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Non-steady Characteristics of Dispersion and Ignitability for High-Pressurized Hydrogen Jet discharged from a Pinhole

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Outline

1. **Purpose**
2. **Outline of Experiment Measurement**
3. **Results of Dispersion Experiment**
   - Velocity Field
   - Concentration Field
   - Ignition characteristics
4. **Results of Ignition Experiment**
   - Visualization of Hydrogen Combution
   - Ignition Probability
5. **Relationship between Ignition and Concentration Fluctuations**
6. **Conclusion**

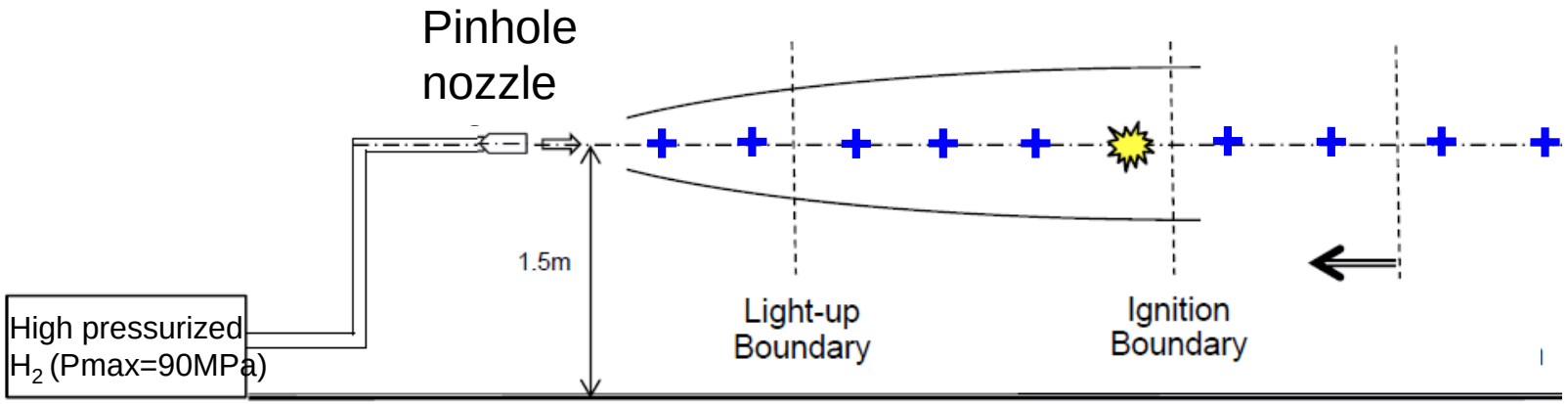
1. Purpose

- In Japan, the government and the industry group are promoting the introduction of hydrogen stations for FCV's in urban areas
- The relaxation of **"1/4 LFL distance"** as the regulation for safety of Japan is necessary

  "A distance between the dispenser of the hydrogen station and public boundary must be kept in more than a 1/4 LFL distance**"**
- Does the 1/4 LFL distance has any degree of risk or safety margin?
- To investigate the characteristics of dispersion and ignitability on 40 to 82MPa high-pressurized hydrogen jet from a pinhole of 0.2mm diameter
- To discuss the effect of different pressure on the characteristics

2. Outline of Experiment Measurement (1/2)

- High pressurized H2 gas with 40 to 82MPa
- Horizontal spouted into air from a nozzle of 0.2mm diameter
- Ignited by the electric spark.



(1) Dispersion Experiment

- H_2 Concentration by FID
  at the sampling rate of 200Hz
- Velocity by PIV

(2) Ignition Experiment

- H_2 Concentration
  by Raman scattering system
- Optical Radiation
  from OH Radical / H_2O species
- Shadowgraph of Flame

2. Outline of Experiment Measurement

(1) Dispersion Experiment
- H_2 Concentration by FID at the sampling rate of 200Hz
- Velocity by PIV

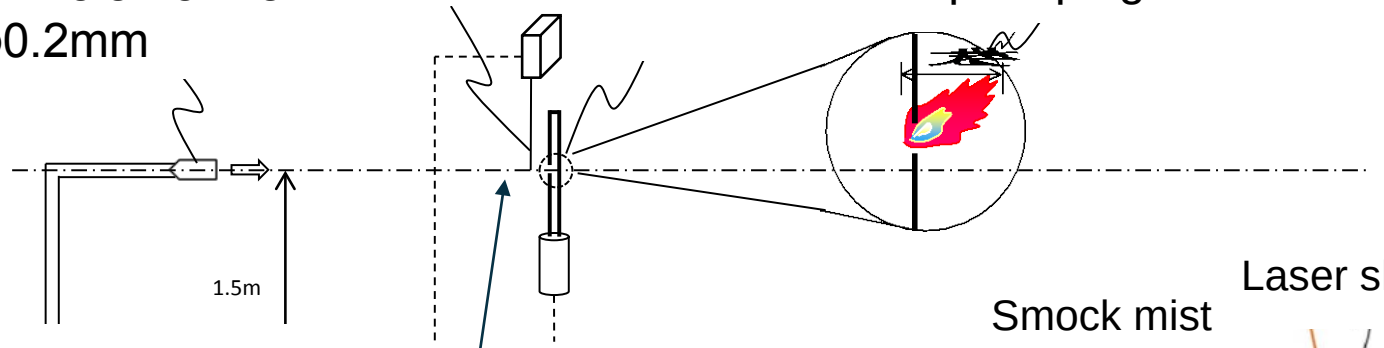
Pinhole nozzle
φ0.2mm

FID sampling head

Spark plug

←FID system

↓ PIV system



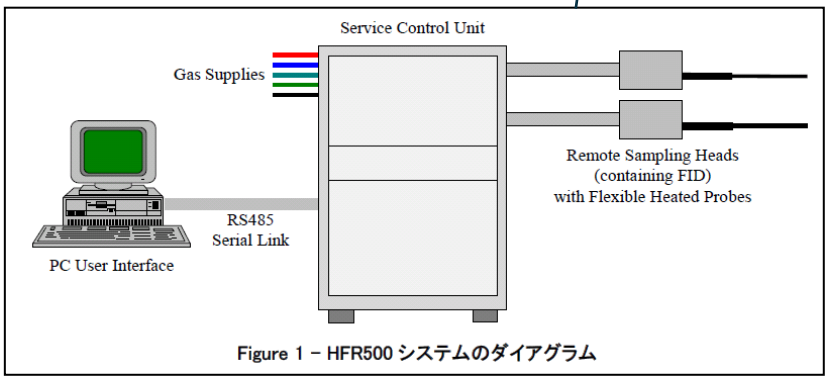
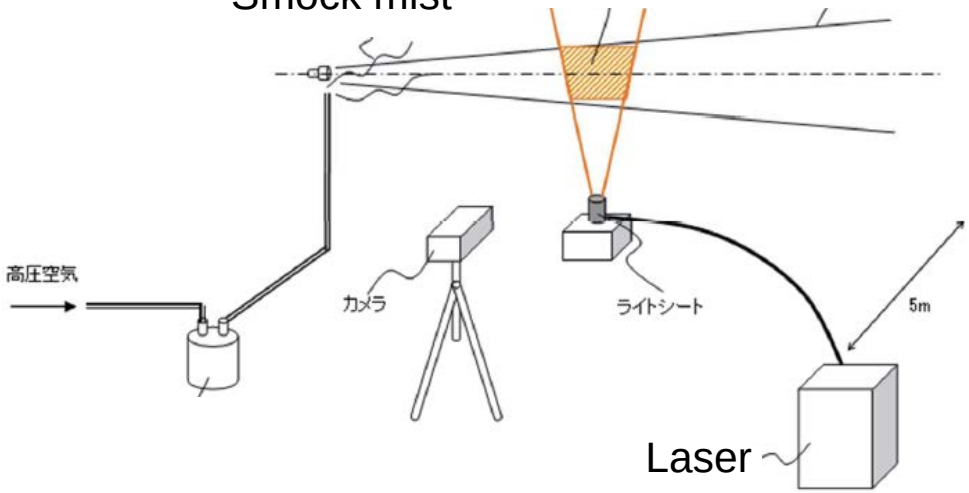


