

Effects of Fuel Physical Properties on Spray and Combustion Characteristics in a Diesel Engine

- (Second Report) Effects of Fuel Physical Properties on Combustion and Exhaust Gas Emission Characteristics -

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In recent years, the effectiveness of internal combustion engines has been re-evaluated from the Well-to-Wheel (WTW) perspective, and diesel engines have attracted considerable attention owing to their superior thermal efficiency achieved by high compression ratios. However, because diesel engines operate by injecting fuel into highly compressed air, locally fuel-rich regions are inevitably formed, leading to significant soot emissions. Fuel droplets injected into the combustion chamber undergo primary breakup induced by Kelvin–Helmholtz (KH) instability, followed by repeated secondary breakup governed by Rayleigh–Taylor (RT) instability, resulting in atomization and dispersion throughout the combustion chamber. To mitigate locally fuel-rich regions, it is essential to promote fuel atomization. Therefore, accelerating the onset of primary breakup is a key factor in improving the atomization process. Because the primary breakup behavior is strongly influenced by the fuel physical properties, including surface tension, viscosity, and density, optimizing these properties is expected to accelerate the onset of primary breakup and enhance fuel atomization. To clarify the effects of fuel physical properties on diesel combustion, engine experiments were conducted using five fuels with different physical properties. Five fuels were used in this study: commercial diesel fuel (JIS No. 2) as the reference fuel, a modified fuel with a 20% lower surface tension achieved by adjusting its hydrocarbon composition, n-heptane (C₇H₁₆), n-tetradecane (C₁₄H₃₀), and diesel fuel blended with 0.5 wt% Span 80 surfactant. Figure 1 shows the normalized physical properties of each fuel, normalized with respect to diesel fuel.

Figure 2 shows the relationship between soot emissions and the effective Jet number obtained from the engine experiments using each fuel. In this study, the effective Jet number was defined as shown in Eq. (1) by incorporating the influence of aromatic components into the Jet number, which is an index representing the rapid growth of Kelvin–Helmholtz (KH) instability and the accelerated onset of primary droplet breakup.

$$J_{eff} = J_e \cdot (1 - \alpha X_{aroma}^m \exp(-\beta v_l)) \quad (1)$$

α, m, β : parameter, X_{aroma} : aromatic volume fraction

As shown in Fig. 2, higher effective Jet numbers were associated with lower soot emissions. In other words, soot emissions decreased as the index representing the accelerated onset of primary droplet breakup, while accounting for the influence of aromatic components, increased. Furthermore, the influence of aromatic components, which could not be explained by the conventional Jet number, was successfully incorporated into a unified correlation by considering the offsetting effect of aromatic components on the soot reduction achieved through the acceleration of primary breakup. In this study, aromatic components were treated as a single parameter in the calculation of the effective Jet number. However, previous studies have reported that the contribution of aromatic compounds to soot formation depends on the number of aromatic rings. Therefore, further improvement in the predictive capability of the effective Jet number requires the introduction of weighting factors that account for the contribution of each aromatic ring class.

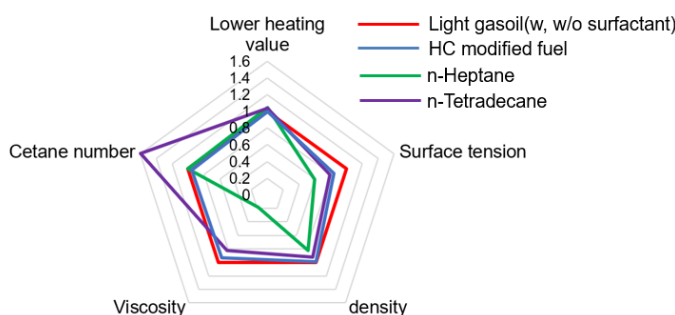


Fig. 1. Normalized fuel properties by diesel fuel

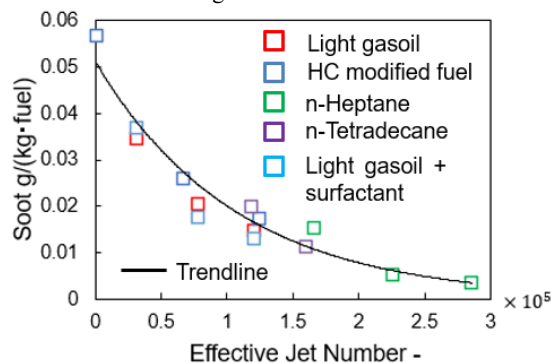


Fig. 2. Relationship between Effective Jet Number and Soot