Visualization of Micro Structure in a Diesel Spray by Use of Photography with High Spatial Resolution

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1.5F Spray and Combustion in Diesel Engine

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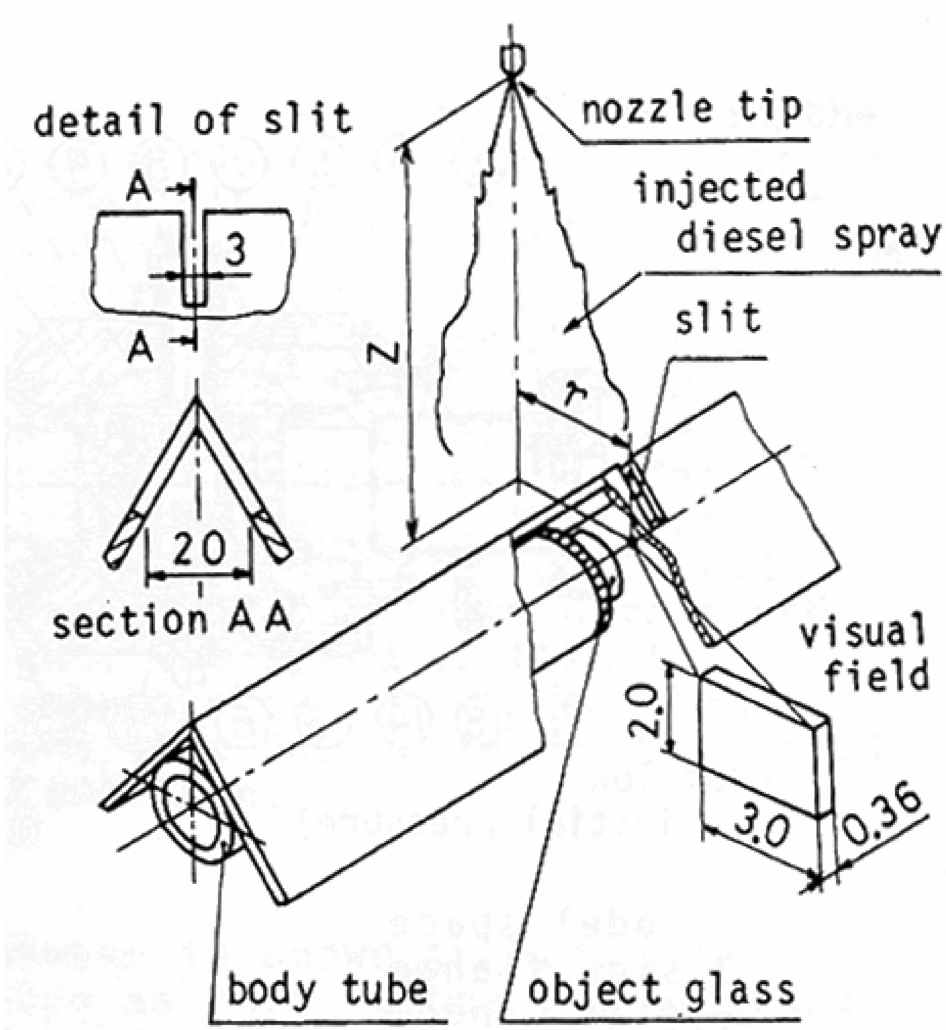
Way of measurement of droplets size

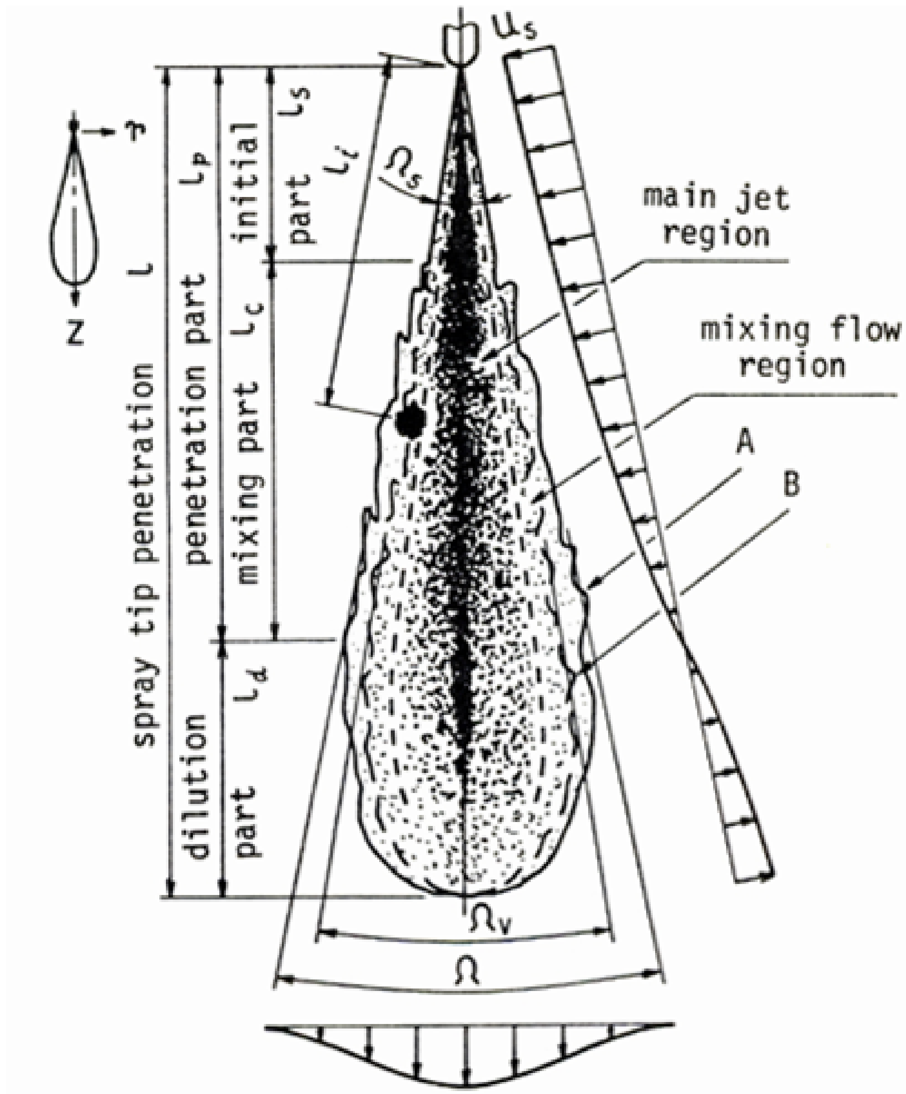
1. Direct photography on an analogue film
2. Direct photography by use of CCD camera
3. LDA
4. PDPA
5. ILIDS

   (Interferometric Laser Imaging for Droplet Size)

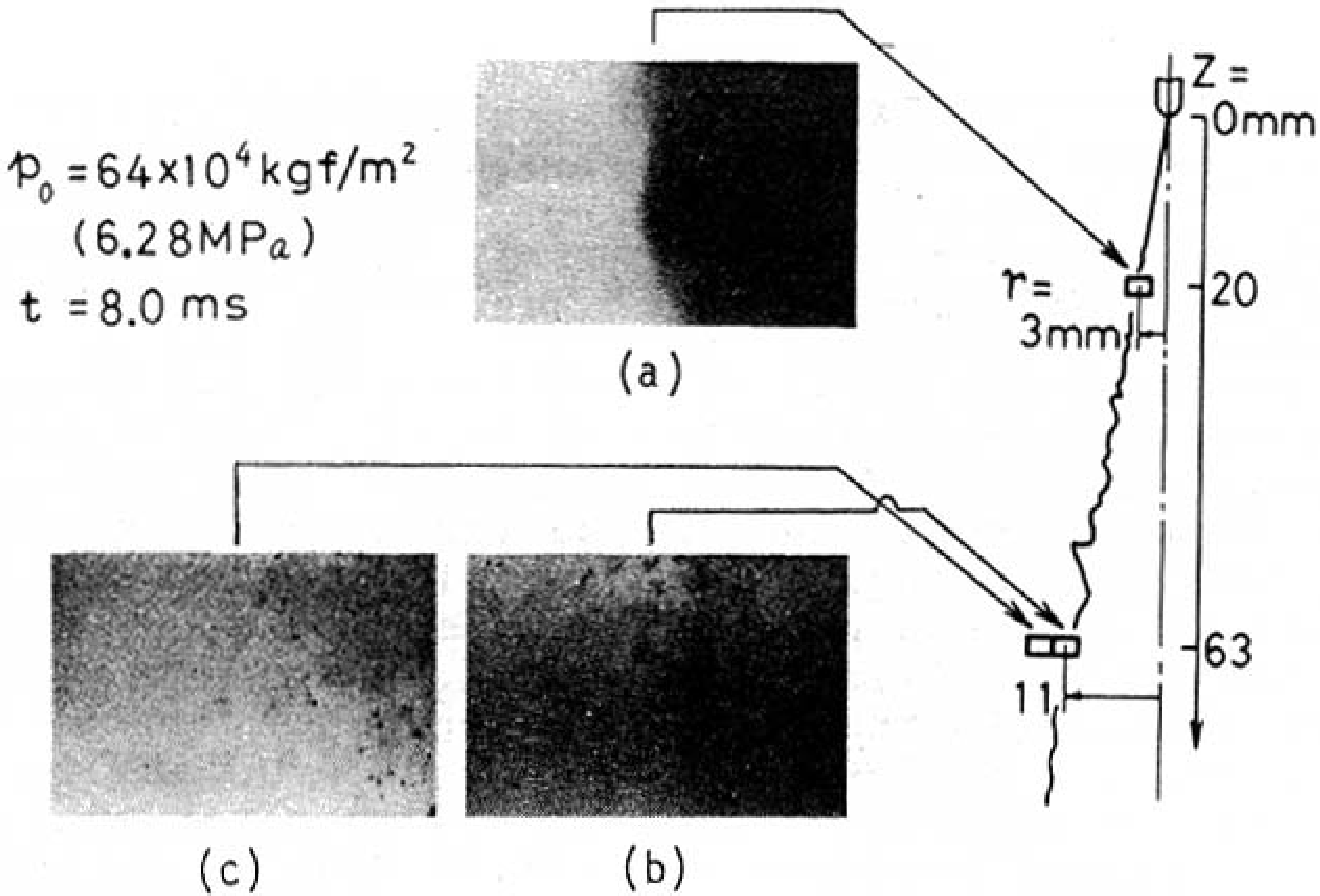
Slit system to measure droplets size [2]



