Particle emission from direct injection internal combustion engine fed with various gaseous fuels

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Introduction & Background: Gaseous fuels as hydrogen and methane are considered most frequently as possible alternatives to conventional liquid fuels. Besides, on-board production of a hydrogen-rich reformate using Thermo-Chemical Recuperation improves thermal efficiency and reduces emissions of gaseous pollutants. Commonly, gaseous fuels are introduced into the ICE intake manifold through a port fuel injection (PFI). The latter results in improved combustion and concomitantly reduced exhaust emissions, as compared to liquid fuels. However, PFI may lead to abnormal combustion phenomena, as well as maximal power loss. Direct injection (DI) of gaseous fuel eliminates these problems, and contrary to the PFI method it reduces the compression work caused by the additional volume of gaseous fuel in the intake manifold. Most of previous studies dealt with particle emissions of IC engines fed with gaseous fuels, considered fuel supply to the engine intake manifold. These works reported on the reduction of particle emission as compared to gasoline. There is a limited number of studies investigating particle formation in DI engines fed with gaseous fuels, and no comparative information is available on the effect of fuel type. The main goal of this work is to investigate particle formation in a direct injection SI engine fed with different gaseous fuels like hydrogen, methane, and hydrogen-rich reformate (containing 75% mol. hydrogen and 25% mol. CO_2). The effect of the end of injection timing (EOI) and fuel type was investigated, and a comparison to PFI with the same fuels was performed.

Methodology: The experimental setup was based on a single-cylinder Lister-Petter AD1 4-stroke engine with a high compression ratio (r=15.5) modified for spark-ignition operation. Particle number concentration and size distribution measurements were performed with TSI model 3090 Engine Exhaust Particle Sizer (EEPS) Spectrometer. A direct experimental comparison was performed between the PFI and DI fuel supply methods and different gaseous fuels: hydrogen, methane, and the reformate.

Results & Conclusions: The results showed that the total particle number emitted from the engine fed by DI of the hydrogen-rich reformate was the highest among the studied fuels. Besides, hydrogen fuel, with no carbon content, resulted in a higher total particle number compared to methane. The increase in particle emissions was noticed especially at high engine loads, while for the lower engine loads, which can be achieved using both PFI and DI methods, no significant difference was noticed between the various fuels. The direct experimental comparison of particle emission between the reformate port and direct injection on the same engine elucidates that the increase in particle formation is a result of the applied direct injection method. Notably, the reformate fuel requiring the longest injection duration due to the lowest fuel heating value resulted in the highest particle emission. Studying the effect of EOI with the DI method for the various fuels revealed the same trend of excessive particle formation at high engine loads. The retarded EOI timing (-70 CA BTDC) with longer injection duration resulted in a higher particle emission compared to the earlier EOI timing (-100 CA BTDC). The observed higher particle formation with direct reformate injection is attributed to the lubricant involvement in the combustion process. The fuel jet developed during the injection causes lubricant vapor entrainment into the jet, while the jet impingement on cylinder walls causes oil removal from the walls. This lubricant is mixed in the cylinder bulk which led to incomplete combustion with resulting excessive particle formation.