Figure 1 – HFR500 システムのダイアグラム

Laser sheet

H2 dispersion

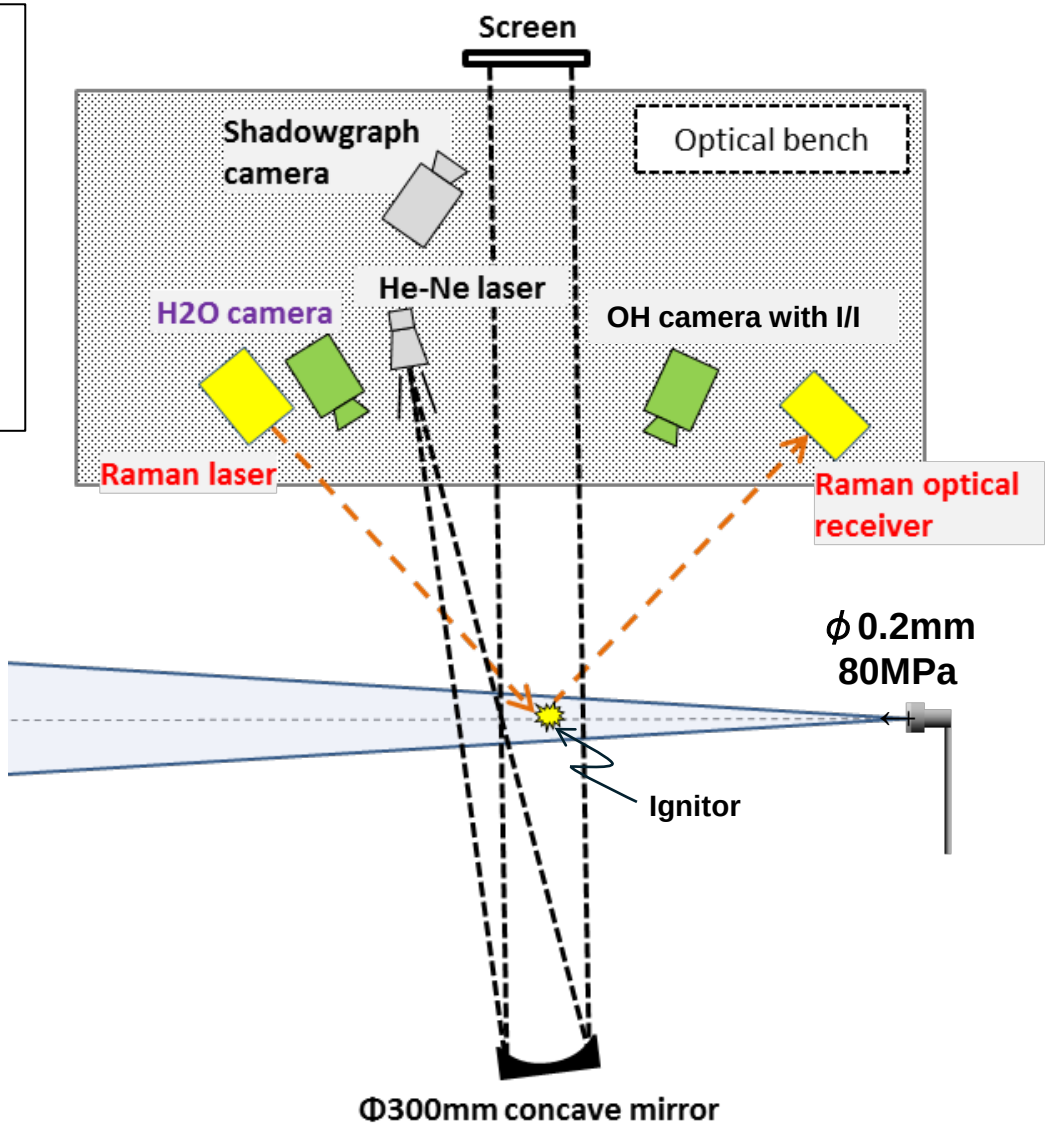
Smock mist



2. Outline of Experiment Measurement

(2) Ignition Experiment

- H_2 Concentration
  by Raman scattering system
- Optical Radiation
  from OH Radical / H_2O species
- Shadowgraph of Flame



2. Outline of Experiment Measurement (2/2)

Table 1 List of Experiments

Pressure at Nozzle	82MPa	60MPa	40MPa
(1) Dispersion Experiment	○	○(Not PIV)	○
(2) Ignition Experiment	○	×	○
Place of Experiment	Indoor		Outdoor

Table 2 List of Experimental Data Analysis

	Measurement Data	Analysis from Measurement Data
(1) Dispersion Experiment	H_2 Concentration by FID	➢ Time-avaraged concetration ➢ Standard deviation of concentration fluctuation ➢ Probablity density function of concentation ➢ Power spetrum of concentration
	Velocity by PIV	➢ Time-averaged streamwise velocity ➢ Intensity of turbulence
(2) Ignition Experiment	H_2 Concentration by Raman scattering system	➢ Time-averaged concentration
	Optical Radiation from OH Radical / H_2O species	➢ Iginition probability
	Shadowgraph of Flame	➢ Visualization of flame structure