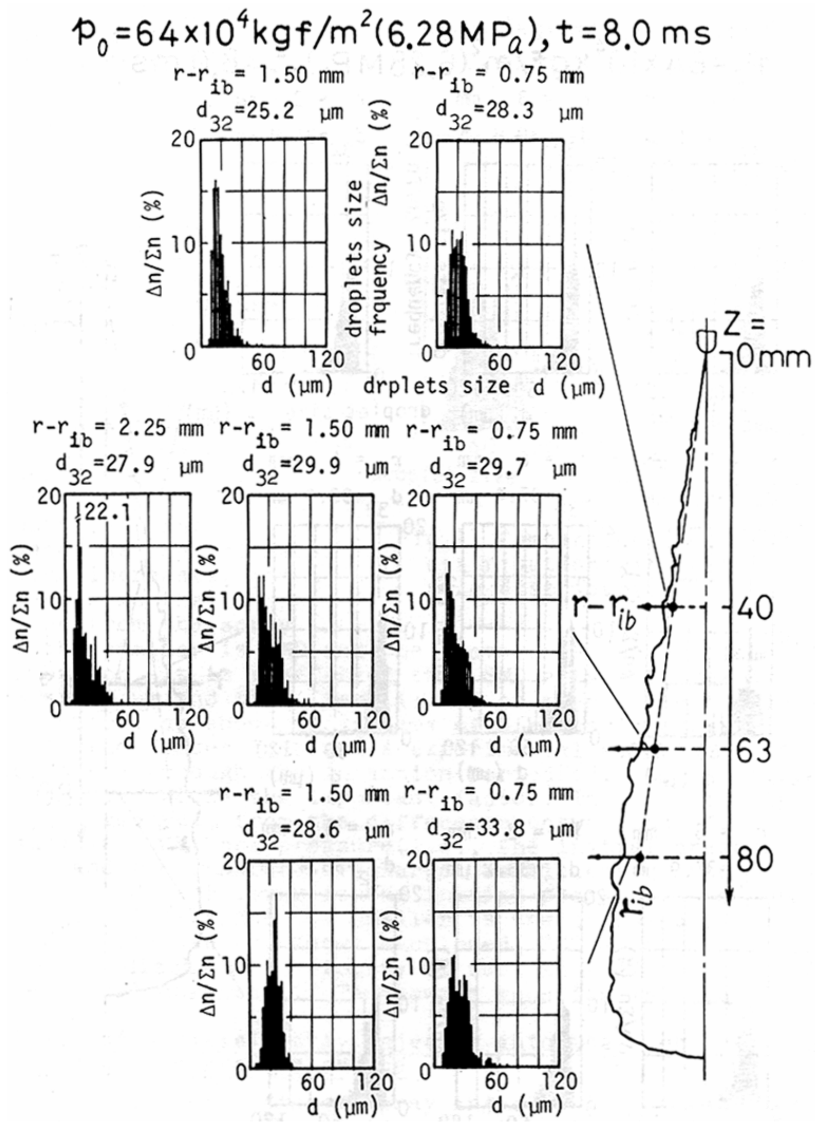
Structure and shape of diesel spray [2],[3]



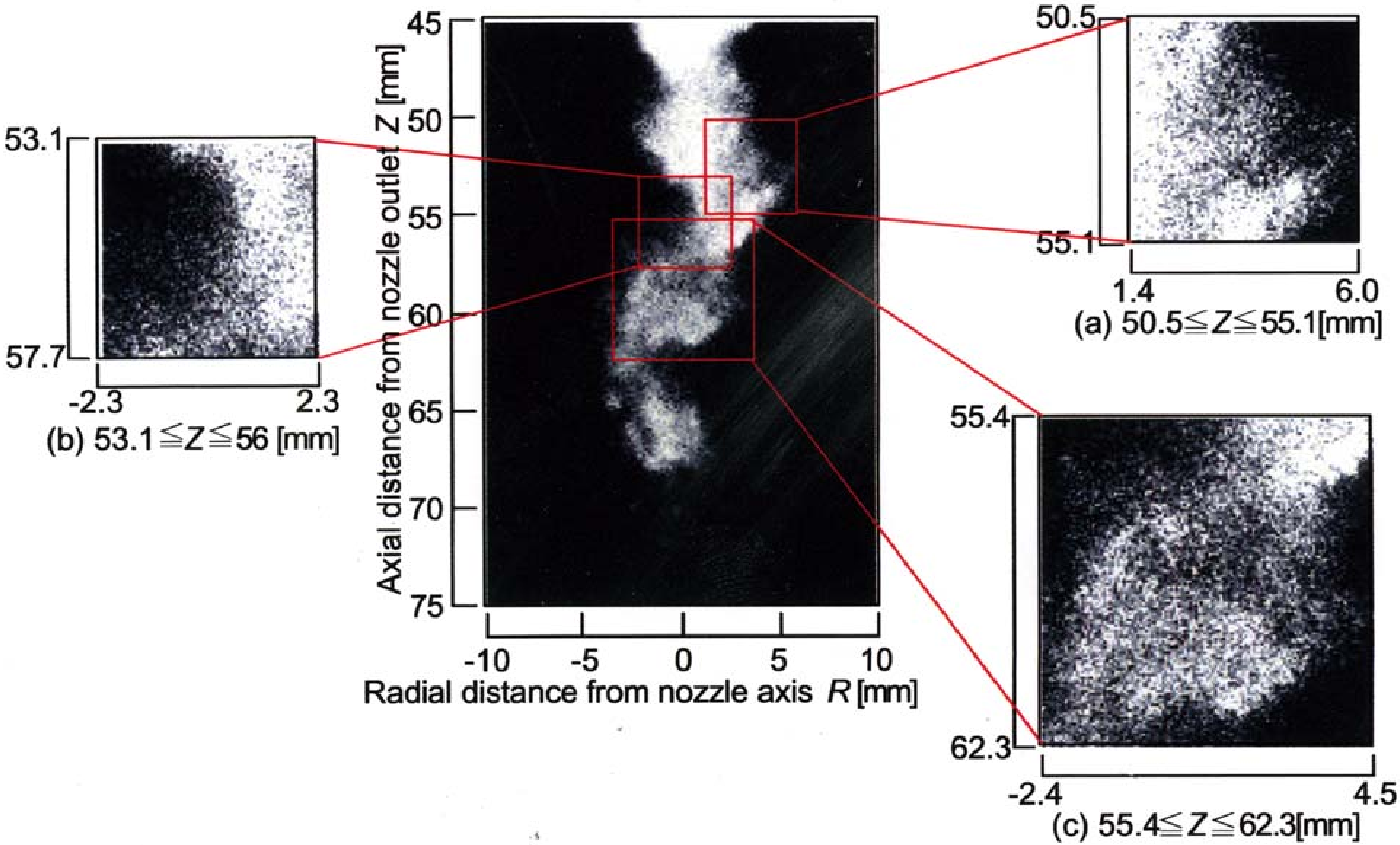
One of examples of photographs of a diesel spray [2]



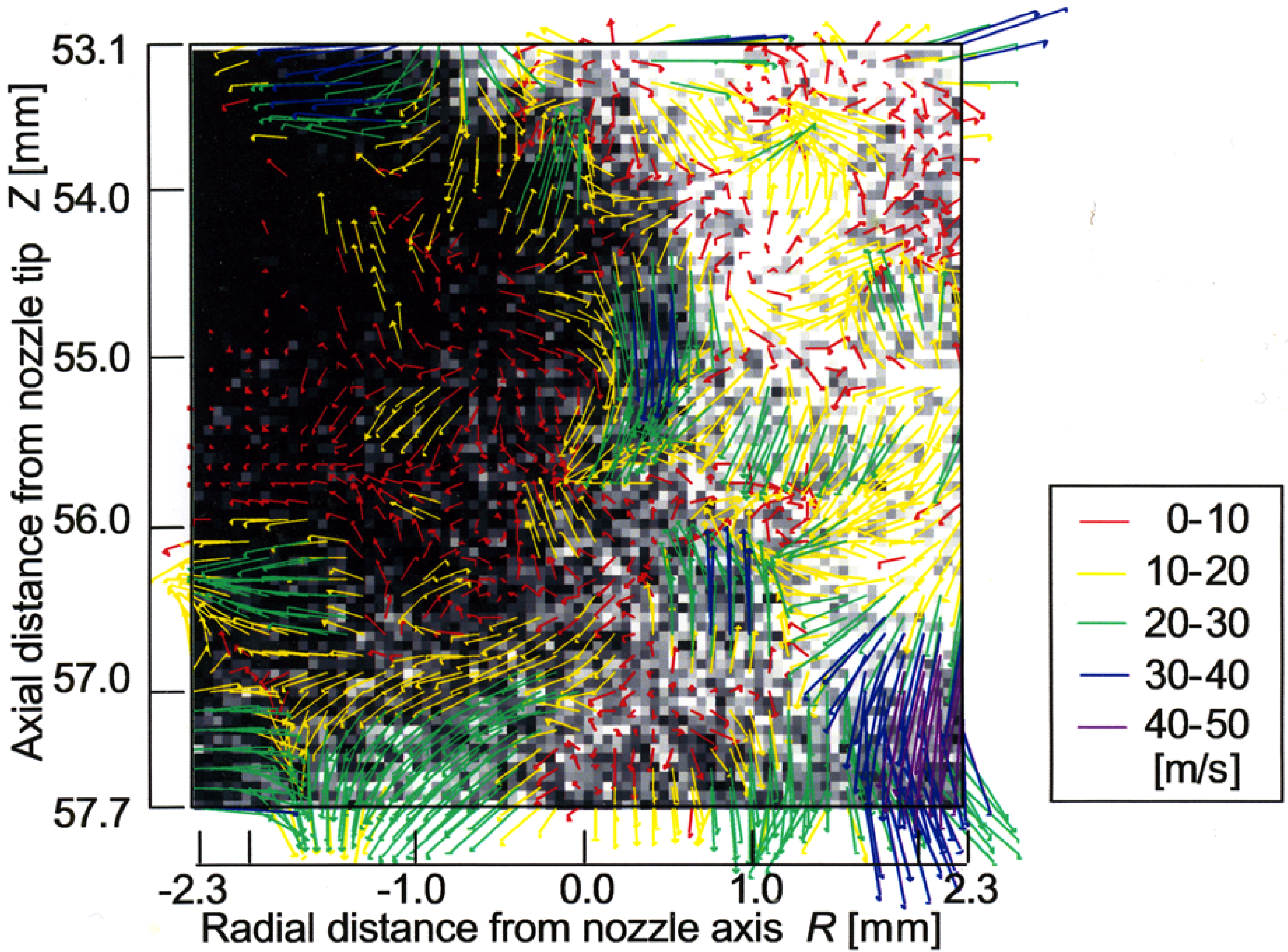
One of examples of distribution of droplet in a diesel spray [2]



