Combustion of Hydrogen into a SI and HCCI Engine. Which one for Ultra-Low Emissions and High Efficiency?

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European Union has fixed drastic objectives to decrease their CO2 emissions by a factor 80% compared to their 1990's CO2 emission for 2050. Concerning the road transport industry, these challenge is stronger and the reduction objective was fixed to 95%. Naturally as function of the future regulation, the pollutant emissions, i.e. CO, HC PM and NOx, will decrease and tend towards extremely low levels. To solve this societal and technological challenge, the powertrain needs to evolve significantly towards high hybrid level technology and high efficiency internal combustion. In parallel, the combustion of low CO2 impact fuel is necessary and biofuel, gas and hydrogen seem to be one solution.

Hydrogen is an interesting fuel due to his physical and chemical properties (high octane number, high Low Heating Value, high diffusivity and high laminar flame velocity). It can burn in SI and HCCI engine [1] and suppress definitively the CO2 emission at the exhaust of any combustion system. In this study, we are interesting to compare these two engine combustion modes to increase the engine efficiency and tend towards zeros emission of NOx by maintaining a reasonable load. In the case of a range-extender powertrain, zero NOx emission signifies that the exhaust after-treatment could be optimized in terms of size or could be suppressed. The load needs to be adequate to reach a power near 10 to 15 kW to increase the autonomous distance of the car. In this work, hydrogen HCCI and SI combustions are compared in both engines: a 0.5 liter Diesel single cylinder HCCI engine and a 0.4 liter single cylinder SI engine. In both cases, port fuel injection strategy was applied and the eventual EGR was simulated by synthetic EGR.

With an octane number of 120 and a high laminar flame velocity, hydrogen is an excellent candidate for SI engine: the compression ratio could be increased and the combustion duration shorted to increase the thermodynamic efficiency of the cycle. However, due to the adiabatic combustion temperature, the NOx emission increases significantly expected if the equivalence ratio is less than 0.4. Near this equivalence ratio, the efficiency of the Si engine is maximum near 38% despite the fact that the compression ratio of the studied engine was equal to 10 (Figure 1). The second strategy to contain the NOx emission was to recirculate burnt gases at the intake for an equivalence ratio equal to 1. H2O+N2 and H2O dilution (with the mole ratio of a stoichiometric combustion) were compared and decrease the NOx emission less than 10 ppm, an EGR level of 60% was necessary. However, due to the heat capacity of the water, the indicated efficiency decreases as function of the EGR level for the case of pure H2O dilution less than 31% and increase up to 36% in the case of the H2O+N2 dilution. Because the intake pressure was fixed to 1 bar, the reached IMEP of 4 bars was not enough for Range Extender application and then boosted pressure was applied in the case of an air diluted combustion (equivalence ratio of 0.4). It was demonstrated that the increasing of the intake pressure up to 1.6 allows the increase of IMEP up to 6 bar while maintaining a level of NOx less than 10 ppm and an indicated efficiency greater than 0.38.

Since many years, it has been demonstrated that HCCI engine could be reached ultra-low NOx emission for many fuels and especially when the equivalence ratio is less than 0.4. Firstly, we compared the HCCI combustion of hydrogen (ON =120) with isooctane (ON=100) at the same equivalence ratio equal to 0.3 and despite the fact that the octane number of the hydrogen is greater than those of isooctane, the auto-ignition appears for intake temperature and intake pressure less than for the isooctane fuel (figure 2). We study the impact of ozone seeding at the intake to manage the phasing of the combustion as demonstrated by [2–5] for different fuels. It was demonstrated that 60 ppm of Ozone at the intake permit to advance to combustion into the cycle of 12 CAD. However, even if the compression ratio was high than those used during the SI engine study, the indicated efficiency was less and equal to 35% and the NOx less than 10 ppm.

