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
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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 82 MPa
- Horizontal spouted into air from a nozzle of 0.2 mm diameter
- Ignited by the electric spark.

(1) Dispersion Experiment
- H₂ Concentration by FID at the sampling rate of 200 Hz
- Velocity by PIV

(2) Ignition Experiment
- H₂ Concentration by Raman scattering system
- Optical Radiation from OH Radical / H₂O species
- Shadowgraph of Flame
2. Outline of Experiment Measurement

(1) Dispersion Experiment
- H₂ 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

Smock mist

Laser sheet

H₂ dispersion

Laser

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2. Outline of Experiment Measurement

(2) Ignition Experiment

- H₂ Concentration by Raman scattering system
- Optical Radiation from OH Radical / H₂O species
- Shadowgraph of Flame
2. Outline of Experiment Measurement (2/2)

Table 1 List of Experiments

<table>
<thead>
<tr>
<th>Pressure at Nozzle</th>
<th>82MPa</th>
<th>60MPa</th>
<th>40MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Dispersion Experiment</td>
<td>○</td>
<td>○ (Not PIV)</td>
<td>○</td>
</tr>
<tr>
<td>(2) Ignition Experiment</td>
<td>○</td>
<td>×</td>
<td>○</td>
</tr>
<tr>
<td>Place of Experiment</td>
<td>Indoor</td>
<td>Outdoor</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 List of Experimental Data Analysis

<table>
<thead>
<tr>
<th>Measurement Data</th>
<th>Analysis from Measurement Data</th>
</tr>
</thead>
</table>
| (1) Dispersion Experiment | H₂ Concentration by FID | ➢ Time-averaged concentration  
➢ Standard deviation of concentration fluctuation  
➢ Probability density function of concentration  
➢ Power spectrum of concentration |
| Velocity by PIV | ➢ Time-averaged streamwise velocity  
➢ Intensity of turbulence |
| (2) Ignition Experiment | H₂ Concentration by Raman scattering system | ➢ Time-averaged concentration |
| Optical Radiation from OH Radical / H₂O species | ➢ Ignition probability |
| Shadowgraph of Flame | ➢ Visualization of flame structure |
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3. Results of Dispersion Experiment – velocity

Characteristics of Velocity Field of Jet

\[
U = \frac{7600}{X/\theta} \quad \theta = D \cdot \left(\frac{\rho_e}{\rho_a}\right)^{0.5}
\]

\[
b_u = 0.091X
\]

82MPa

- Experiment

<table>
<thead>
<tr>
<th>Distance X(m)</th>
<th>Half width of velocity b_u (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.5</td>
<td>51</td>
</tr>
<tr>
<td>1</td>
<td>102</td>
</tr>
<tr>
<td>1.5</td>
<td>153</td>
</tr>
<tr>
<td>2</td>
<td>204</td>
</tr>
<tr>
<td>2.5</td>
<td>255</td>
</tr>
</tbody>
</table>

\[
\theta = \frac{82}{D \rho \theta} \cdot \left(\frac{\rho_e}{\rho_a}\right)^{0.5} \cdot \left(\frac{X}{\theta}\right)^{-1}
\]

\[
Y = 91.486X
\]

\[
b_u = 91.5X(m)
\]
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

\[ C = 4300 \cdot \left( \frac{X}{\theta} \right)^{-1} \]

\[ \theta = D \cdot \left( \frac{\rho_e}{\rho_a} \right)^{0.5} \]
3. Results of Dispersion Experiment – concentration

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

\[ \frac{\sigma_c}{C} = 0.20 \sim 0.25 \]

\[ b_c = (0.10 \sim 0.11) \times X \]
Occurrence Probability of Concentration on Jet Axis

For Log-normal distribution

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

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

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

For Gaussian distribution

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

- \( c \) : Concentration
- \( C \) : Time-averaged concentration
- \( \sigma_c \) : Standard deviation of concentration fluctuation
Occurrence Probability of Flammable Concentration

- Occurrence probability of flammable concentration $P_c$ (%)
- Non-dimensional distance $X/\theta$
- 82MPa (indoor)
- 40MPa (outdoor)
Power Spectrum of Concentration Fluctuations

Non-dimensional expression

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

\[
A = 1.3 \quad \overline{f_m} = 0.35
\]

\[
\overline{S} = f \cdot S / \sigma_c^2
\]

\[
\overline{f} = f \cdot b_c / U
\]

Notations

- \( S \): Power spectrum
- \( f \): Frequency
- \( U \): Velocity of jet
- \( b_c \): Half width
- \( \sigma_c \): Standard deviation
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# Example of Visualization of Hydrogen Combustion

<table>
<thead>
<tr>
<th>Phase of flame development</th>
<th>Just after ignition</th>
<th>Growth phase of flame</th>
<th>Before flame disappearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time from spark (initiation: 0msec)</td>
<td>2msec</td>
<td>10msec</td>
<td>18msec</td>
</tr>
</tbody>
</table>

**OH**
- Image 1: 158mm
- Image 2: 315mm

**H₂O**
- Image 1: 239mm
- Image 2: 383mm

**Shadowgraph**
- Image 1: 300mm
Ignition Probability on Jet Axis

![Graph showing Ignition Probability on Jet Axis](image)

- **Ignition probability Pf (%)**
- **Non-dimensional distance X/θ**

- **82MPa**
- **40MPa**

(No data : 60MPa)
Relationship between Ignition and Concentration

At ignition boundary $P_f=0$,

$X/\theta = 900$

$C=4\%$

$P_c=40$ to $50\%$
6. CONCLUSION

- We studied the non-steady behavior of the high-pressurized hydrogen jet with 40 to 82MPa discharged from a pinhole of 0.2mm diameter 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.
MOVE THE WORLD FORWARD