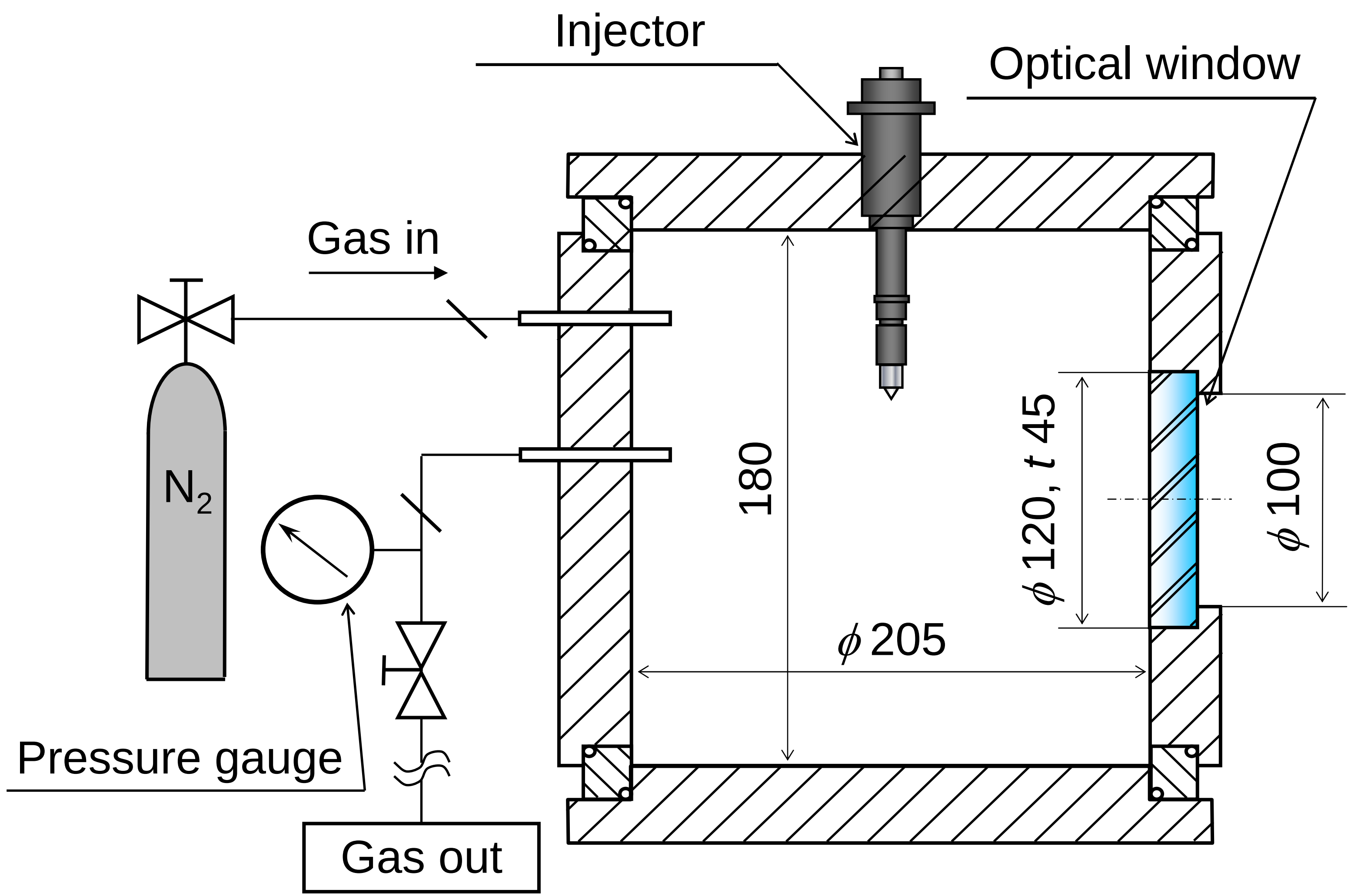
Given three different small local areas applied to PIV technique (*t* = 1.12 [ms]) [9]



One of results of distribution of velocity vector in an evaporating diesel spray [9]



Section of constant volume chamber and gas supply system

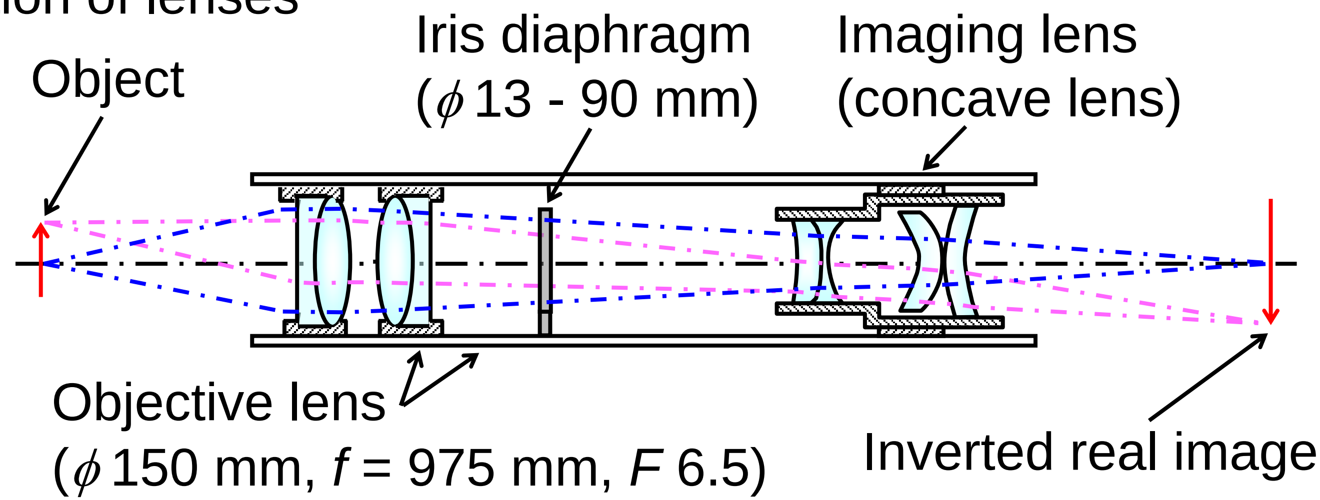


Experimental condition

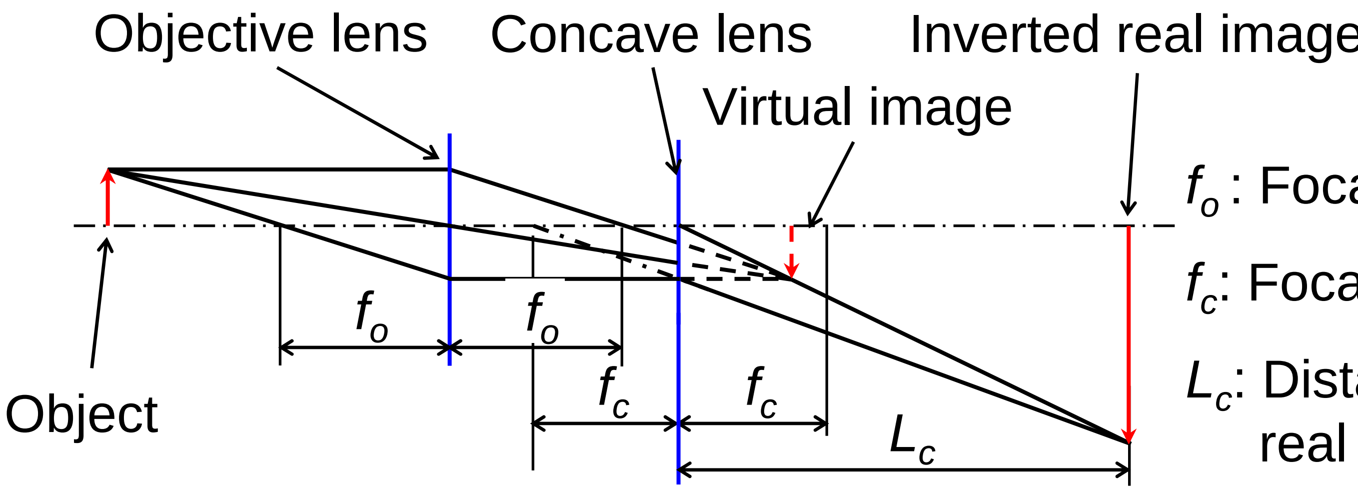
Fuel oil			n-tridecane		
Ambient gas			N_2		
Ambient temperature	T_a	[K]	room temperature		
Ambient density	ρ_a	[kg/m³]	17.3		
Ambient pressure	p_a	[MPa]	1.50		
Injection pressure	p_{inj}	[MPa]	55	77	99
Injection duration	t_{inj}	[ms]	1.68	1.42	1.25
Injection quantity	Q_{inj}	[mg]	12.0		
Number of nozzle hole			1		
Nozzle hole diameter	d_n	[mm]	0.20		
Nozzle hole length	L_n	[mm]	0.80		