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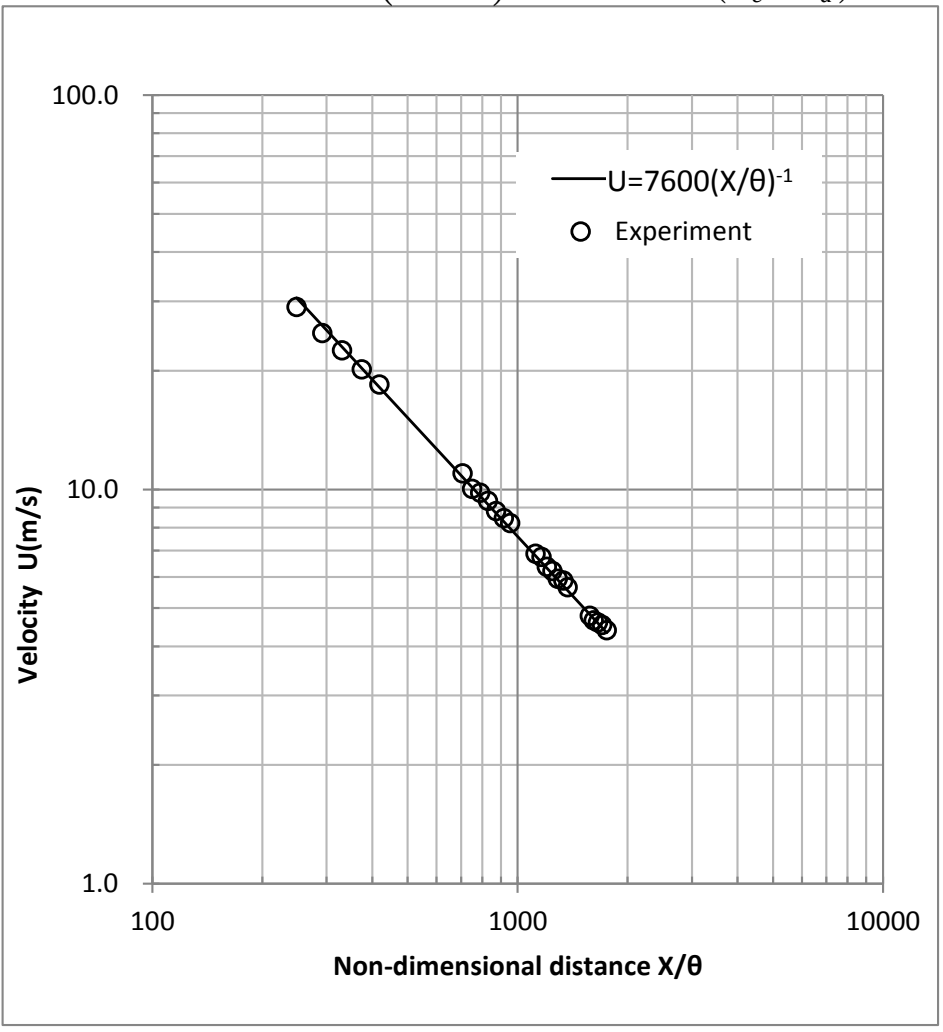
3. Results of Dispersion Experiment –velocity

