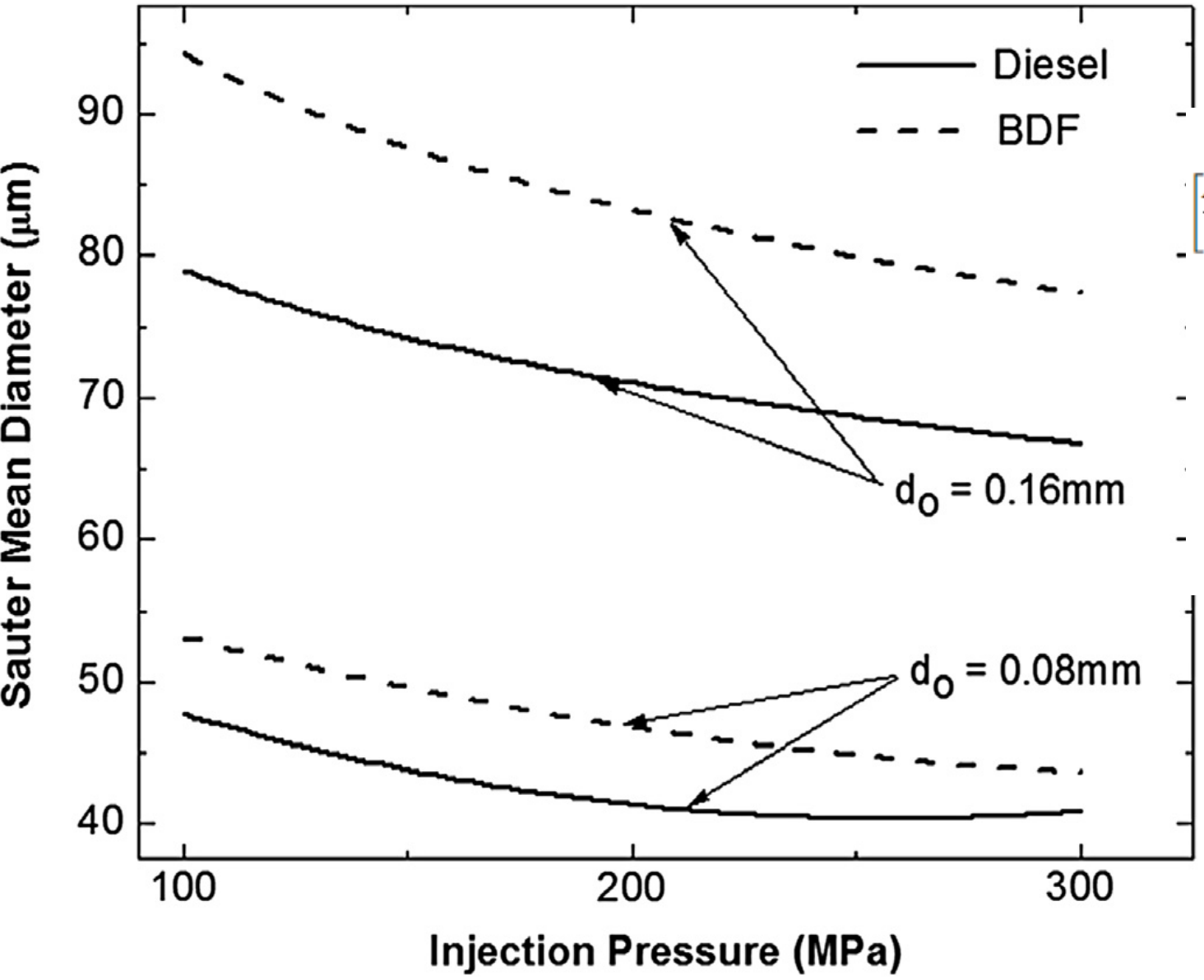
Results (Spray tip penetration)



Results (Spray angle)



Results (Droplet size)