Specialized lens system

(a) Combination of lenses



(b) Geometrical optics



f_o : Focal length of objective lens

f_c: Focal length of concave lens

L_c: Distance between inverted real image and last concave lens

Depth of Field DOF

$$DOF = \frac{sf^2}{f^2 - \delta F s} - \frac{sf^2}{f^2 + \delta F s} \qquad (1)$$

$$F = \frac{f}{D_e} \qquad (2)$$

f : Focal length of lens

S : Distance between subject and lens

δ : Permissible circle of confusion

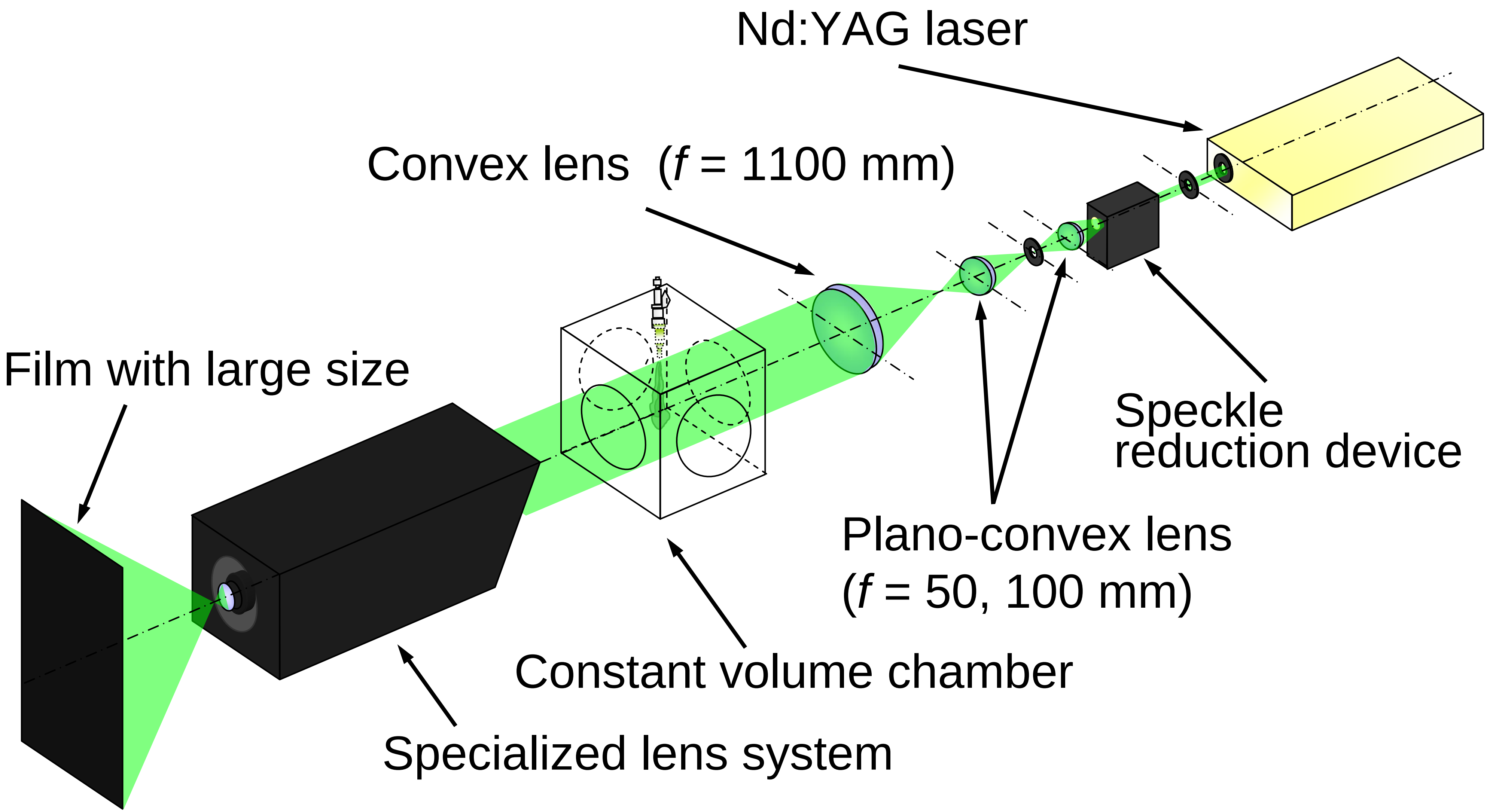
F : Brightness of image through lenses

D_e : Effective diameter of lens

In this experiment

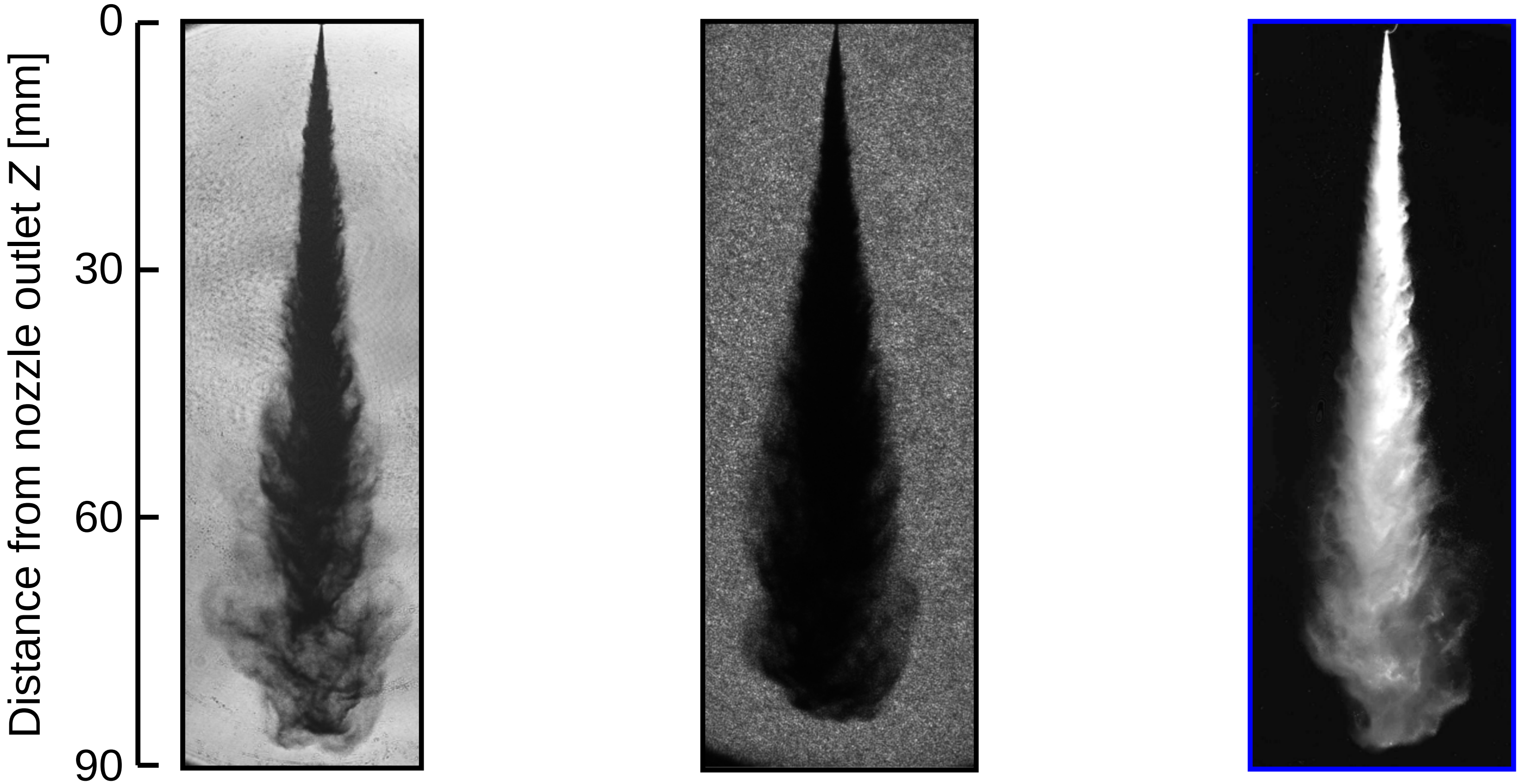
F = 975 [mm] , *DOF* = 205[μm]

Optical setup



Three kinds of photograph taken by different way

DOF **□ 200 [μm]** | ***DOF*** **□ 4.23 [mm]** | **Sheet thickness 0.2 mm**



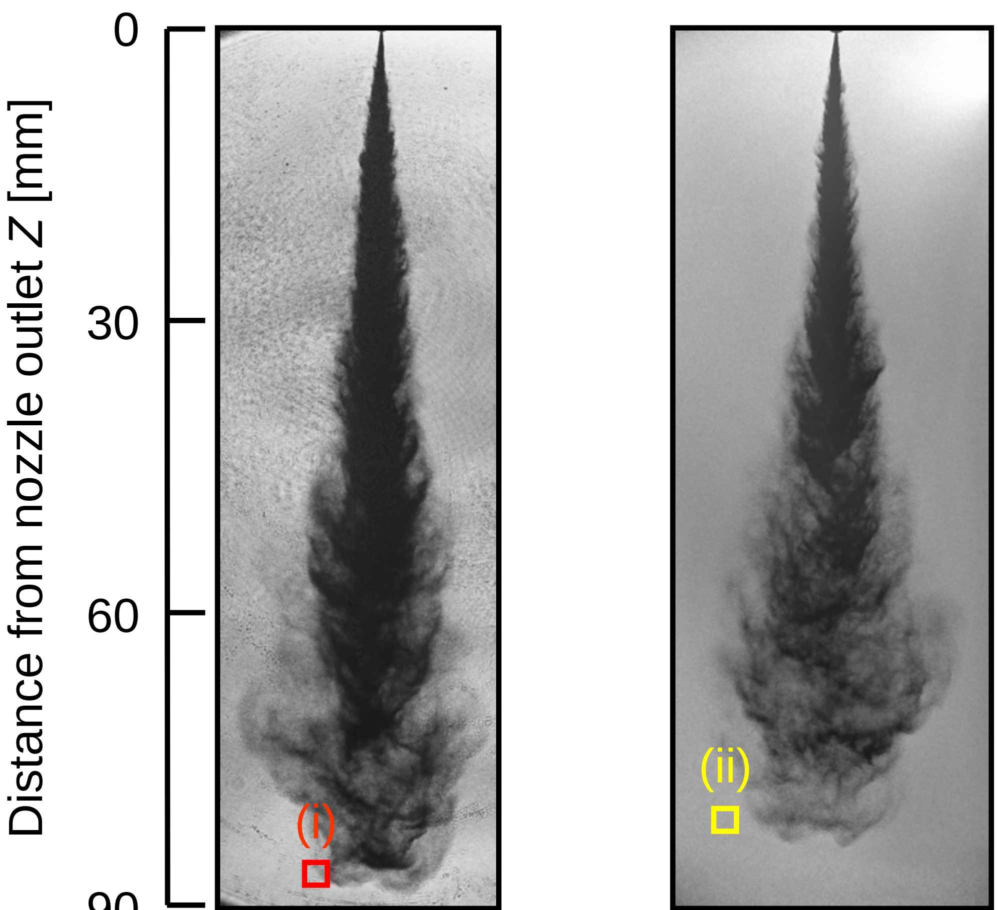
(a) Photograph taken by the optical setup proposed

