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Experimental study of flame propagation limits resulting from mixture dilution in methane fueled gas engines

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EXPERIMENTAL STUDY OF FLAME PROPAGATION LIMITS RESULTING FROM MIXTURE DILUTION IN METHANE FUELED GAS ENGINES.

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KEYWORDS – Optical HD engine, Laser diagnostics, Premixed mixture, Dilution limit, Combustion regime

ABSTRACT –

Research and/or Engineering Questions/Objective

Natural gas is considered as one of the near term alternative automotive fuels with highest potential. In practice, most of its automotive applications are based on premixed charge ignition and consequent turbulent flame propagation. To minimize fuel consumption this charge is often diluted with recirculated exhaust gas or with excess air. In 1-D models of such lean mixture combustion, it is usually assumed that these flames have a truncated spherical shape and in most 1-D as well as in 3-D models it is assumed that flame propagation is through so-called wrinkled or corrugated flamelets. The purpose of this study was to test these assumptions up to the dilution limit by combining new experimental data on laminar burning velocity and on turbulent flame shape (tomography) with information on the corresponding turbulent flow field. In these tests methane was used instead of natural gas.

Methodology

The burning velocity of lean methane-air and also stoichiometric methane-air-diluent mixtures has been measured with the constant-volume technique using a combustion bomb. Then, measurements were conducted in a single-cylinder, optically accessible engine with 2 liter displacement volume. For optical access this engine combined a sapphire liner with a sapphire piston bowl. Using PIV, the flow field in the combustion chamber was determined as well as turbulence levels and –scales. Mie scattering was used to visualize the size and shape of the zone with burned products.

Results

Laminar burning velocity, as function of pressure, unburned temperature, equivalence ratio and dilution is described using a power law type relation which can be used in an engine simulation codes. Combining this info with PIV flow field data, the combustion regime was determined (in a Borghi-Peters combustion regime diagram). Further, a two-zones heat release model (using the measured cylinder pressure signal as input) was used to calculate the instantaneous mass burning rate. Next, Mie scattering imaging was employed to describe the instantaneous flame front surface shape. Combination of the results suggests that premixed combustion under these conditions takes place in the flamelet regime.

Limitations of this study

Burning velocities were measured for unburned mixtures with $T \leq 600$ K and $p \leq 3.5$ MPa. For higher pressure and temperatures extrapolation is necessary. Further, indicated mean effective pressure in the optical engine was limited to 0.8 MPa. Finally, only 2-D visualization of flame shape and flow field was possible.

What does the paper offer that is new in the field including in comparison to other work by the authors?

This study is an extension to the (limited) database on and understanding of the lean limits of turbulent flame propagation with methane in conditions typical of HD combustion engines (i.e. up to 8 bar imep).

Conclusions

The above combustion process for stoichiometric mixtures occurred in the corrugated flamelets regime. For lean mixtures, the thin reaction zones regime was a more appropriate assumption. For 1-D modeling of lean mixture flame propagation, the truncated spherical model is inappropriate.