

Study on Modeling of Combustion Chamber Deposits in High-efficiency Gasoline Spark-Ignition Engines

- (Fifth Report) Development of a Predictive Model for Deposit Growth Rates in Carbon-Neutral Fuels Integrating Engine Data and Laboratory Simulations -

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Improving the efficiency of internal combustion engines and utilizing carbon-neutral (CN) fuels have become increasingly important. Combustion chamber deposits (CCDs), however, can affect the compression ratio and induce abnormal combustion. Therefore, predicting deposit growth is important for maintaining stable high-efficiency combustion. In this study, a predictive model for CCD growth applicable to various CN fuels was developed based on the deposit growth model proposed by Price et al. The model was extended to account for fuel composition and was calibrated using experimental data obtained from engine tests.

The original model proposed by Price et al. estimates deposit growth based on the formation, condensation, evaporation, and polymerization of partially oxidized fuel components. However, its applicability is limited for oxygenated and nitrogen-containing fuels. In the present study, the original model structure was retained, while the estimation of the nominal boiling points of partially oxidized species was replaced by a multiple regression model using seven fuel descriptors: boiling point, molecular weight, polarizability, and the presence of double bonds, non-aromatic rings, aromatic rings, and hydroxyl groups. The coefficient of determination for the prediction of relative deposit growth rate was improved from 0.930 to 0.972. Model parameters were subsequently calibrated using engine-test data for premium gasoline (PG).

The developed model reproduced the experimentally observed increase in deposit thickness caused by the addition of 20 vol% toluene to PG. The model was then applied to several CN fuel compositions. Figure 1 shows the calculated deposit thickness after 30 h of engine operation. For PG-based fuels, the predicted deposit thickness decreased monotonically with increasing ethanol content. This trend is mainly attributed to the higher volatility of ethanol compared with aromatic components that act as deposit precursors.

The predicted deposit thickness of methanol-to-gasoline (MTG) fuel was lower than that of PG and was further reduced by ethanol addition. The MTG fuel used in this study contained almost no components with carbon numbers of C10 or higher. In practical MTG synthesis, however, high-boiling aromatic compounds such as durene (C₁₀H₁₄) can be present. Therefore, the effect of durene addition was also evaluated. Deposit thickness increased monotonically with increasing durene content, and MTG containing 20 vol% durene showed a greater deposit thickness than PG. These results indicate that high-boiling components in CN fuels can significantly affect CCD formation and suggest that the distillation cut point of MTG fuel is an important parameter for controlling deposit growth.

A predictive model for CCD growth applicable to various CN fuels was developed by extending the conventional Price model using a multiple regression approach and calibrating the model with engine-test data. The model successfully represented the effects of fuel composition on deposit growth. The calculations indicated that ethanol addition reduces deposit formation, whereas high-boiling aromatic components such as durene can substantially increase deposit growth in MTG fuels. These results demonstrate that fuel composition, particularly the content of high-boiling components, is a key factor governing CCD formation in CN fuels.

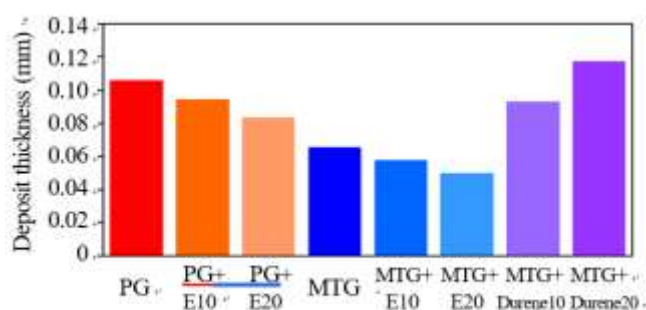


Fig.1 Deposit thickness after 30 hour operation