(b) Photograph taken by CCD camera through transmitted light

(c) Photograph taken through thin laser light

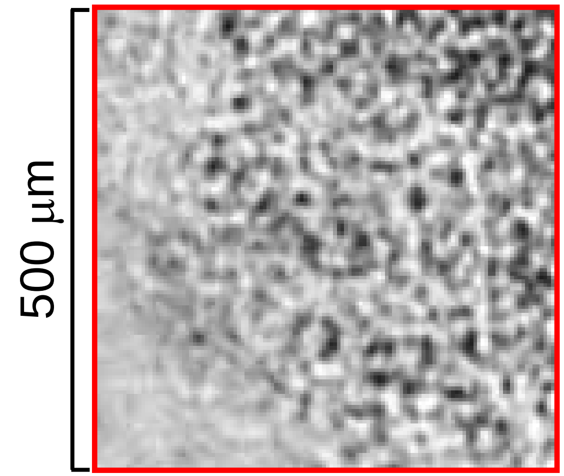
(p_{inj} = 55.0 [MPa], ρ_a = 17.3 [kg/m^3], at end of injection)

Effect of speckle reduction device

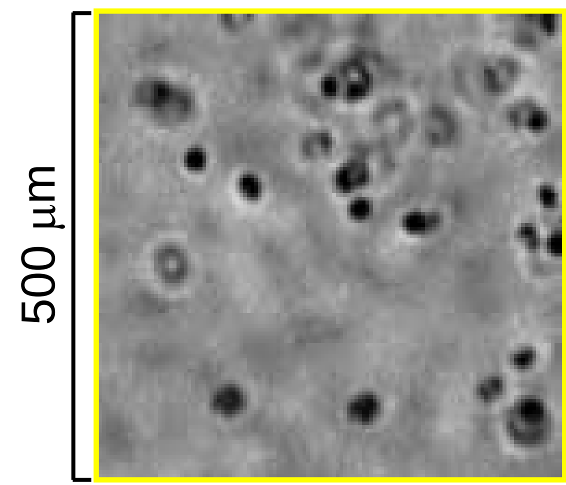


(a) Without speckle reduction device

(b) With speckle reduction device



(i) Photograph at location (i)



(ii) Photograph at location (ii)

(p_{inj} = 77.0 [MPa], ρ_a = 17.3 [kg/m^3], at end of injection, M = 2.7)

Decision of droplet diameter

$$D = \sqrt{4A/\pi} \qquad (3)$$

$$L/L_0 = \frac{S^2/A}{4\pi} \qquad (4)$$

D : Equivalent droplet diameter

A : Area of droplet

L : Aspect ratio of droplet

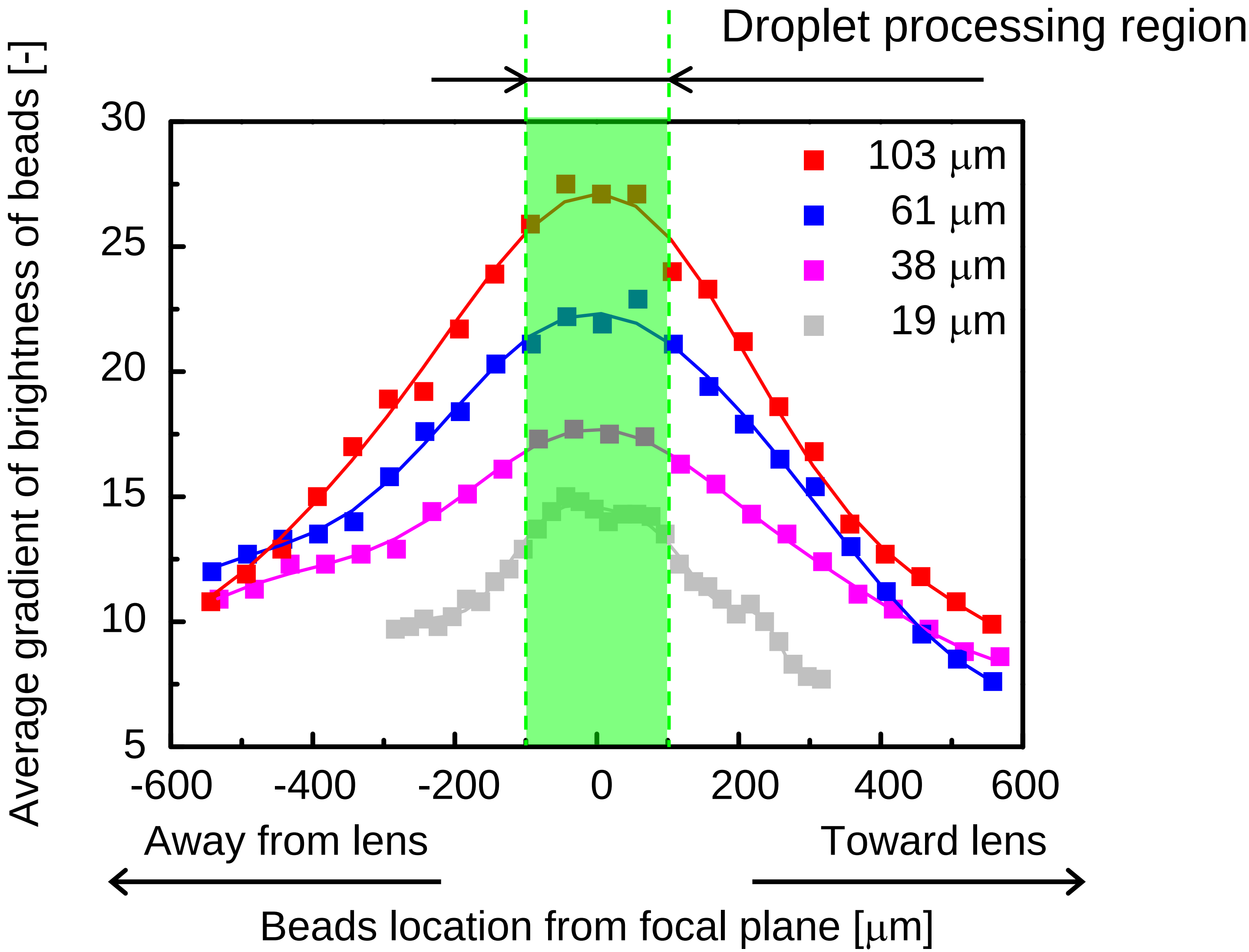
L_0 : Degree of dispersion of perfect round droplet

