An Experimental Analysis on the Behavior Characteristics of Evaporative Impinging Spray

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1. Introduction

In order to reduce the emissions from diesel engines, it is important to study the mixture formation process concerned with formation of PM(Particulate Matter) and NOx. In diesel engines, atomization, evaporation, and mixture formation process of injected fuel affect ignition characteristics and combustion process. Therefore, purpose of this work is laid on making a clear the mixture formation process in an evaporative field of high temperature and pressure. In the factors affecting behavior of diesel spray, especially, the density of ambient gas dominates spray development process such as spray angle and spray tip penetration. Then, the density of ambient gas was selected as experimental parameter. The subject of this study was diesel impinging spray under the variation of ambient gas density. Exciplex fluorescence method was used for visualization of experiment phenomenon.

2. Experimental apparatus and procedure

Figure 1 shows a schematic diagram of the experimental apparatus. The experiments were conducted under the conditions of 700K in ambient temperature and 2.55MPa in ambient gas pressure inside a high pressure vessel with constant volume. This vessel consists of two quartz glass windows which were installed perpendicular to each other. Nitrogen was utilized as the ambient gas to prevent quenching of liquid fluorescence by oxygen. This ambient gas was heated up using heaters inside the vessel. The n-tridecane as the reference fuel oil of JIS second class gas oil was injected into the quiescent atmosphere of nitrogen gas through a single hole.
the oxidation of TMPD. The high pressure injection system (ECD-U2 system) proposed by Denso Co., Ltd. was used in this study. The diameter and the length of nozzle were 0.2mm and 1.0mm, respectively. The ambient gas pressure was varied in the range from 1.04MPa to 2.55MPa by the change in the ambient density. The injection pressure and the fuel injection quantity were kept constantly as 72MPa and 12.0mg, respectively. Table 1 shows the experimental conditions.

Figure 2 shows a schematic of the optical system. The light source was the third harmonic of an Nd:YAG laser at 355nm (power 60mJ/pulse, pulse width: 8ns, pulse, maximum frequency: 10Hz, beam diameter: 6.4mm, beam shape: doughnut type). The detailed explanation for the experimental method is also found in Yeom et al. 3.

![Fig. 1 Experimental apparatus](image1)

![Fig. 2 Schematic diagram of laser sheet optical system and photography system](image2)

