Exhaust particulate matter emissions of ethanol in comparison with gasoline and diesel fuels in a heavy-duty compression ignition engine

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Vehicles with compression ignition (CI) engines are responsible for a significant fraction of air pollution in urban areas. Major air pollutants from CI engines with conventional lean diesel combustion techniques are soot and NO_x. To limit the negative impact on climate and health, emission legislation regulating emissions from internal combustion vehicles is continuously made stricter, which has driven the major part of the engine research to focus on providing efficient engines of both low emissions and fuel consumption. As a consequence, more advanced combustion CI combustion strategies have been developed, of which the low temperature combustion (LTC) has seen much attention. In this new combustion concept, NO_x formation can be suppressed by lowering combustion temperatures and soot formation can be minimized by adequate premixing of fuel and air. One of the common techniques among LTC strategies is to employ high amount of exhaust gas recirculation (EGR) as well as different types of fuels. It has been reported that gasoline-like fuel emit much less soot than diesel (Kalghatgi et al., 2007), while ethanol was found to generate ultra-low soot emissions (Shen et al., 2013).

To determine the characteristics of exhaust particulate matter (PM) emissions in terms of particle mass concentration and size distribution, particle measurements were performed in the exhaust on a modern heavy-duty diesel engine with varying EGR (corresponding to inlet oxygen concentrations from 9% to 18%). A comparison of the total particle mass and particle size distributions between ethanol, gasoline and diesel fuels was done in order to determine the exhaust particle characteristics for different fuels. Particle size distributions were measured with a Fast mobility analyzer (DMS500; Cambustion Ltd. UK) and particle mass concentrations with an AVL micro soot sensor.

When adding EGR with gasoline and diesel fuels, particle mass emissions increase as the inlet oxygen concentration decreases and then decline upon further reduced oxygen concentration (Fig.1). Ethanol, in contrast, emitted almost zero soot mass regardless of the inlet oxygen concentration. Compared to diesel fuel, particle mass emissions of gasoline were much lower and this reduction becomes increasingly significant as EGR increases. In high temperature combustion with low EGR (18% O_2) large particles in accumulation mode dominate the size distribution while most particles from ethanol are in the nucleation mode. Although almost no soot is detected from combustion with ethanol, the magnitude of the nucleation mode depends on the level of EGR.

The increase in soot mass observed when increasing EGR during combustion with gasoline and diesel is explained by a significant increase in both particle number and particle size (Fig.1). At very low levels of oxygen, the decrease in gasoline and diesel soot mass is mainly due to a reduction in particle numbers. Regardless of EGR, the geometric mean diameter (GMD) of the soot size distribution was lower for gasoline than for diesel. We thus conclude that, compared to conventional, diesel high octane gasoline emits lower particle number emissions and of smaller sizes.

The results show that new fuel strategies to complement EGR in LTC may be powerful tools for continued particle emission reduction in CI engines. Although gasoline show great improvements in emission levels compared to conventional diesel, ultra-low soot emissions from ethanol are more attractive.

The altered soot properties obtained from different fuels and EGR could have implications for the efficiency of soot after-treatment systems. However, especially emissions from LTC at high EGR requires further study including particle chemical composition, optical properties and micro- and nano structure.

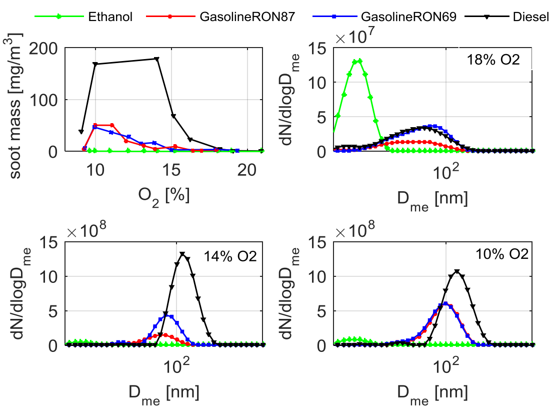

Figure 1. Exhaust particle mass and size distributions at various inlet oxygen levels and for different fuels.

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Kalghatgi, G. T., Risberg, P., & Ångström, H. E. (2007). SAE paper, (2007-01), 0006.

Shen, M., Tuner, M., & Johansson, B. (2013). (No. 2013-01-0277). SAE Technical Paper.