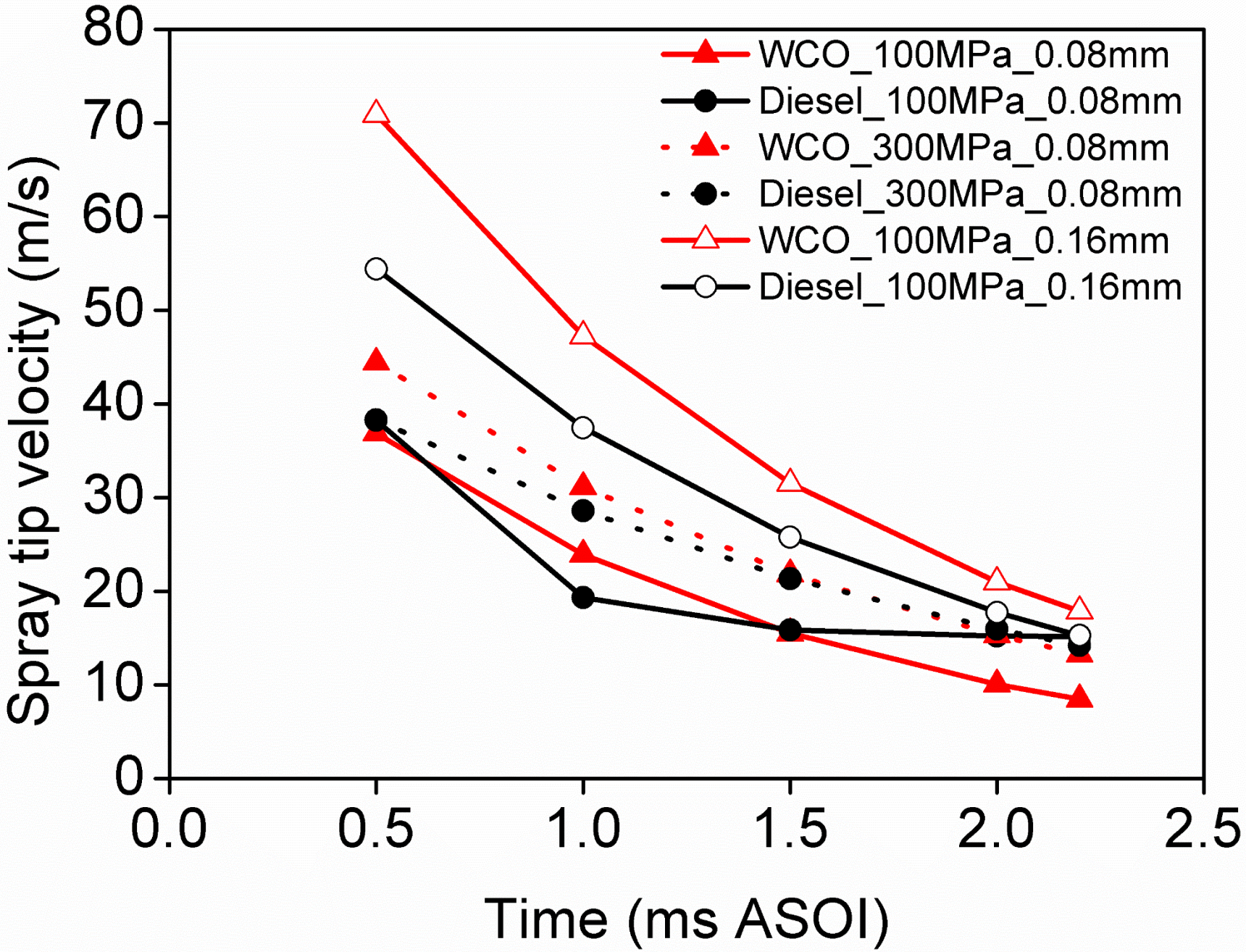


$$\left[\frac{X_{32}}{D}\right] = 0.38\mathrm{Re}^{0.25}\mathrm{We}^{-0.32}\left(\frac{\mu_l}{\mu_g}\right)^{0.37}\left(\frac{\rho_l}{\rho_g}\right)^{-0.47}$$

