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Effects of Hydrogen Substitution Ratio on the Performance and Emission Characteristics of a Hydrogen–Diesel Dual-Fuel Engine

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This study presents an experimental investigation using a single-cylinder diesel engine to examine hydrogen–diesel dual-fuel combustion characteristics. Under steady-state operation at 1800 rpm, total input heat was maintained at a constant level while the hydrogen substitution ratio r_{H2} varied between 0 and 90%. The primary objective was evaluating the effects of these parameters on engine performance and exhaust characteristics, focusing on soot particle number (PN) and size distribution. The test engine featured a 550 cc displacement, 16.3 compression ratio, and a toroidal combustion chamber. Results demonstrated that even a small amount of hydrogen addition leads to a significant reduction in soot emissions and PN. Specifically, at middle load (IMEP ~ 0.7 MPa), increasing r_{H2} from 0 to 0.25 caused both smoke and PN to drop to less than half of the values observed during diesel-only operation, as depicted in Fig. 1. Analysis of the particle size distribution revealed that this reduction was primarily due to a sharp decrease in agglomeration mode particles, typically found in the 20 to 100 nm range. This shift is illustrated in Fig. 2. In terms of performance, thermal efficiency initially decreased as r_{H2} increased due to low hydrogen combustion efficiency at lower concentrations. However, once r_{H2} reached 0.75, efficiency began rising again. At this level, the hydrogen premixed gas reaches an equivalence ratio of ~0.24, enabling flame propagation. The pilot diesel spray acts as an ignition source triggering the hydrogen flame, leading to improved combustion efficiency despite higher cooling losses. Nevertheless, a trade-off occurred at high substitution; at r_{H2} = 0.75 under middle load, smoke emissions returned to diesel-only levels. Combustion analysis in Fig. 3 suggests rapid flame propagation from pilot injections shortened the main injection ignition delay, resulting in locally oxygen-deficient mixtures that accelerated soot formation. Ultimately, while hydrogen addition is an effective retrofit for reducing particulate emissions, optimization of injection timing and substitution ratios is required to manage hydrogen flame and diesel spray interactions.

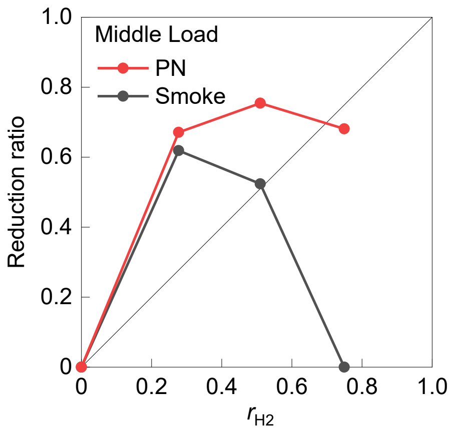

Fig.1 Effect of H_2 energy fraction on smoke and PN reduction at middle load

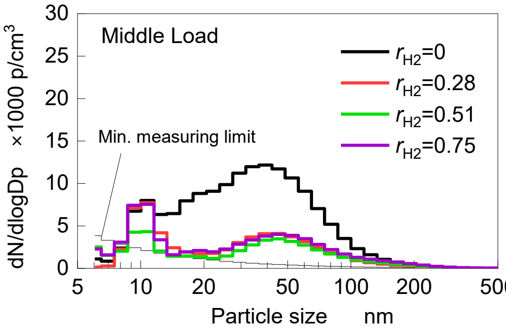

Fig.2 Effect of H_2 energy fraction on particle number size distribution at middle load

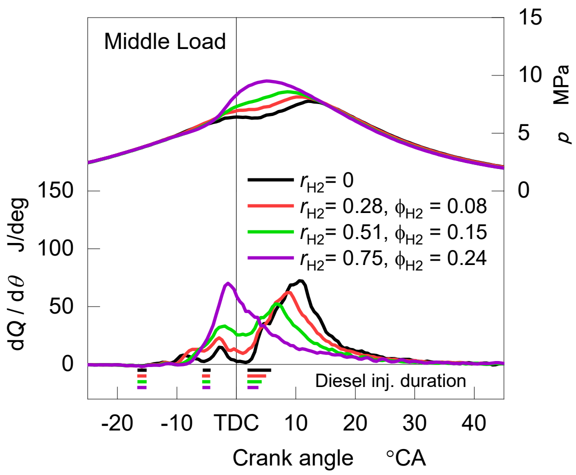

Fig.3 Effect of H_2 energy fraction on in-cylinder pressure and heat release rate at middle load