

Effects of azeotropic phenomena in ethanol-blended gasoline on liquid film evaporation characteristics during cold start

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The Agency for Natural Resources and Energy is considering a policy to raise the biofuel blending ratio to approximately 20% by 2040, viewing it as a measure that can be implemented at relatively low cost and yield immediate results⁽¹⁾. It has previously been suggested that blending ethanol into gasoline impairs mixture homogeneity during cold starts due to the cooling effect caused by ethanol's high latent heat of vaporization⁽²⁾. Furthermore, it is known that an azeotropic phenomenon, which raises the vapor pressure, occurs as ethanol is blended into the fuel⁽³⁾. However, limited research has examined cold-start evaporation characteristics through both experimental and numerical analysis. Therefore, this study aims to clarify the effect of the azeotropic phenomenon—which occurs when ethanol is blended with the hydrocarbons found in commercial gasoline—on evaporation behavior during cold starts, using constant-volume vessel experiments and corresponding three-dimensional thermal-fluid simulations.

The experiments were conducted under conditions simulating fuel injection into a low-pressure environment during the intake stroke—corresponding to engine operating conditions of 400 kPa IMEP and 1500 rpm—with an ambient temperature of 350 K, an ambient pressure of 60 kPa, and a wall temperature of 60°C. To simulate the azeotropic evaporation of a mixed fuel within a 3D CFD, the activity coefficient γ_i was calculated using the Margules equation⁽⁴⁾, and the mass fraction $Y_{A,int}$ at the liquid film interface was subsequently determined using Eq. (2). Furthermore, the evaporation mass for each component was calculated from the obtained mass fraction by sequentially incorporating these results into the simulation, the azeotropic phenomenon during the liquid film evaporation process was accounted for.

To quantitatively examine the evaporation characteristics of the fuel types used in the experiments, the average evaporation rates were calculated. This comparison is shown in Fig. 1. In cases where no azeotrope forms, the evaporation rates of ethanol-blended fuels should fall along a straight line connecting the rates of the pure hydrocarbon and pure ethanol components. For isooctane and toluene—where the data points lie above the green dots, indicating an increase in evaporation rate—it can be seen that azeotrope formation occurs upon mixing with ethanol. To elucidate the evaporation characteristics of iso-Octane and toluene—for which azeotrope formation due to ethanol mixing was confirmed in constant-volume vessel experiments—we reproduced the experiments through calculation. Figure 2 shows the visualization results of the ethanol fraction within the liquid film. EO20 is a fuel consisting of isooctane mixed with 20 vol% ethanol, while ET20 is a fuel consisting of toluene mixed with 20 vol% ethanol. Visualization results from 3D simulations reveal that the ethanol fraction in the liquid film is lower in the model that accounts for azeotropy, indicating the preferential evaporation of ethanol. Based on these visualization results, the increase in evaporation rate observed in the ethanol mixing experiments with isooctane and toluene is attributed to the occurrence of azeotropy within the liquid film, which promoted the evaporation of ethanol.

$$\ln \gamma_i = (A_{ij} + 2(A_{ji} - A_{ij})x_i)x_j^2 \quad (1)$$

$$Y_{A,int} = \frac{\gamma_i P_{sat,A} | \tau_{film}}{P} \frac{M_A}{M_{mix}} \quad (2)$$

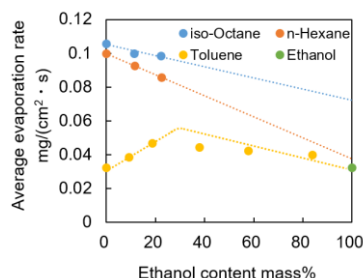


Fig.1 A comparison of Ethanol blend fuel evaporation rate between volume based Ethanol content.

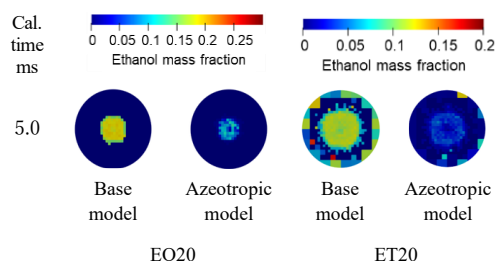


Fig.2 Calculated fuel film ethanol mass fraction

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