HCCI Combustion: the Sources of Emissions at Low Loads and the Effects of GDI Fuel Injection

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Abstract

Homogeneous Charge Compression Ignition (HCCI) engines have been shown to provide both high efficiency and low emissions of NO_X and particulate. However, hydrocarbon (HC) and carbon monoxide (CO) emissions are often high, with amounts depending on operating conditions. To gain a better understanding of the reasons for these emissions and their relative importance over the operating range, a study of HCCI combustion and emissions has been conducted, with particular emphasis on understanding the sources of HC and CO emissions and the associated combustion inefficiencies during low-load operation. This investigation included both experimental measurements and computations for a variety of fuel loads and engine speeds.

The experiments were conducted in a single-cylinder engine (0.98 liters/cyl.) fitted with a custom HCCI piston that minimizes crevice volume, using iso-octane as the fuel. For three engine speeds (600, 1200, and 1800 rpm) the fuel loading was varied from near the knocking limit to loads at or below idle (based on typical diesel-engine fueling). For each condition, cylinder pressure and exhaust-gas data (CO_2, O_2, CO, HC, NO_X, and smoke) were acquired. Comparative computations were made using the Senkin application of the CHEMKIN III kinetic rate code with the full chemistry mechanisms for iso-octane. This single-zone model provides results that are representative of the bulk-gas behavior for an idealized engine with no crevices.

The experimental data show that when the fueling rate is reduced below an equivalence ratio (ϕ) of 0.18, CO emissions begin to increase substantially, reaching levels corresponding to 60% of all fuel carbon at idle loads (ϕ = 0.1 to 0.12). As this occurs, the combustion efficiency falls from 95% to less than 60%. These high CO levels are found to be in very good agreement with those predicted by the model, indicating that the high CO emissions and the associated combustion inefficiencies are due to incomplete bulk-gas reactions. HC emissions also increase, but the effect is less pronounced than that of CO. In addition, the model indicates that high levels of oxygenated hydrocarbons (OHC) should occur as bulk-gas reactions become less complete. Since these emissions are not readily measured, a method of estimating the OHC level from the available data was developed, and is shown to compare well with the modeling results. Finally, partial charge stratification, obtained using a gasoline-type direct fuel injector has been investigated as a means of mitigating the problem of incomplete bulk gas reactions at lower loads, and the results are presented and discussed.