

Influence of hydrogen volume fraction on co-combustion of hydrogen with RME-diesel and PRO Diesel™ blends in CI engine

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Abstract

The article presents the test results of CI engine operating on biofuel and diesel blends with H₂. Two types of liquid fuels were tested. The purpose was to examine the influence of the hydrogen fraction on efficiency and emissions. H₂ fraction was increased from 0 to 43% by energy, or from 0 to 8% by volume. Tests were performed at optimal injection timing at low, medium and nominal loads. With increase of H₂ fraction above it lower flammability limit, the increase of *ITE*, decrease of CO, CO₂, smoke opacity, and increase of NO were noticed. The optimal H₂ volume fraction of 3–4% proposed.

Key words

Hydrogen, RME, PRO Diesel, HVO, diesel fuel, CI engine, combustion, emission

Introduction

In 2019, the global CO₂ emission reached 32.3 GtCO₂, while transport accounted for 8.2 GtCO₂. [1]. The use of renewable fuels such as biomass based biofuels and H₂ has the potential to reduce the emissions and, thus mitigate the effects of the environmental crisis of climate change. Although the use of sole H₂ for combustion engines are hardly possible [2], the co-combustion with various fuels including renewable fuels makes it the subject of research interest of many scientists [3] [4] [5] [6]. They still found new phenomenas of H₂ influence on efficiency and emission parameters of the engine. This study is focused on the influence of H₂ volume fraction (HVF) on the co-combustion of hydrogen with blends of rapeseed methyl ester (RME) with ultra-low sulfur diesel (ULSD) and hydrotreated vegetable oil (HVO) with ULSD. Also the lower flammability limit of H₂ has been discussed.

Experimental setup/Methodology

Tests have been performed on a single cylinder CI engine (Fig. 1). Displacement of engine – 1810 cm³, compression ratio – 17. The engine was set to operate at the constant speed of 965 rpm. Each experiment was conducted at the three *IMEP*: LL – low load, ML – medium load, NL – nominal load. The *IMEP* was controlled with amounts of liquid and gaseous fuel. Two types of liquid fuels were tested: RME7 (mixture of ULSD and 7% RME) and Neste PRO Diesel™ (mixture of ULSD and 15% of HVO), produced by Neste

Oil Corporation. The injection timing ϕ_1 for liquid fuel operation was determined at the position of 50% MFB, and this position was set within the 8–12 deg crank angle (CA).

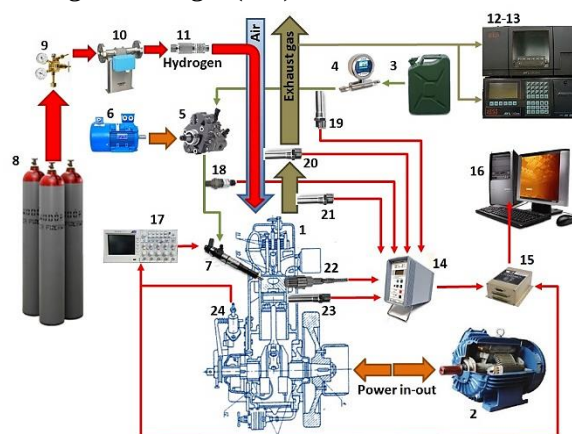


Figure 1. Experimental installation. 1 – CI engine; 2 – generator; 3 – fuel tank; 4 – DF flow meter; 5 – DF high pressure pump; 6 – DF pump drive el. engine; 7 – DF common rail injector; 8 – hydrogen balloon; 9 – pressure reducer; 10 – flow meter; 11 – firebreak arrester; 12 – smoke analyser; 13 – emissions analyser; 14 – amplifier & A/D converter; 15 – data acquisition system; 16 – PC; 17 – DF injection controller; 18 – DF pressure sensor; 19 – DF temperature sensor; 20 – inlet air temperature sensor; 21 – exhaust gas temperature sensor; 22 – in-cylinder pressure sensor Kistler 6061B; 23 – engine temp. sensor; 24 – CA encoder Kistler 2612C.