S : Length of circumference of droplet

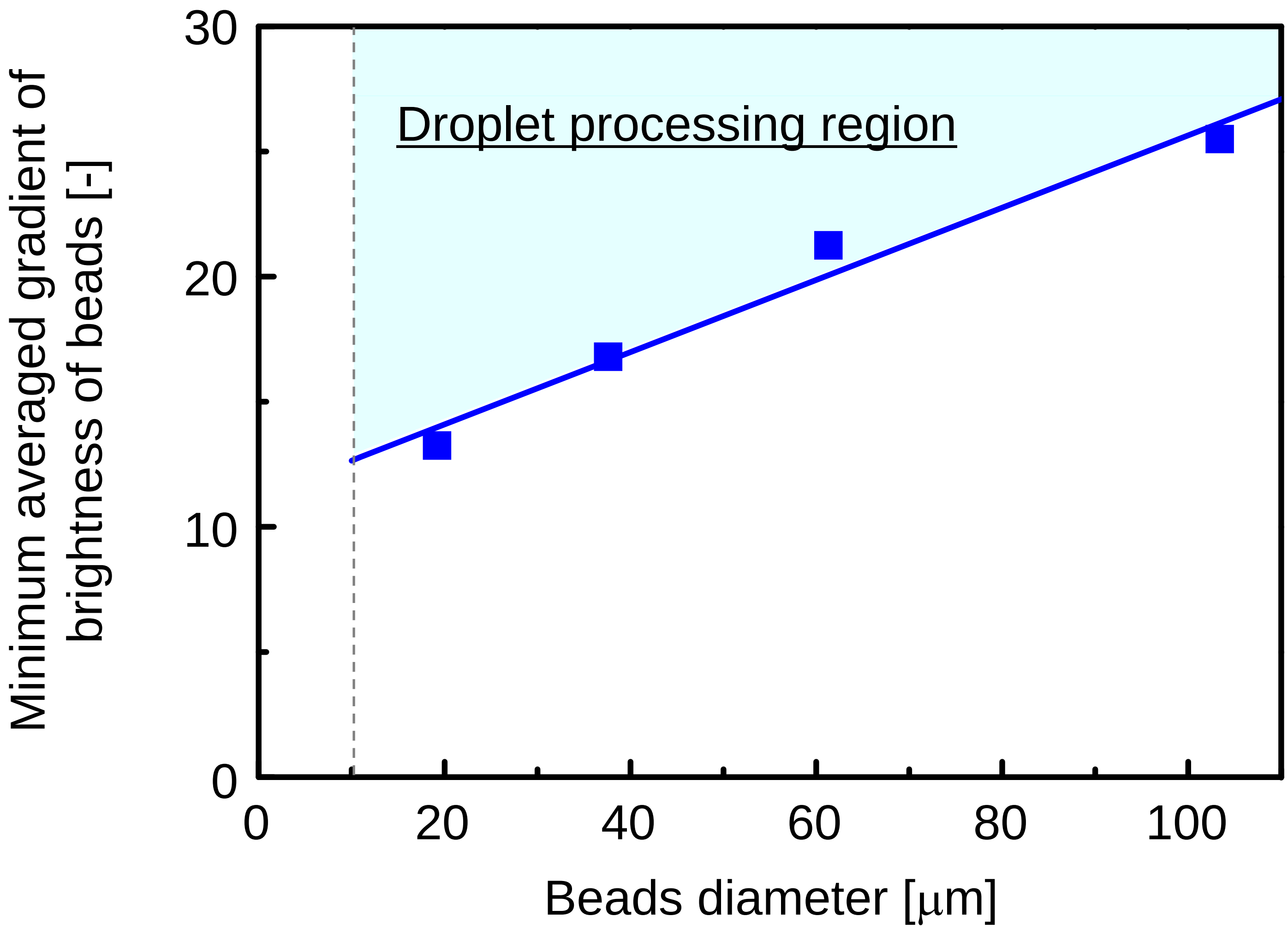
L/L_0=1.0 ⟶ Perfect round

In this experiment the data is rejected when $L/L_0 \geq 1.5$

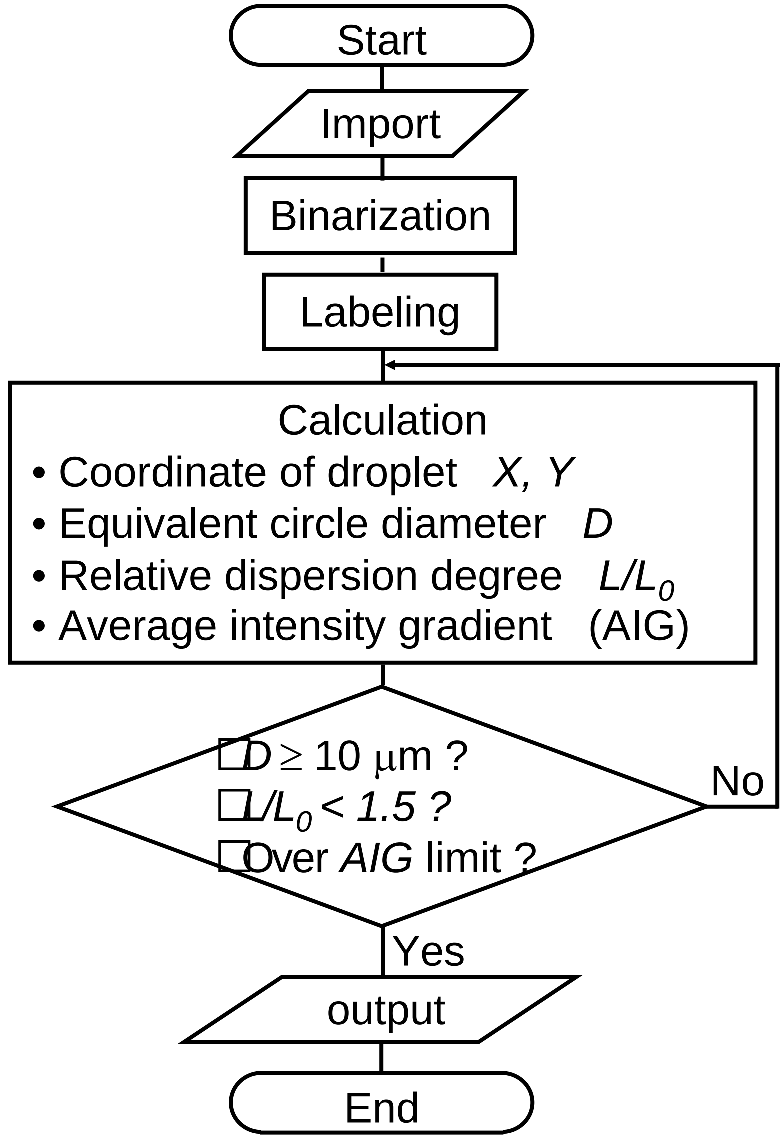
Relation between averaged intensity gradient of beads and beads location from focal plane



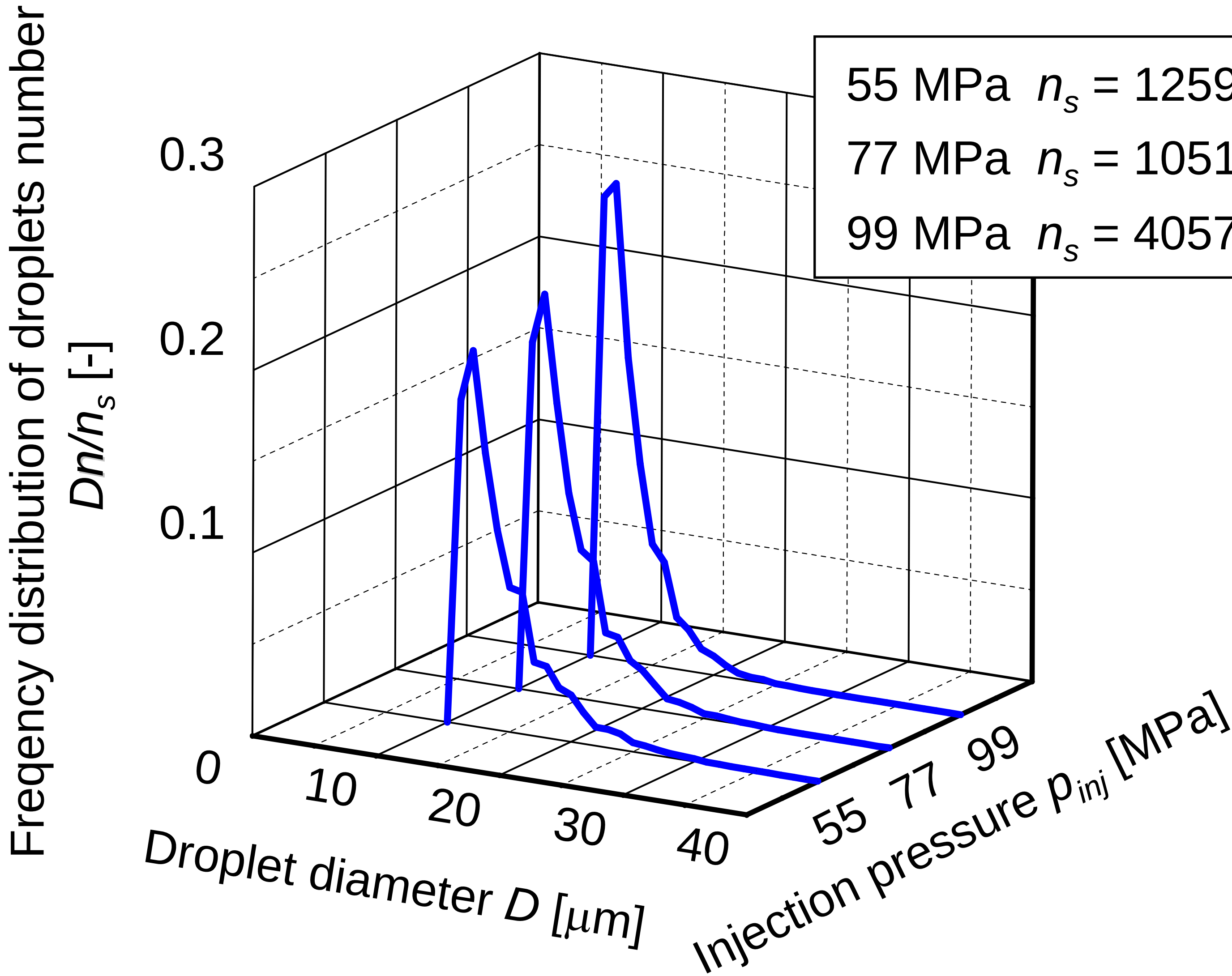
Relation between beads diameter and Minimum averaged gradient of brightness of beads