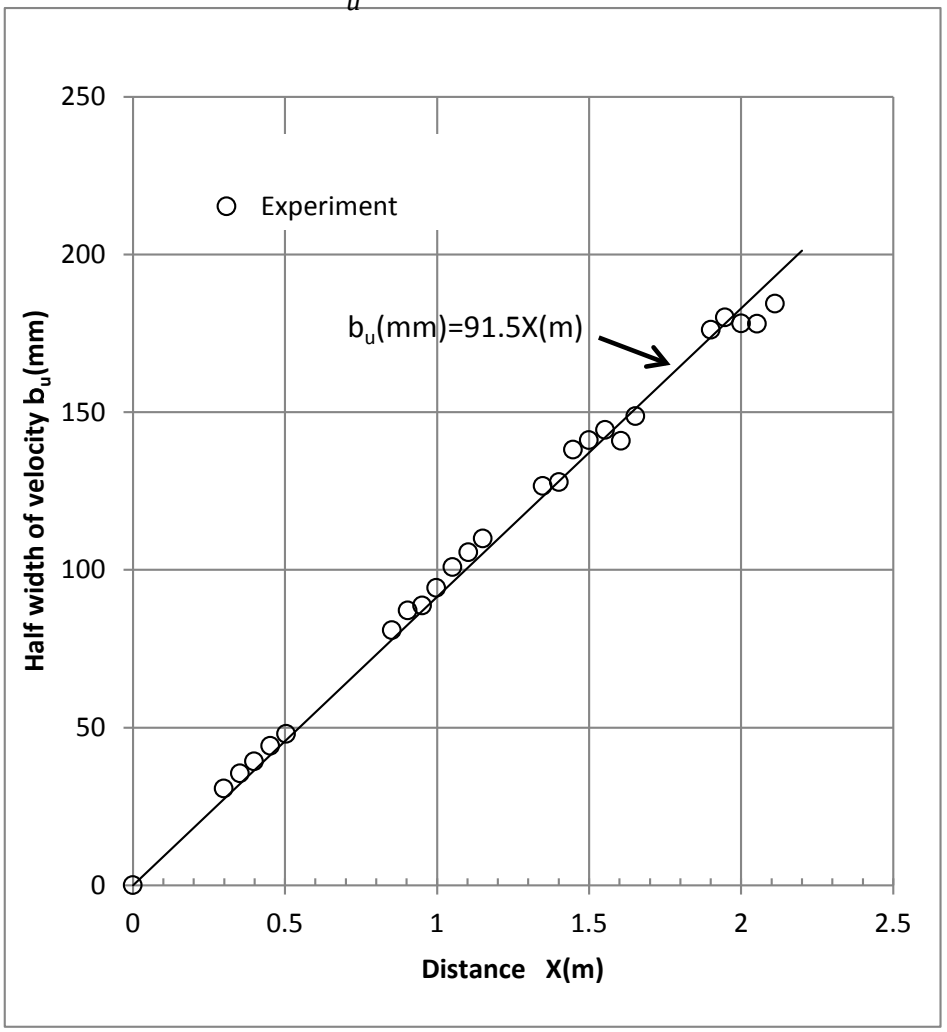
Chracteristics of Velocity Field of Jet

82MPa

$$U = 7600/(X/\theta) \qquad \theta = D\cdot(\rho_e/\rho_a)^{0.5}$$

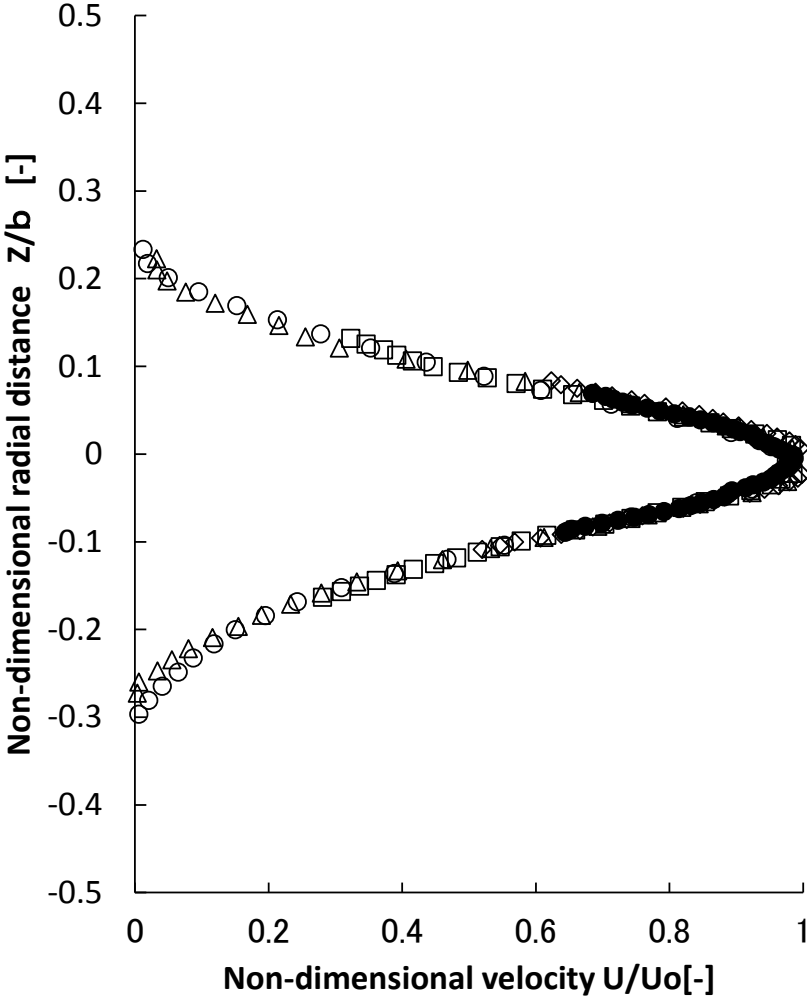
$$b_u = 0.091X$$

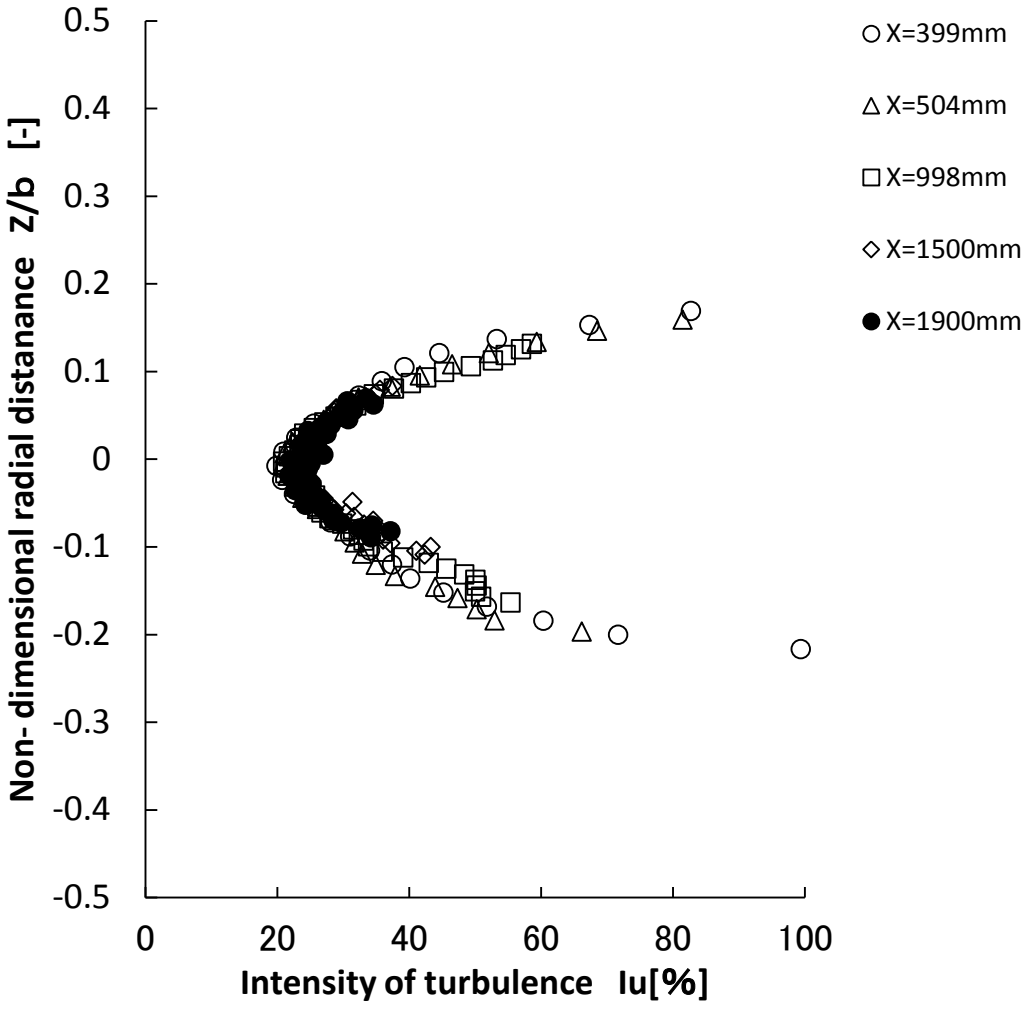




3. Results of Dispersion Experiment –velocity

Radial distributions of velocity and turbulence





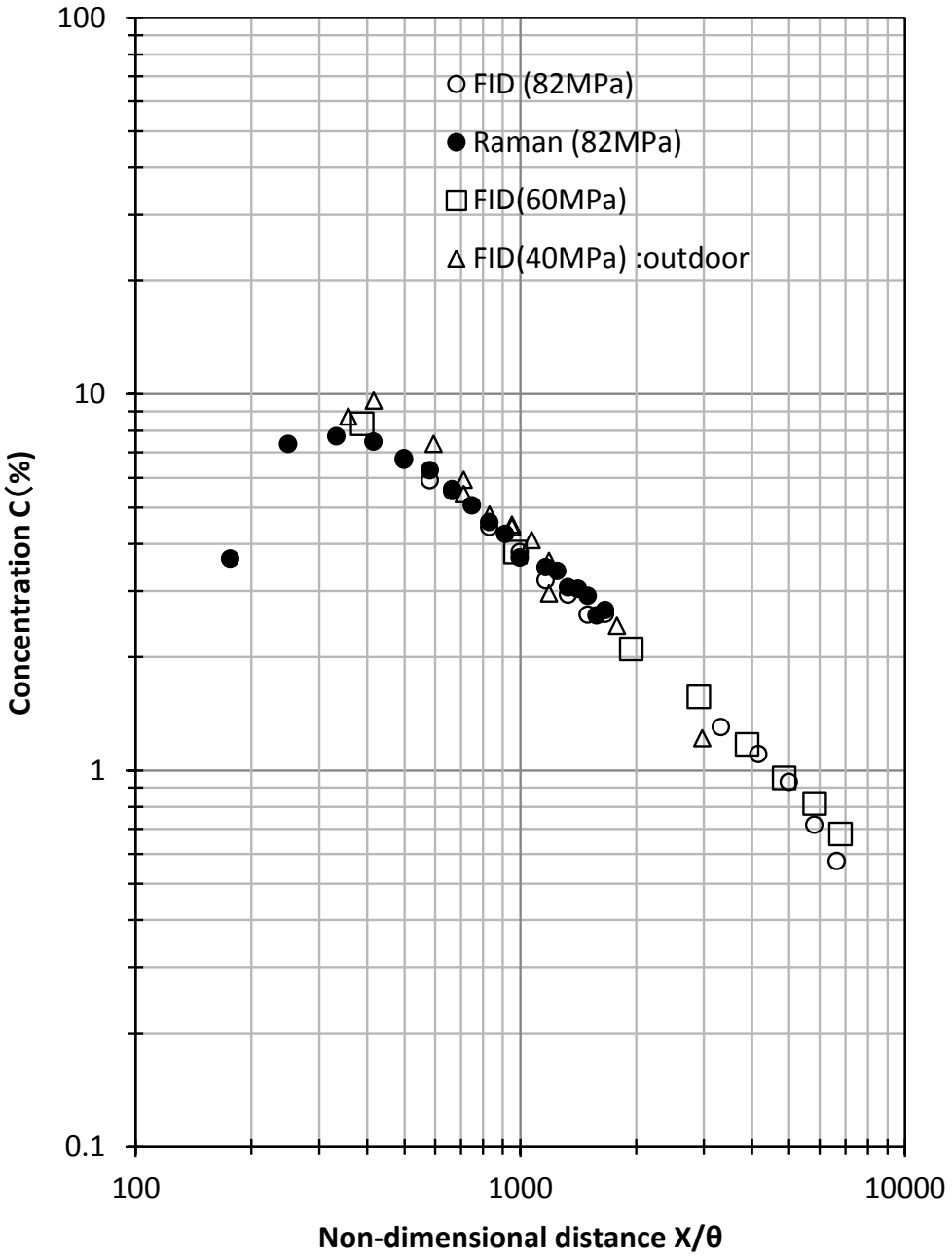
U_0: Streamwise velocity on the jet axis