Injection timing ϕ_2 was determined with the lowest HES, at the combustion of 50% MFB within the range of 8–12 deg CA. Further experiments with hydrogen energy fractions up to 43% were performed with ϕ_2 .

Results

The increase of in-cylinder p_{max} was noticed with increase of HVF more than 3% at LL and NL. The increase of p_{max} at LL was negligible (Fig. 2).

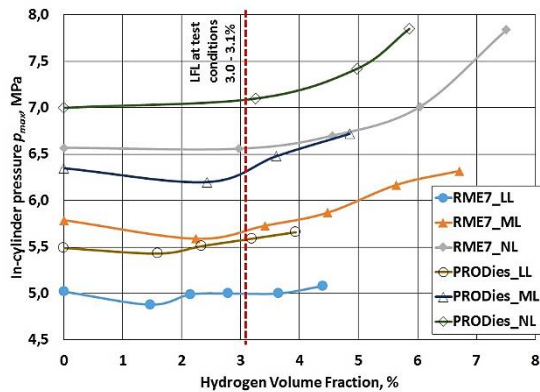


Figure 2. In-cylinder max. pressure vs. hydrogen volume fraction at various engine loads.

The negligible influence of H_2 fraction at the LL and partially at the ML explained by the low volume fraction of the H_2 in the combustion chamber. The volume fraction of H_2 at LL tests were 1.38–2.87%, which is below the lower flammability limit of H_2 – 4% and the combustion was not intensified by presence of the H_2 .

The indicated thermal efficiency (ITE) increased steadily with increase of the HVF with both tested fuels (Fig. 3), and that increase is more significant with PRO Diesel because of the higher cetane number and shorter ignition delay.

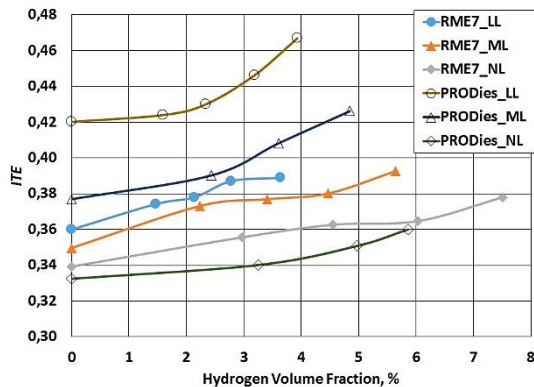


Figure 3. ITE vs. hydrogen volume fraction at various engine loads.

The addition of H_2 up to 3.0–3.1% HVF do not effect NO emissions, however with further increase of HVF, NO increased significantly (Fig. 4). The negligible increase of NO at low HVF was because the lean hydrogen – air mixture does not support the flame propagation and results in low combustion temperature. Furthermore, due to the low H_2 volume fraction, there are insufficient amount of the active hydroxygen radicals, which in fact intensifies the combustion.

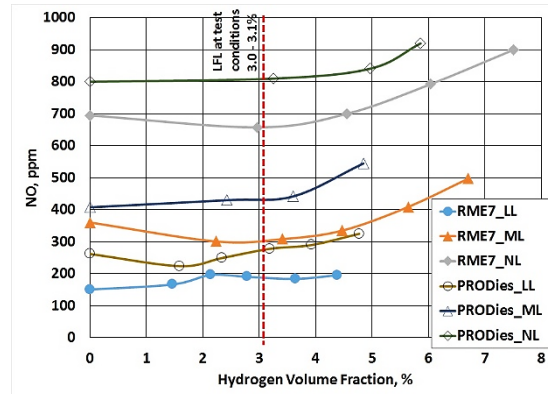


Figure 4. The dependance of NO on fuel used and hydrogen volume fraction at various engine loads.

Conclusions

1. Increase of HVF enhances the p_{max} as the result of the higher laminar flame speed of the H_2 and increased chemical reaction rates.
2. Efficient H_2 co-combustion with biodiesel starts at HVF, corresponding the LFL = 3.0–3.1%.
3. Enhancement of ITE effected by increased mass flow rate of the H_2 and it intensive combustions after LFL of H_2 was overstepped.
4. Presence of H_2 with HVF of 3–4% was determined as the optimal range for all test loads with respect to efficiency and emissions.

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