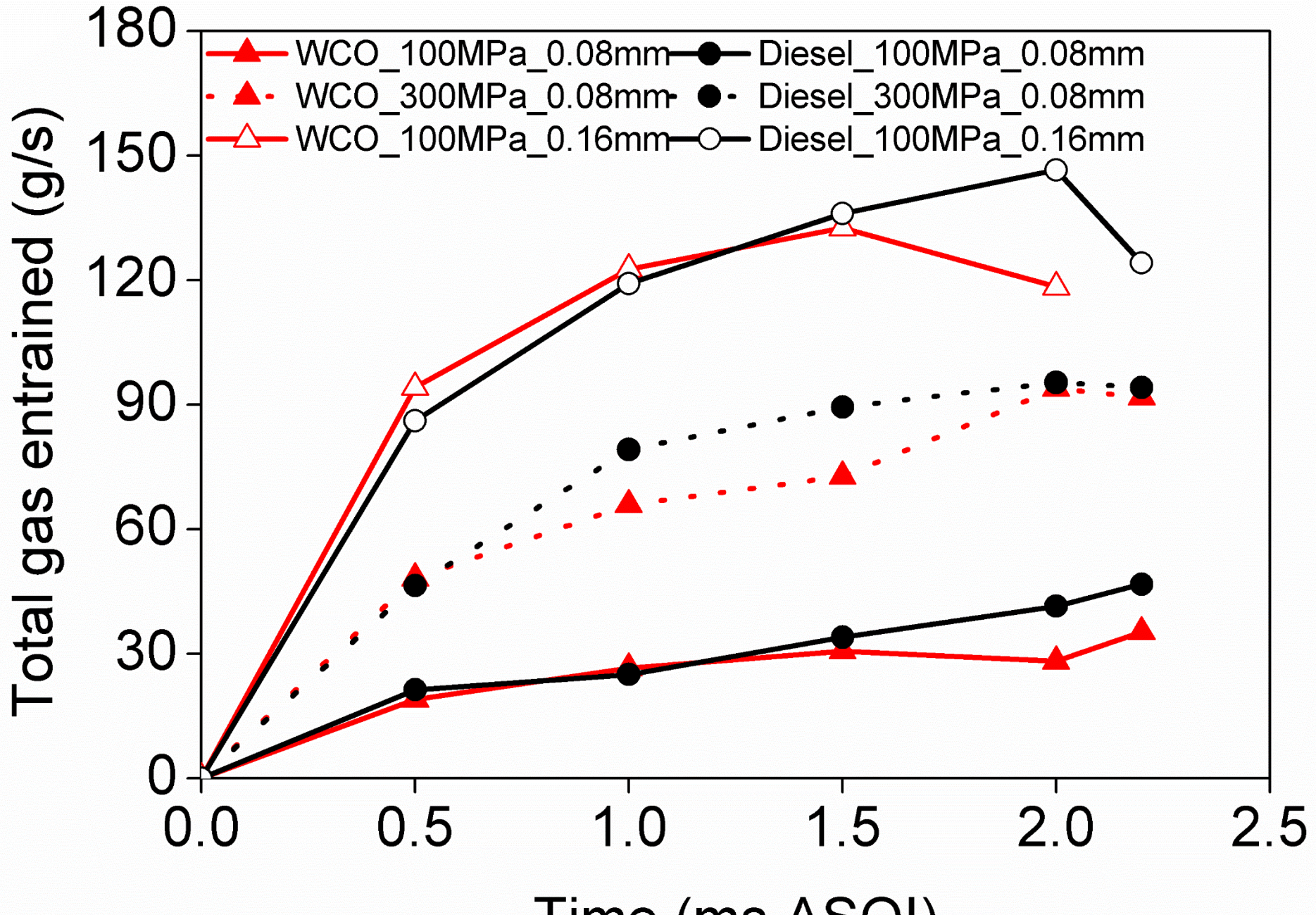
X_{32}: Sauter mean diameter (SMD)
D: nozzle diameter
Re: Reynolds number of nozzle hole flow
We: Weber number of injected fuel
μ_l and μ_g: viscosities of the injected fuel and ambient gas
ρ_l and ρ_g: densities of the injected fuel and ambient gas

Source: Hiroyasu et al. Empirical equations for the Sauter mean diameter of a diesel spray. SAE Paper 890464 1989.