3. Results of Dispersion Experiment –concentration

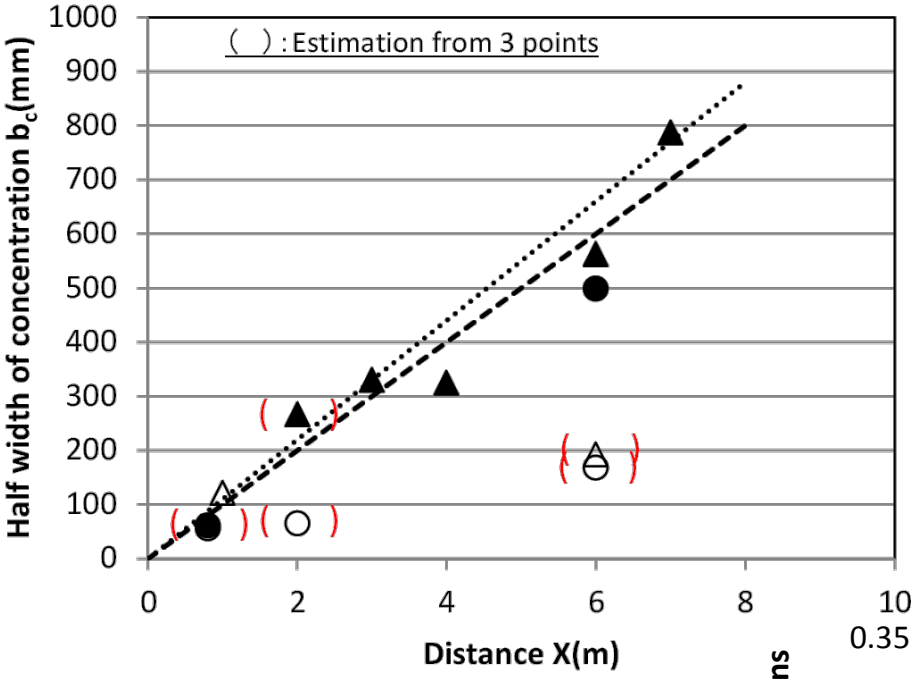
Concentration Distribution on Jet Axis

$$C = 4300 \cdot \left(X / \theta \right)^{-1}$$

$$\theta = D \cdot \left(\rho_e / \rho_a \right)^{0.5}$$



3. Results of Dispersion Experiment –concentration

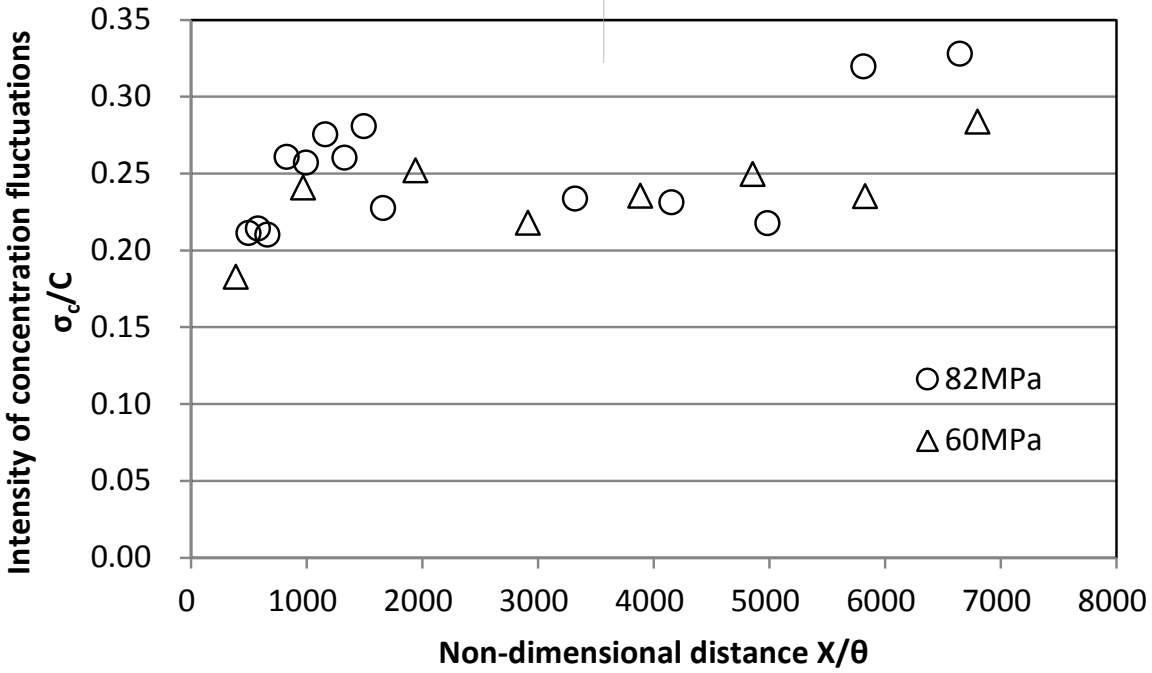


$$b_c = (0.10 \sim 0.11)X$$

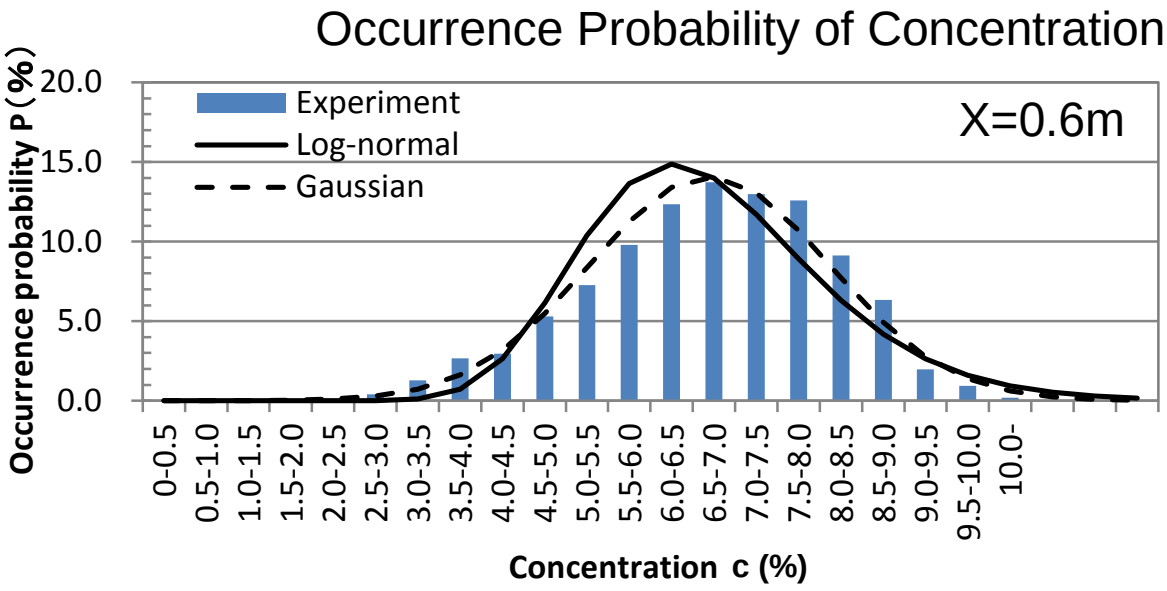
Characteristics of Concentration Field of Jet