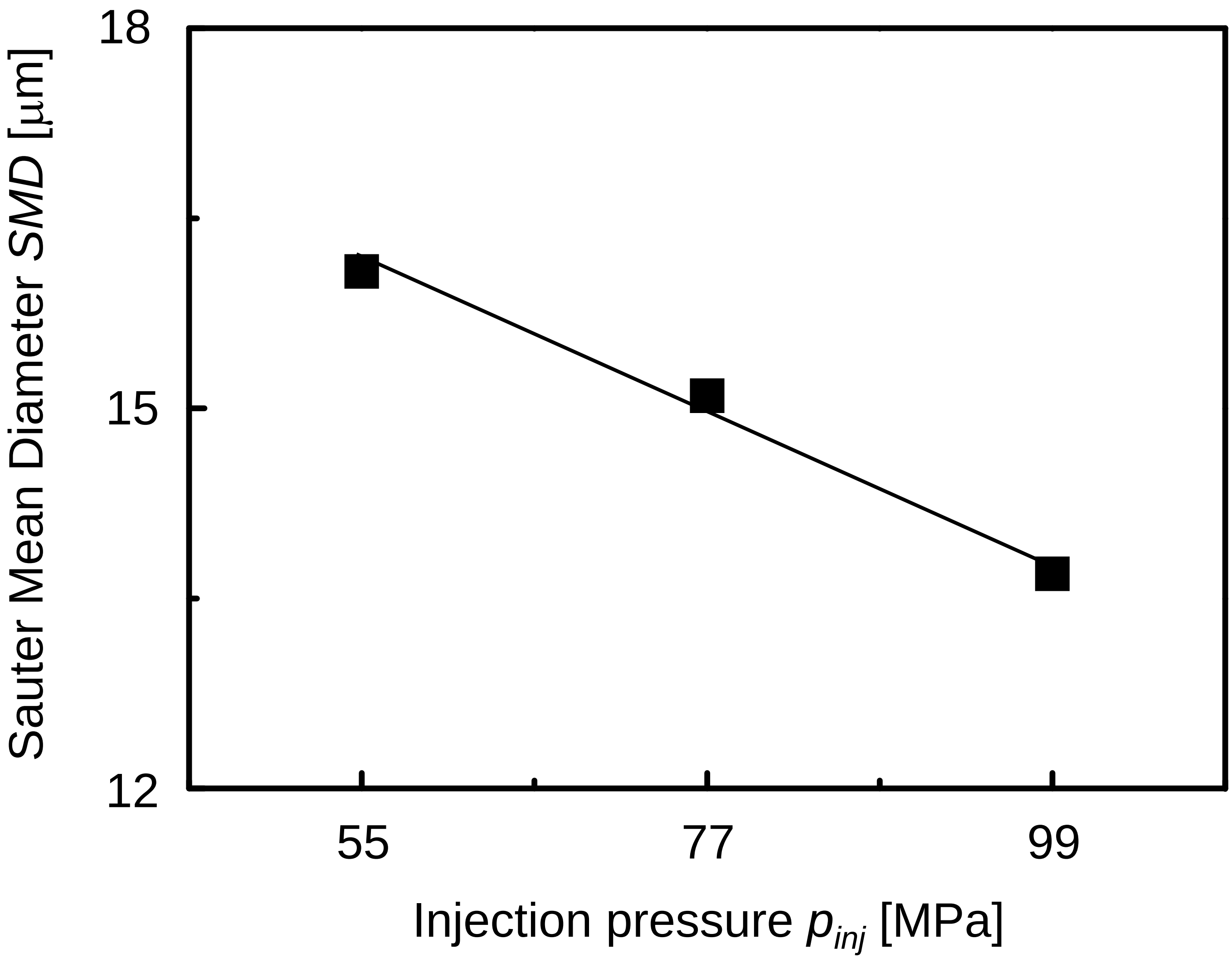
Flow chart of image processing



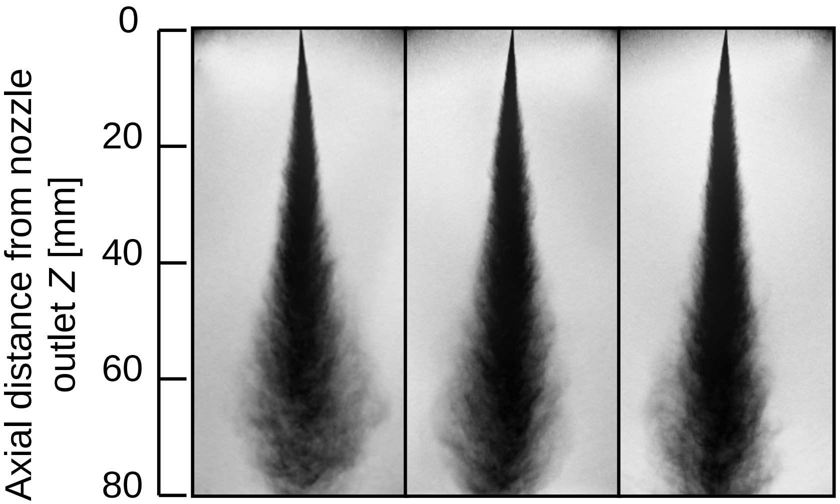
Frequency distribution of droplets number as a function of injection pressure



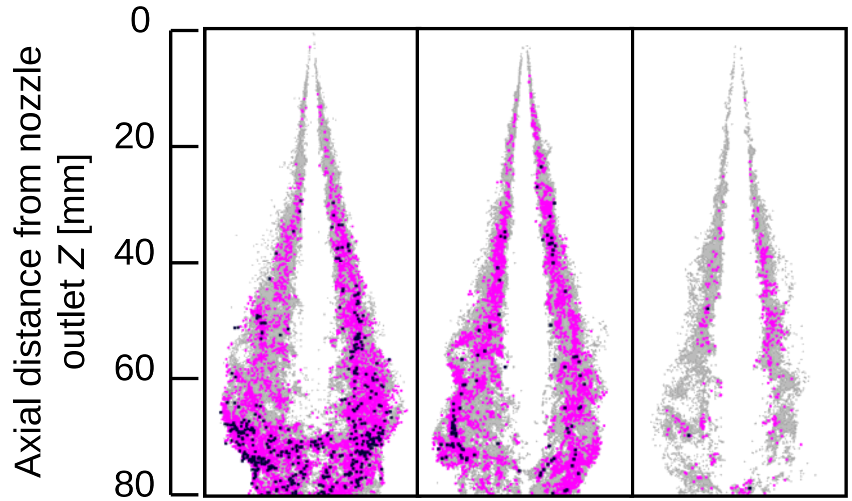
Relation between Sauter mean diameter SMD and injection pressure



Averaged spray image, spatial distribution of droplets diameter and that of local SMD

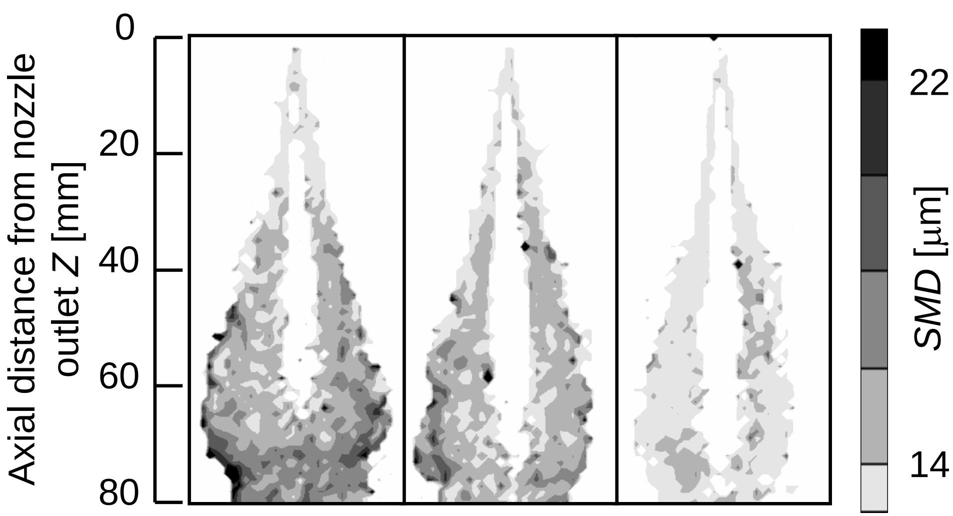


(a) Averaged spray images



(b) Spatial distribution of droplets diameter

10-20 [μm] 20-30 [μm] 30 [μm] -



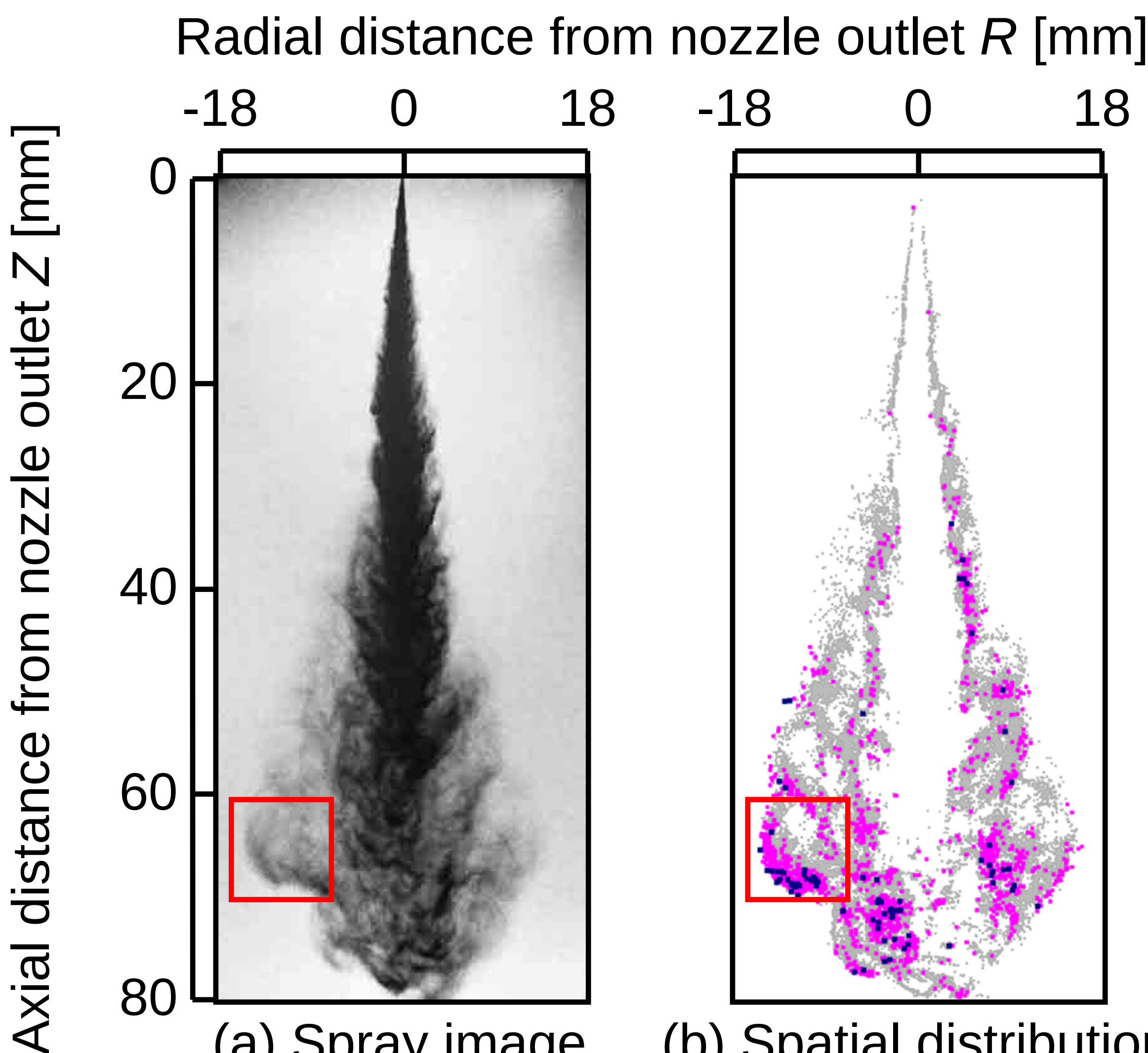
(c) Spatial distribution of local *SMD*

Photograph on the left : p_{inj} = 55 [MPa]