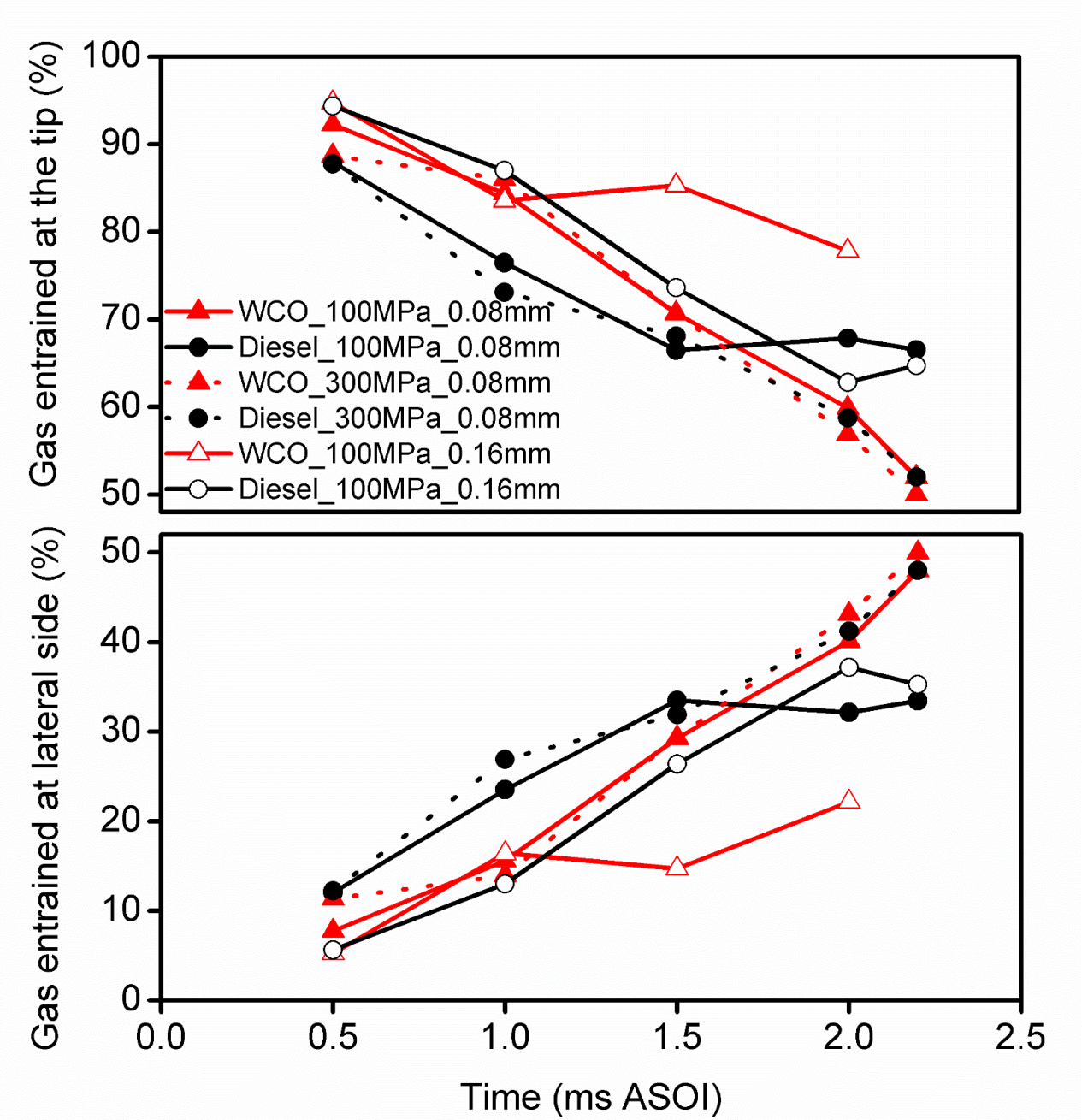
Results (Instantaneous spray tip velocity)