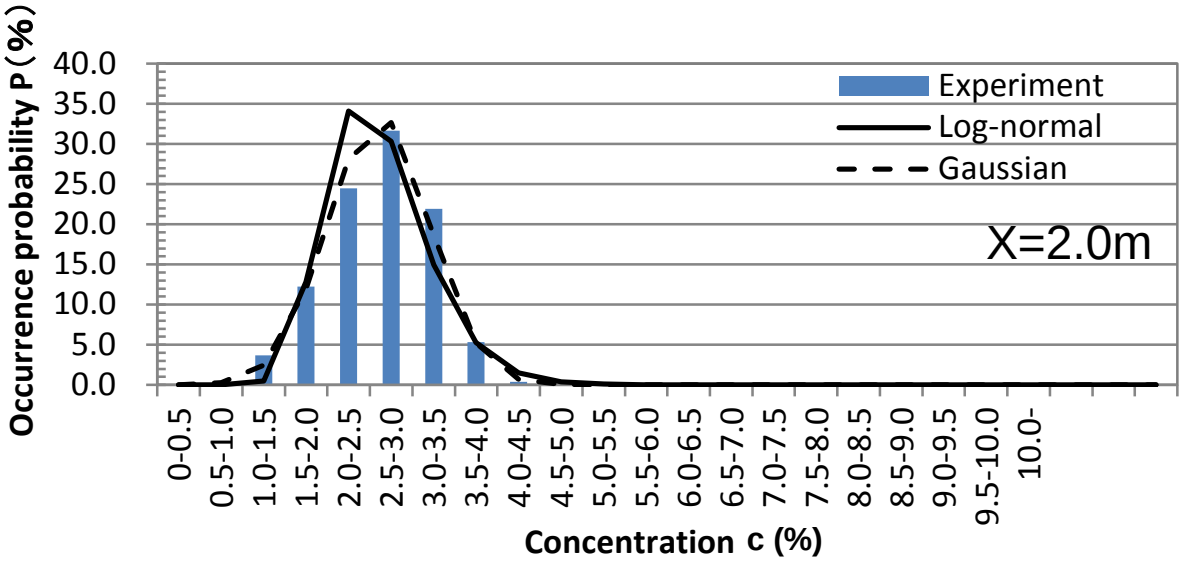
- ▲ z-direction at 60MPa
- ● z-direction at 82MPa
- △ y-direction at 60MPa
- ○ y-direction at 82MPa
- bc=0.10X
- bc=0.11X

$$\sigma_c / C = 0.20 \sim 0.25$$



Occurrence Probability of Concentration on Jet Axis





For Log-normal distribution

$$P(c) = \frac{1}{\sqrt{2\pi}\sigma \cdot c} Exp\left(\frac{(\ln c - m)^2}{2\sigma^2} \right)$$

$$\sigma^2 = \ln\left((\sigma_c / C)^2 + 1 \right)$$

$$m = \ln\left(C / \sqrt{1 + (\sigma_c / C)^2} \right)$$

For Gaussian distribution

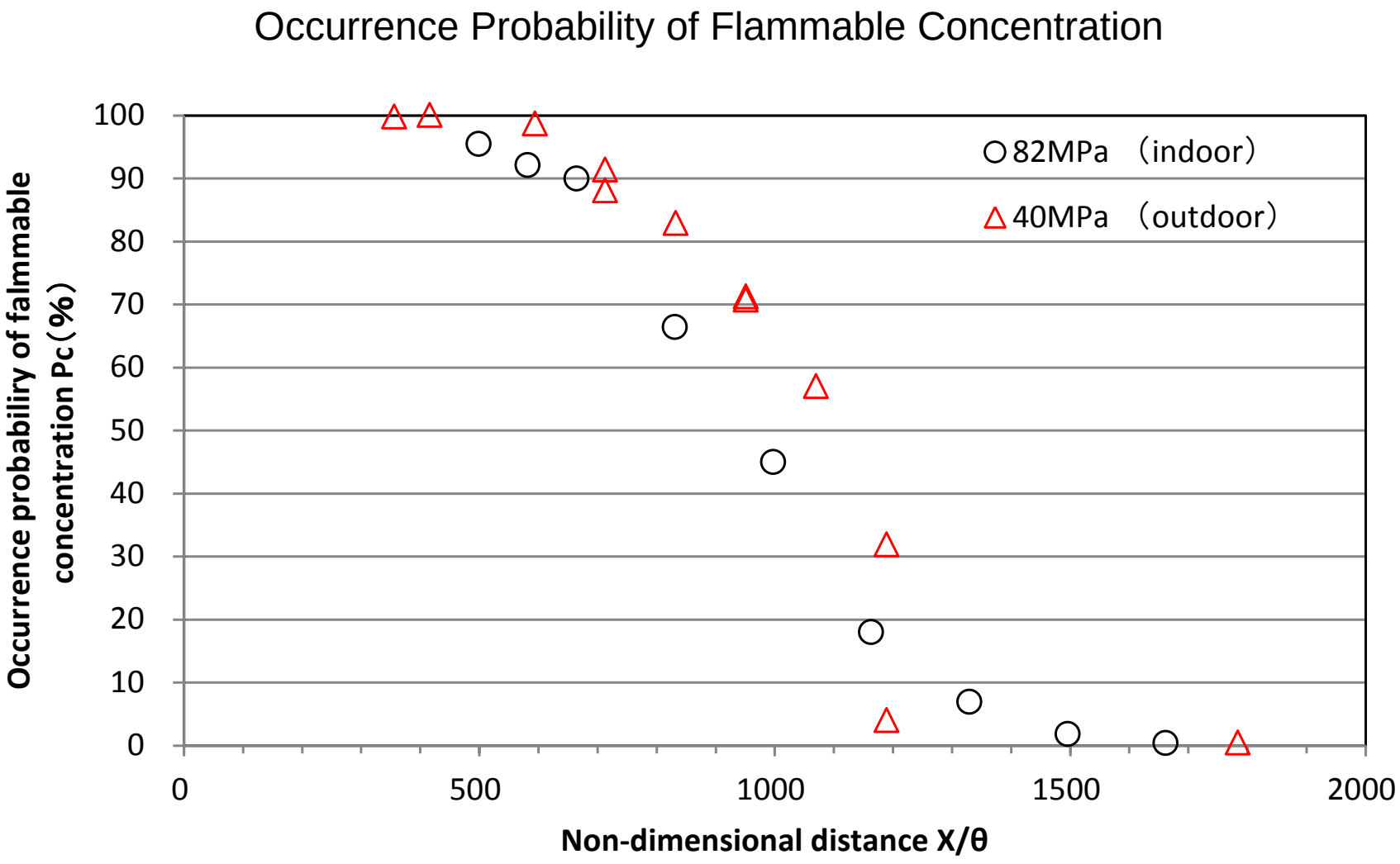
$$P(c) = \frac{1}{\sqrt{2\pi}\sigma_c} Exp\left(\frac{(c - C)^2}{2\sigma_c{}^2} \right)$$