Photograph on the center : p_{inj} = 77 [MPa]

Photograph on the right : p_{inj} = 99 [MPa]

Structure of vortex



(a) Spray image

(b) Spatial distribution of droplet diameter

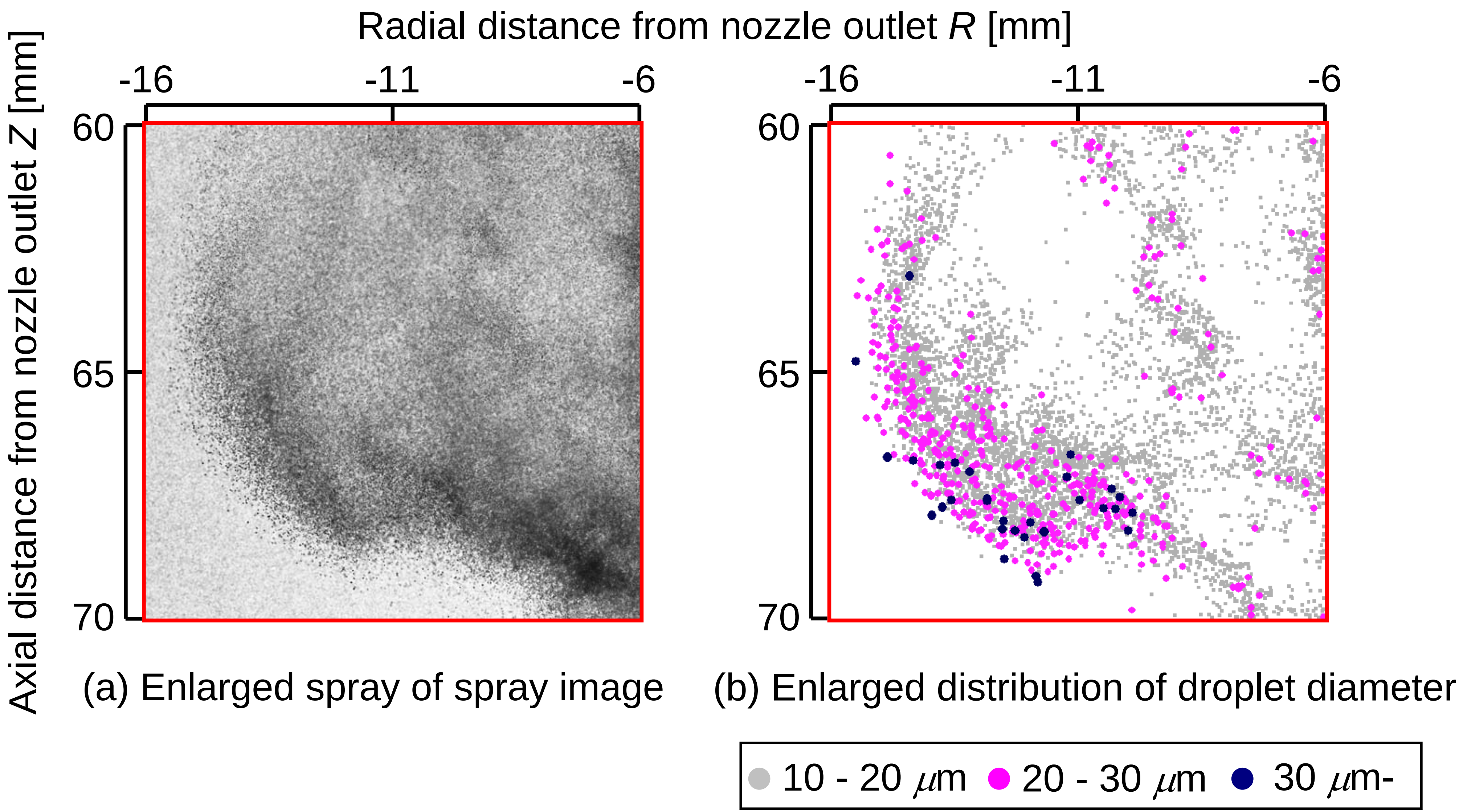
p_{inj} = 55 MPa

p_{inj} = 1.50 MPa

t/t_{inj} = 1.0

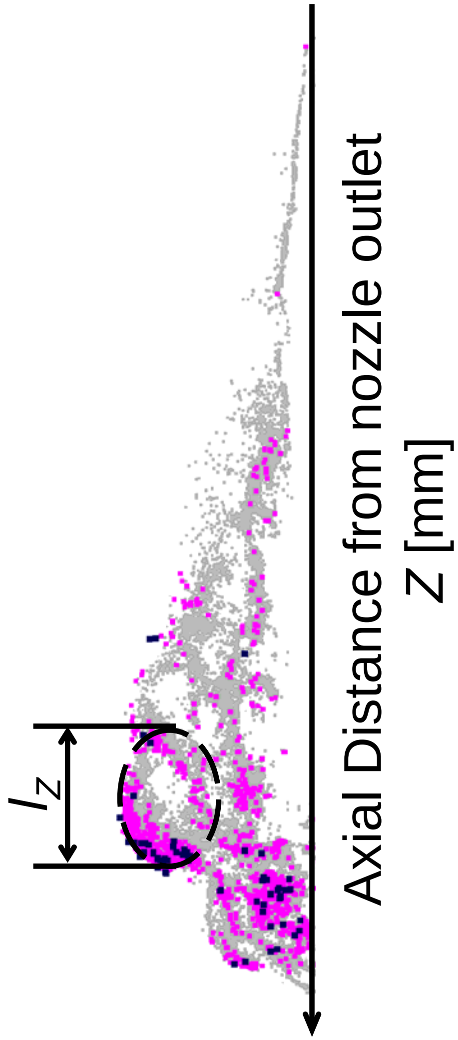
M = 3.0

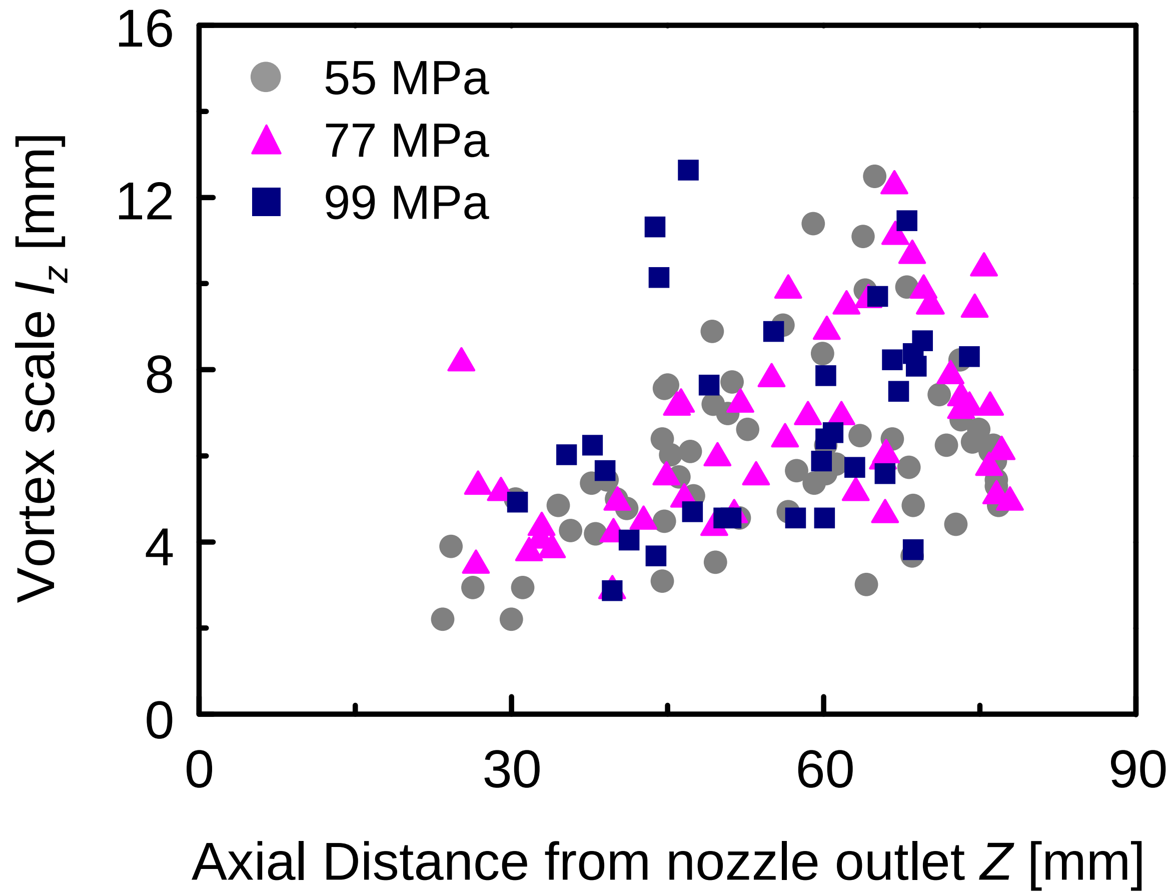
Structure of vortex



(a) Enlarged spray of spray image (b) Enlarged distribution of droplet diameter

Definition of vortex scale and relation between vortex scale and axial distance from nozzle outlet





Conclusion

1. It is able to detect the droplets information in the region from the axis to about 3 [mm] and even at the spray periphery of the initial part of a non-evaporating spray through the specialized lens system with a speckle reduction device, an analogue film with large size an the data processing way.

2. It is capable of capturing the vortex structure in detail on a film taken by the system mentioned above.

3. The small droplets increase as the increase in the injection pressure. They locate mainly at the spray periphery. They follow the vortex motion, thus, a part of them exists inside the vortex.

Conclusion (continued)

4. The large droplets appear as the decrease in the injection pressure. They place mainly place at the spray periphery of the spray tip region.

5. The vortex does not appear at the initial part, that is, at the region near the nozzle exit.

6. The vortex scale becomes larger at the region between the end of initial part (from the nozzle outlet to about 20 [mm] and that of the penetration part, in other words, the base of the conical part of spray. However, it becomes smaller due to the drag force of the ambient.