![Table 1 Experimental conditions](table)

```markdown
<table>
<thead>
<tr>
<th>Injection nozzle</th>
<th>Diameter of hole ( d_h ) [mm]</th>
<th>Length of hole ( l_h ) [mm]</th>
<th>Ambient gas</th>
<th>Ambient temperature ( T_o ) [K]</th>
<th>Ambient pressure ( P_a ) [MPa]</th>
<th>Ambient density ( \rho_a ) [kg/m³]</th>
<th>Injection pressure ( P_{inj} ) [MPa]</th>
<th>Injection quantity ( Q_{inj} ) [mg]</th>
<th>Injection duration ( t_{inj} ) [ms]</th>
<th>Impingement distance ( Z_w ) [mm]</th>
<th>Wall temperature ( T_w ) [K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hole nozzle DLL-p</td>
<td>0.2</td>
<td>1.0</td>
<td>( N_2 ) gas</td>
<td>700</td>
<td>1.04, 1.70, 2.55</td>
<td>5.0, 8.2, 12.3</td>
<td>72</td>
<td>12</td>
<td>1.54</td>
<td>40</td>
<td>550</td>
</tr>
</tbody>
</table>
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![Fig. 3 Schematic summary of naphthalene and TMPD exciplex system](image3)

Figure 3 shows a schematic summary of the photophysics of the naphthalene/TMPD exciplex fluorescence system. 3.0

**3. Experimental results and discussion**

Figure 4 shows the two-dimensional images of impinging spray at various ambient gas densities which were obtained by the exciplex fluorescence method.
3.1 Behavior study of the liquid phase fuel

From each image of the Fig. 4-(iii), in the impinging wall surface, the liquid phase fuel spreads in radial direction, with decreasing ambient gas density. In the case of ambient gas density \( r_a = 5.0 \text{ kg/m}^3 \), the high fluorescence intensity of free spray region of the liquid phase fuel reaches to the impinging wall surface. In the liquid phase fuel, with decreasing ambient gas density, the distance between central spray axis and spray periphery decreases due to increase in drag force from ambient gas. This result corresponds with spray angle decreasing in non-evaporating diesel free spray\(^6\).

3.2 Behavior study of the vapor phase fuel

For the vapor phase of the Fig. 4-(i), the lean mixture is formed over the central spray axis to the spray tip region at the impinging wall surface and the spray tip proceeds to radial direction. In the region between stagnation point(spray radius, \( R_w = 0 \)) and the spray tip region(spray radius, \( 0 < R_w \)), the spray structure can be divided into two regions of fuel rich region near the impinging wall and the fuel lean region in spray periphery as shown in Fig. 4. In the case of vapor phase fuel, the height from the impinging wall surface of the rich concentration region decreases, with decreasing ambient gas density and the lean concentration region of the vapor phase fuel becomes wider. Furthermore, in case of ambient gas density \( 8.2 \text{ kg/m}^3 \), the rich concentration region of vapor phase fuel near the impinging wall surface is similar to that of ambient gas density \( 12.3 \text{ kg/m}^3 \), however, the lean concentration region of vapor phase fuel is similar to that of ambient gas density \( 5.0 \text{ kg/m}^3 \) in spray periphery.
The effects of ambient gas density on the spray height ($h$) and the spray radius ($R$) are shown in Fig. 5. In the figure, the $h_{\text{max}}$(Standard) and $R_{\text{max}}$(Standard) are maximum height and radius in ambient gas density $r_a=12.3\text{kg/m}^3$, respectively. From the Fig. 5, spray radius increases with decreasing ambient gas density, because drag force from ambient gas decreases at spray tip.

Figure 6 shows distribution of fuel vapor
concentration in the spray. In Fig. 6-(i), the distributions concentration of the vapor phase fuel at \( r_s = 12.3 \text{ kg/m}^3 \) and \( r_s = 8.2 \text{ kg/m}^3 \) are higher than that of the case at \( r_s = 5.0 \text{ kg/m}^3 \) at the distance from impinging wall surface, \( h = 1 \text{ mm} \). Figure 6-(ii) shows the vapor–phase concentration distribution at \( h = 3 \text{ mm} \) and the tendency of concentration distribution is nearly similar to that for \( h = 1 \text{ mm} \). As a result, in the case of the impinging diesel spray, with decreasing ambient gas density, the rich concentration region of vapor phase fuel decreases in the vicinity of impinging wall surface and the lean concentration region of vapor phase fuel increases in spray periphery.

![Temporal change in non-dimensional entropy](image)

**Fig. 7 Temporal change in dimensionless entropy**

Figure 7 is dimensionless entropy change found from Figure 4. A detailed explain about the entropy analysis can be found in Yeom. As in the results of Figure 7, entropy of vapor phase fuel decreases with increase of the density of ambient gases. This means that in case of high ambient density, diffusion of spray vapor phase fuel is suppressed by increase in drag force of ambient gases against developing spray. Therefore, increase in the density of ambient gases limits uniform mixture formation of evaporative spray and reduces entropy. According to above results, application of entropy theory based on diffusion theory of molecules to interpretation of evaporative spray development process has enough validity.

4. Conclusions

In this study, an experimental study was performed for evaporative impinging spray. In order to measure images of the vapor and liquid phase of the fuel, the exciplex fluorescence method was used. The following conclusions are drawn from this study.

1) With increasing ambient gas density, the penetration tip region of impinging spray decreases due to increase in the drag force of ambient gas.

2) In the case of the impinging spray, with decreasing ambient gas density, the spray spreads in radial direction due to decrease in drag force of ambient gas.

3) If density of ambient gases is low (e.g. \( r_s = 5.0 \text{ kg/m}^3 \), \( r_s = 8.2 \text{ kg/m}^3 \)), larger dimensionless entropy is obtained in comparison to lower density. Low density allows easier growth of spray in axial and radial directions and contributes to formation of a more uniform mixture.

Acknowledgement

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References