c : Concentration

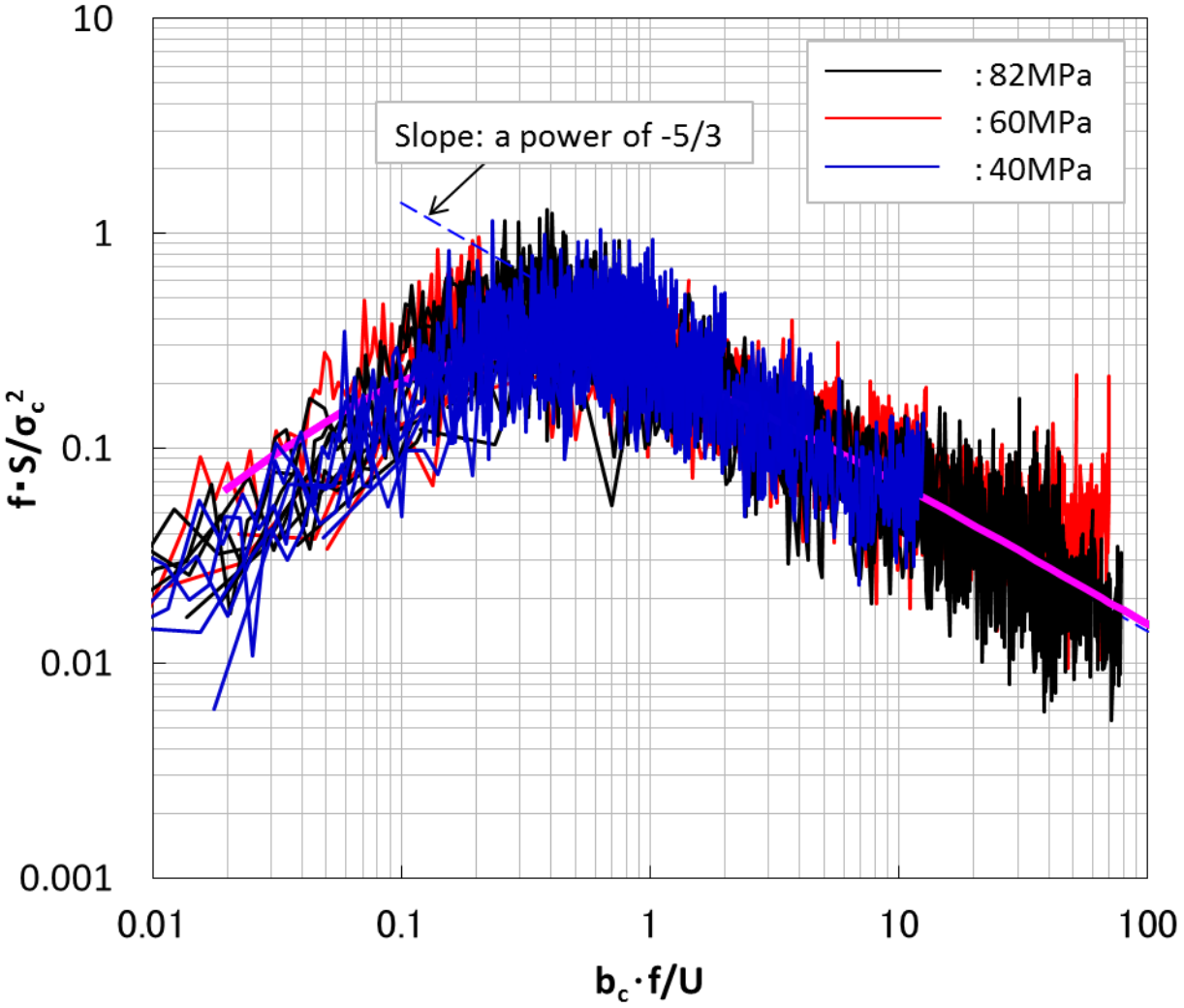
C : Time-averaged concentration

σ_c : Standard deviation of concentration fluctuation

Occurrence Probability of Flammable Concentration



Power Spectrum of Concentration Fluctuations



Non-dimensional expression

$$\overline{S} = \frac{A \cdot \overline{f} / \overline{f_m}}{(1 + 1.5 \cdot \overline{f} / \overline{f_m})^{5/3}}$$

$$A = 1.3 \qquad \overline{f_m} = 0.35$$

$$\overline{S} = f \cdot S / \sigma_c^{\,2}$$

$$\overline{f} = f \cdot b_c / U$$

Notations

S : Power spectrum
f : Frequency
U : Velocity of jet
b_c : Half width
σ_c : Standard deviation

