Flow field studies of laminar flames

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Spherically expanding premixed laminar flames have, in recent years, provided invaluable information about premixed combustion systems. A number of research groups have used spherically expanding laminar flames to provide the stretch free laminar burning velocity. This is relatively straight forward as it can be shown that the stretch rate acting on the flame is a function of the flame radius and the flame speed only. The influence of stretch on the burning velocity can be expressed as a Markstein number.

At elevated pressures spherically expanding flames develop instabilities. The initially smooth surface generates cracks which grow as the flame expands. At a critical radius the whole surface becomes apparently spontaneously covered in cells. These phenomena are the result of hydrodynamic (Landau-Darrieus) and thermo-diffusive effects. As the flame becomes increasingly cellular its surface area increases resulting in an increase in the flame speed. It has been suggested this will ultimately result in the self generation of turbulence and potentially lead to a detonation.

In this study, spherically expanding flames were investigated using high speed Schlieren photography and particle image velocimetry. Using these two techniques the flame speed and flow field ahead of the flame were obtained, as well as two different and complimentary images of the flame.

Three conditions were investigated (a) a stable flame, stoichiometric iso-octane/air at atmospheric pressure (b) a classically cellular flame, fuel rich ($\phi = 1.8$) flame at 5 bar and (c) a completely unstable flame that no longer retains an overall spherical geometry, fuel lean ($\phi = 0.3$) hydrogen/air at 5 bar. Measurements were performed inside a high pressure spherically combustion vessel with optical access.

Particle Image Velocimetry was used to study the flow field of the unburned mixture ahead the developing flames. One image per ignition was taken at different times after ignition, over the range 1-20 ms. The olive oil seeding density was sufficient that the flame edge could be identified. The imaging area was 109 x 82 mm.

The expanding flames pushed the unburned gas ahead of themselves the difference between the flame speed and the gas expansion velocity at the flame front being the laminar burning velocity. The gas velocity decreased with increasing radius from the flame fulfilling mass conservation. Overall the flow ahead of the flame appeared completely laminar. In the case of the two cellular flames, maps of the velocity magnitude demonstrated increased velocities where the flame surface was convex relative to the unburned mixture. Lower velocities were generally observed where deep cracks were present at the surface. This behaviour has been widely predicted, but to the authors knowledge not been demonstrated previously.

The cartesian coordinate systems were converted to polar coordinates with the origin centred at the spark plug. The cellular flames were not perfectly spherical and the tangential velocities were in particular very sensitive to the position of the origin. These plots were used to look of evidence of flame generated turbulence.