

Combustion and Exhaust Gas Characteristics of a Spark-Ignition Engine using Carbon Neutral Fuels (MtG: Methanol to Gasoline, EtG: Ethanol to Gasoline)

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At the 2026 Vienna International Motor Symposium, Volkswagen unveiled a new engine, underscoring that strong hybrid powertrains equipped with high-efficiency spark-ignition engines remain highly relevant in both Japanese and European markets. Simultaneously, the European Commission is considering regulatory updates to promote E20 gasoline containing up to 20% renewable ethanol. Replacing the remaining gasoline with carbon-neutral synthetic fuels like e-fuels enables complete carbon neutrality for E20-compliant vehicles. In this study, to evaluate the applicability of alternative synthetic fuels in existing gasoline engines, a comprehensive comparative evaluation of combustion, exhaust emissions, and knock resistance was conducted across operating conditions from low to wide-open throttle loads using Methanol to Gasoline (MtG) and Ethanol to Gasoline (EtG).

Fuel characterization via PIONA analysis, heating value measurement and distillation testing showed that MtG and EtG maintained lower heating values comparable to commercial gasoline while exhibiting slightly higher research octane numbers (RON), expecting enhanced knock resistance. Engine experiments conducted across low, medium, and high loads at constant engine speed and excess air ratio revealed that brake thermal efficiency increased from low to medium loads, reaching a peak around brake mean effective pressure (BMEP) of 0.7 MPa. In low load region (BMEP 0.2–0.4 MPa), no knocking occurred, enabling operation at maximum thermal efficiency without significant differences among three fuels. Under medium to high load conditions (BMEP $\geq$ 0.6 MPa), where knocking was confirmed, MtG and EtG maintained thermal efficiency equivalent to commercial gasoline under trace knock (TK) conditions. The higher RON of the synthetic fuels minimized necessary ignition timing retardation, thereby suppressing thermal efficiency decline.

Comparison of combustion and exhaust characteristics among three fuels are shown in Fig.2. At the peak efficiency point (BMEP 0.7 MPa), MtG, EtG, and gasoline exhibited no significant differences in brake thermal efficiency or TK ignition timing sensitivity, indicating that MtG and EtG fuels can operate effectively under existing control methods near the knock limit. Regarding combustion stability, the coefficient of variation of IMEP (CoV_{IMEP}) slightly increased for MtG and EtG compared to gasoline. Exhaust emissions reflected distinct fuel composition and distillation effects. CO emissions of MtG and EtG increased due to lower H/C ratios and localized incomplete combustion of heavy components, whereas NO emissions decreased due to lower combustion temperatures suppressing thermal NO_x formation. Total hydrocarbon (THC) emissions for MtG were comparable to gasoline, while EtG showed an increase due to the slower evaporation of heavy aromatic components. Finally, CO₂ emissions for EtG were equivalent to gasoline, whereas MtG demonstrated lower CO₂ emissions.

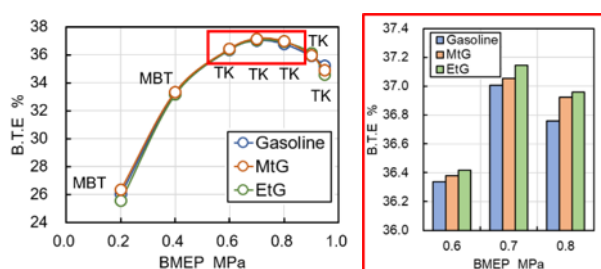


Fig.1 Brake thermal efficiency of each fuel at ignition timing in MBT or TK under each load (2000 rpm, $\lambda=1.0$, EGR 0.0%, Fuel type : Gasoline, MtG, EtG)

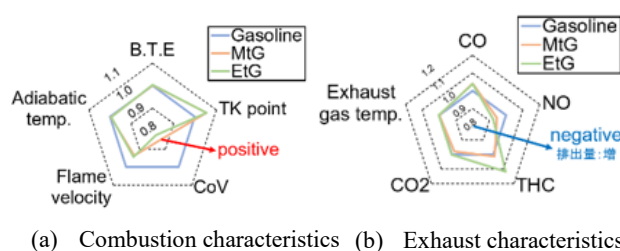


Fig.2 Relative evaluation of MtG and EtG relative to gasoline using radar charts (2000 rpm, BMEP : 0.7 MPa, $\lambda=1.0$, fuel type : Gasoline, MtG, EtG)