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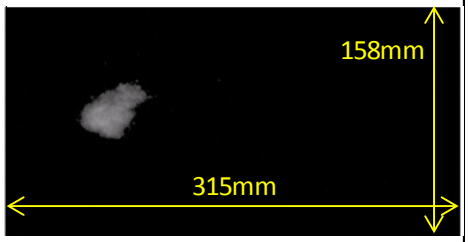
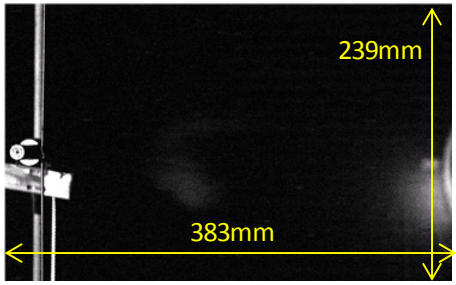
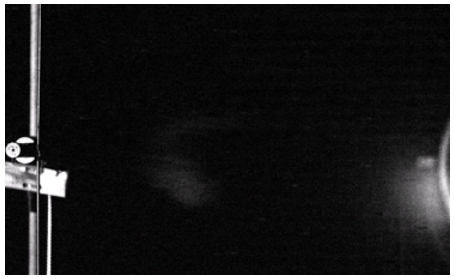
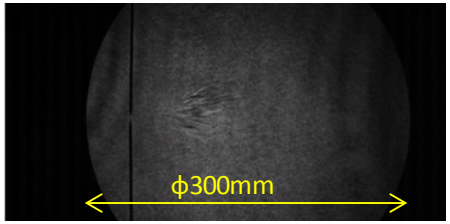
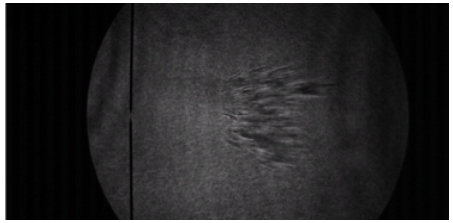
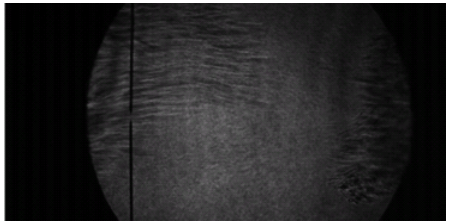
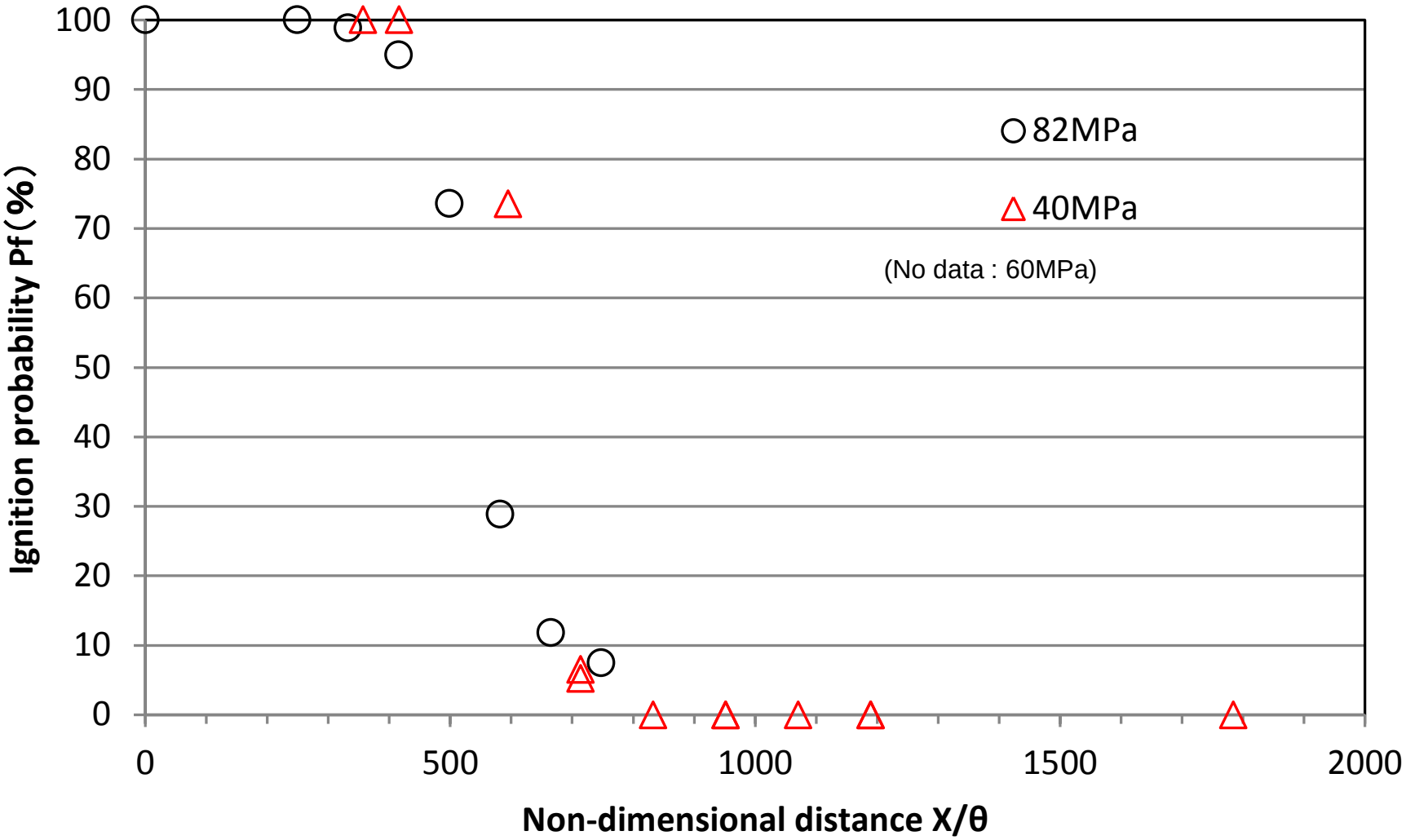
Example of Visualization of Hydrogen Combustion

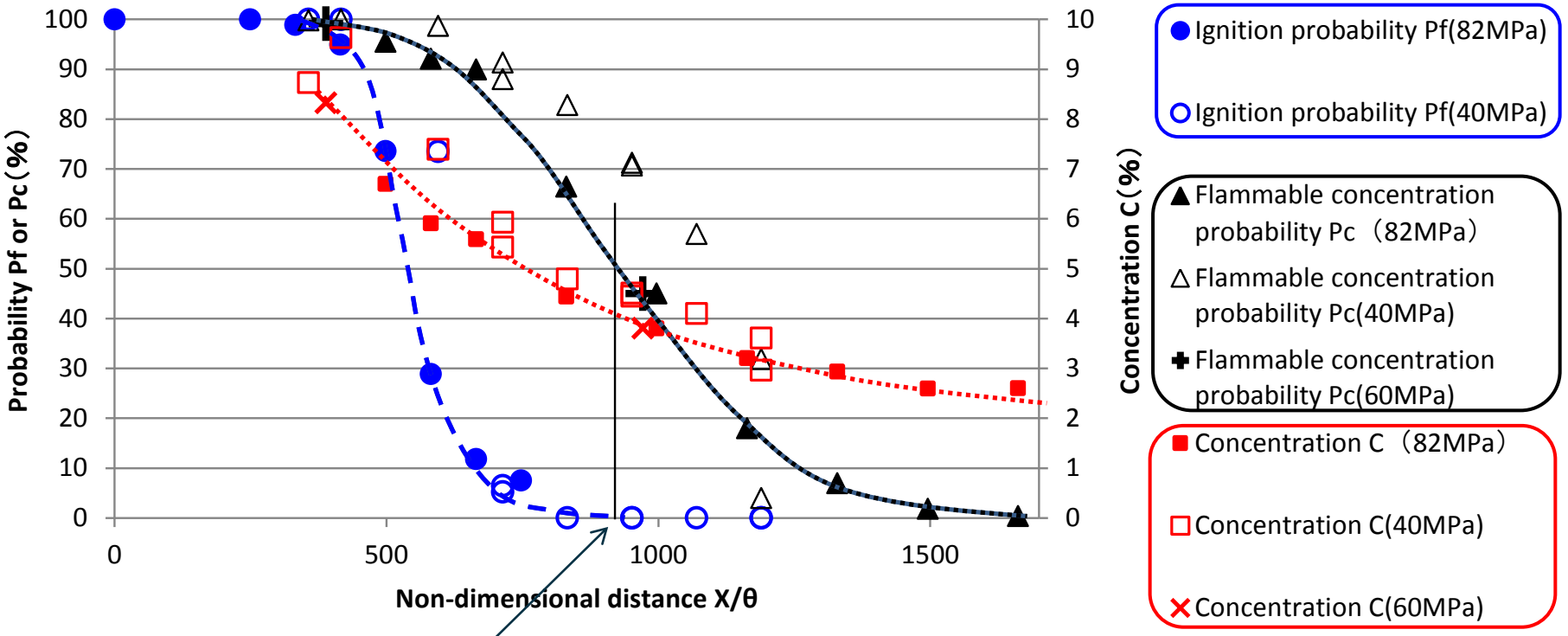
Phase of flame development	Just after ignition	Growth phase of flame	Before flame disappearance
Time from spark (initiation : 0msec)	2msec	10msec	18msec
OH			
H_2O			
Shadowgraph			

Ignition Probability on Jet Axis



Relationship between Ignition and Concentration

Blue : Ignition Probability
Black : Flammable concentration Probablity
Red : Time-averaged Concentration



At ignition boundary P_f=0,
X/ θ = 900
C=4%
Pc=40 to 50 %

6. CONCLUSION

- We studied the non-steady behavior of the high-pressurized hydrogen jet with 40 to 82MPa dscharged from a pinhole of 0.2mm diamter in detail.
- We discussed about the similarity of flow and dispersion of high-pressurized hydrogen jet to clarify the characteristics of ignitability, normalizing by the representative scales.
- Through the above discussion, it was expected that ignitability could be expressed independent of hydrogen discharged pressure.
- As a result, the boundary at Pf=0 could be obtained from the distance of C=4% and Pc=40 to 50%, using the empirical formula.

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