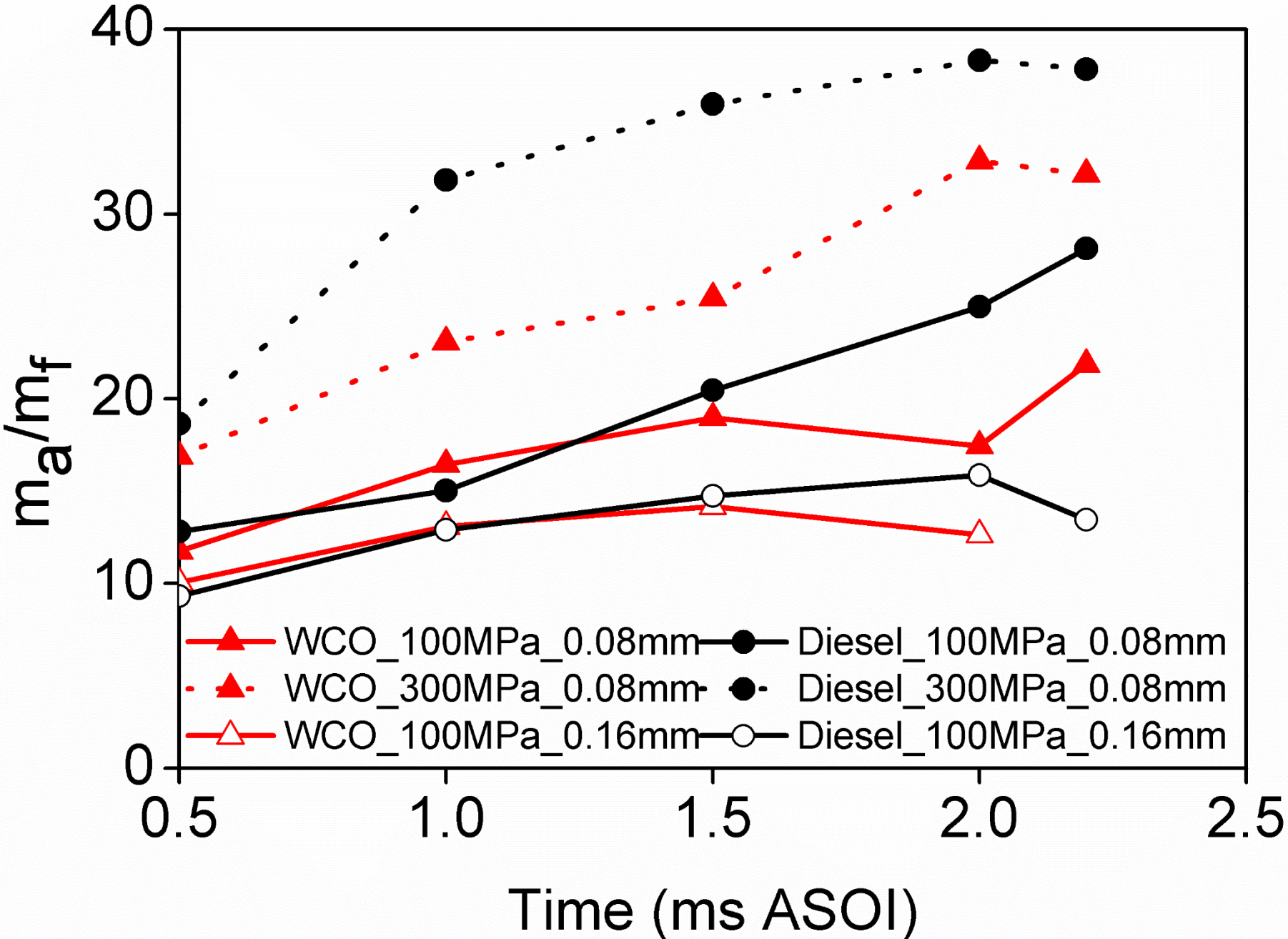
Results (Total gas entrained)



Results (Gas entrainment- lateral vs pushing)



Results (Rate of mixing)



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Conclusions

- Spray and gas entrainment characteristics of waste cooking oil biodiesel (WCO) was investigated using the LIF-PIV (Laser Induced Fluorescence-Particle Image Velocimetry). As compared to diesel;

  - ***WCO spray penetrates more and faster. Higher injection pressure and larger nozzle size led to increase in spray penetration and tip velocity.***

  - ***WCO spray angle smaller while droplet size is larger (inferior atomization). Higher injection pressure with smaller nozzle diameter enhanced atomization.***

  - ***WCO entrains less gas especially toward end of injection. Higher injection pressure and larger nozzle size promotes gas entrainment (larger surface area).***

  - ***Less mixing achieved by WCO .Higher injection pressure and smaller nozzle size enhanced mixing.***