Investigation of turbulent combustion in SI-homogeneous charge engines using hydrogen-gasoline mixtures

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Hydrogen appears to be one of the most promising long-term alternative fuels. Its major combustion product is water, it is easily ignited, and it has wide flammability limits. Nevertheless, some important issues arise, such as on-board storage, safety concern, pre-ignition and backflash, combustion control, emission of NOx, power density for transport applications and some more, not least lack of infrastructure for distribution. In the mid-term time frame, the addition of small quantities of hydrogen to gasoline appears to be a good opportunity to combine the major advantages given by both fuels, avoiding many problems, especially if an hydrogen-rich gas is produced on-board directly from gasoline by means of a reformer.

Addition of hydrogen-rich gas to gasoline has recently gained interest in the industrial and academic community in terms of the anticipated potential of these fuel mixtures to improve part-load efficiency and cold start pollutant emissions in internal combustion engines. Of particular relevance in this context is the dependence of unsteady turbulent flame propagation speed, EGR tolerance, lean limit extension, NOx formation and wall quenching distance on varying percentage content of H_2 in the fuel mixture.

This project is part of a joint ETH Zürich, HTI Biel and Bosch initiative. The aim of ETH part is to carry out both experiments and simulation intended to answer to the following questions:

dethrottling effect on BSFC, evaluation of NO_x and UHC as a function of H_2 rate, EGR rate and air/fuel ratio;

investigation on heat release rate, combustion duration and cyclic stability;

correlation of combustion duration and turbulent flame speed;

correlation of wall heat and quenching distance.

An extension of the experimental work, refers to the simulation of turbulent premixed combustion with a CFD code. A simple model for the reaction rate closure will soon be implemented to the code and its performance shall be assessed by means of the heat release rate measurements mentioned above.

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A bottled blend of CO, H_2, and N_2 (24%, 21%, 55% by volume) has been chosen in order to simulate the most likely output of a partially oxidative reformer suitable for Internal Combustion Engine applications.

Experiments are carried out on a Lombardini 4-stroke, 2-cylinder, 0.5-liter engine, model LGW 523 OHC. As it is originally a carbureted engine, it has been modified in order to electronically control the injection of gasoline and hydrogen-rich-gas in the intake port, through an electronic control system based on Matlab/Simulink and dSpace/Control Desk, which allows full control and free programming on all engine parameters. The engine has been equipped with a water-cooled EGR line and water trap.

Investigation on flame propagation is carried out using ion-detection probes on the cylinder head surface and an optical spark plug for light emission detection in the ignition phase. Investigation on wall heat transfer will make use of dedicated unsteady heat release sensors.

The analysis of the heat release rate has shown that, when running at λ=1 and without EGR, addition of hydrogen-rich gas produces a significant shortening of the very first phase of combustion (inflammation phase) rather than of the remaining combustion process, because the high reactivity of H_2 molecules makes promptly available a quantity of radicals, speeding up the hydrocarbon chain branching. On the other hand, for the same reason, addition of hydrogen-rich gas allows running the engine at extremely high λ or EGR rate, as the engine is able to tolerate a much bigger amount of inert gas, which would otherwise hinder the ignition of the mixture and the propagation of the flame front through the combustion chamber.
When increasing quantities of hydrogen-rich gas are substituted to gasoline, and the engine runs in each condition at the highest possible λ or EGR (limited by COV increase), the duration of all phases of combustion remains almost unaffected by the amount of diluents.
When increasing amounts of hydrogen-rich gas replace gasoline, a significant decrease of UHC and NOx emissions has been observed, down to near-zero values at pure hydrogen-rich gas operation even without a 3-way catalyst.
In all conditions due to a significant dethrotteling at part loads a significant increase of engine efficiency has been measured, which seems to be enough to compensate and overcome the losses due to the partial oxidation of Gasoline in the Reformer, which should eventually provide the hydrogen-rich gas.
Further investigation focused on measurements of the flame speed and shape through ion-detection probes placed on the cylinder head surface, as well as investigations on the inflammation phase through a light-collecting spark plug. Such experiments allowed reconstructing the flame shape during its propagation inside the combustion chamber, confirming the predominant effect of the H2-rich gas on the early phase of the combustion process.
The quenching phase of the combustion process will be investigated through correlation with the wall heat transfer, which will be measured by means of unsteady heat flux sensors. On the simulation side, investigation on the basic chemistry of combustion of hydrogen-carbon monoxide-gasoline mixture is presently being carried out, as well as the integration of a simple model for such kind of combustion in a CFD code.

[1] Conte E., Boulouchos K., *Influence of hydrogen-rich gas addition on combustion, pollutant formation and efficiency of an IC-SI engine*, SAE Paper 2004-01-0972

[2] Allgeier T., Klenk M., Landenfeld T., Conte E., Boulouchos K., Czerwinski J., *Advanced emission and fuel economy concept using combined injection of gasoline and hydrogen in SI-engines*, SAE paper 2004-01-1270;