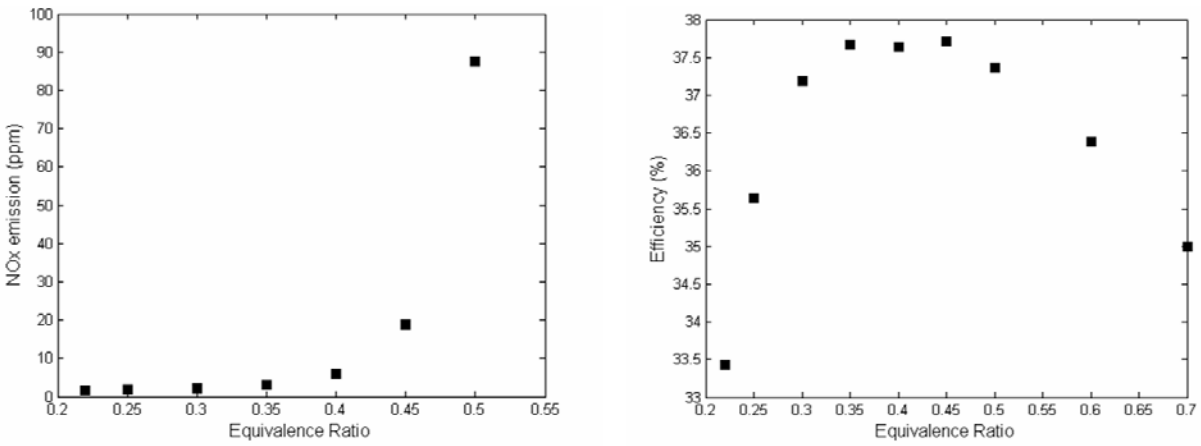

Figure 1: N=1400 rpm, Tintake =40°C, f = 0.4, optimal spark ignition advanced, Pexhaust=Pintake

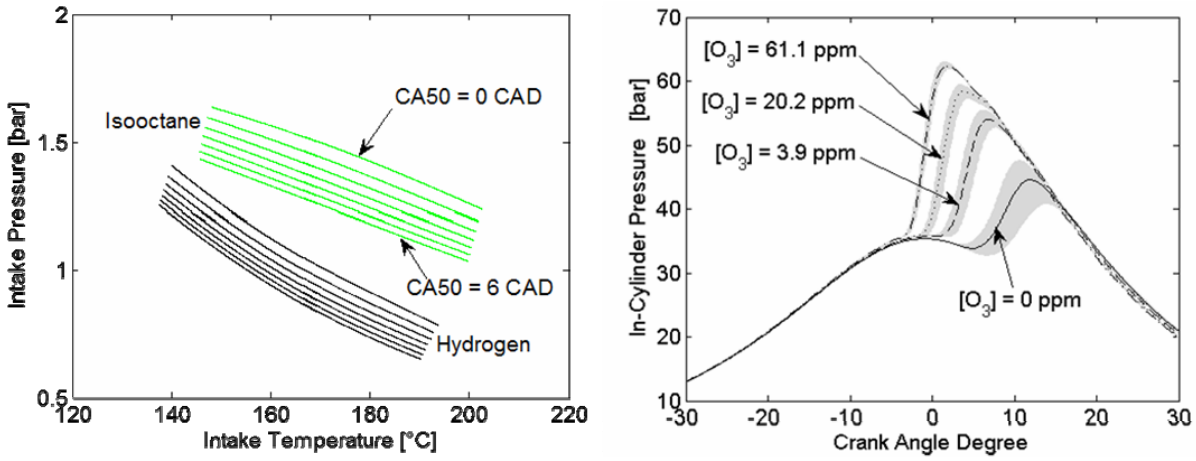

Figure 2: Left: Comparison between combustion isooctane and hydrogen combustion as function of the intake temperature and pressure. Right: Effect of Ozone seeding at the intake to control the combustion phasing.

In conclusion, Hydrogen could be an interesting fuel for future powertrain and could archive high efficiency if the compression ratio of SI engine is optimized. Low equivalence ratio is the key to decrease the NOx emission and suppress any exhaust gas after-treatment however turbocharger need to be used to reach a specific power near 10 KW. Despite the fact that HCCI engine has a potential high efficiency, the one is less than a traditional SI engine and more even if ozone could be used to control the combustion phasing, the benefit of the engine was not been demonstrated.

References:

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