Thesis Abstract

Premixed fuel-air combustion in constant volume channels is studied to understand the flame dynamics and the acoustic phenomena inside the channel. Experimental studies are carried out in a closed type and half-open type straight channel having a square cross-section and a closed planar angular channel having a rectangular cross-section where the top and bottom walls make 4° angle with the channel axis. All the experimental studies are carried out using liquefied petroleum gas (LPG)-air premixed mixture at different equivalence ratios (ϕ). High-speed photography and background oriented schlieren (BOS) techniques are employed to characterize the tulip flame formation and the acoustic phenomena in the closed-ends type channels. Different stages of flame development including the flame inversion and the tulip flame are observed. The refractive index gradients and projected flow density are calculated numerically using Poisson's equation and Gladstone-Dale relation. Pseudo-schlieren images, shadowgram, and density contours are plotted using the BOS technique, and these reconstructed fields matched well with the direct observations. Instantaneous velocity fields are calculated using consecutive images as the reference image for the BOS correlation method. The results show that the velocity during the early stages of the flame expansion is close to the laminar burning velocity of the premixed LPG-air flame. As the flame started to inverse, the flame tip close to the wall accelerated to approximately 1.16 m/s. But later the fully-formed tulip flame propagates at 0.25–0.3 m/s till the end of the chamber. A reverse flow in the burned gas region is observed after the tulip flame formation. However, BOS could not capture any acoustic changes in the unburned gas except for a high gradient backflow just behind the flame front. The asymmetric tulip flame propagation was studied with simultaneous visualization from the top and front view. It is found that the tulip flame remains symmetric in the top view, even when the flame is seen to be unsymmetrical from the front view.

A disturbance-free optical measurement technique is used for capturing the acoustic waves and the flame for stoichiometric premixed LPG-air combustion in the straight closed channel. The optical measurement system primarily employs a continuous point laser (near-infrared wavelength), polarisers, a photon detector, and an oscilloscope to capture the acoustic waves. The technique mainly measures the deflection of light rays due to the change in the refractive index. The density gradient across the flame front or the pressure wave will generate the deflection in the laser beam. The deflected laser beam is collected using a photomultiplier tube (PMT) detector. The signals are captured using an oscilloscope. The laser beam is placed at different locations across the channel length. The pressure waves generated initially due to the ignition and its interaction with the flame during different stages of the flame propagation are captured. The transmission and reflection of pressure waves from the top and bottom walls, and the end walls are also observed as high-frequency and low-frequency signals, respectively. Signals for the acoustic are more pronounced when the laser is placed without the polarizer-analyzer system. Flame front location

can also be identified clearly from the optical technique.

Propagation of H_2-air premixed flame in a closed channel is studied numerically. The Navier-Stokes equations along with the species conservation equations are solved in a two-dimensional finite volume framework to get the distribution of pressure, velocity, temperature, and species concentrations in the domain at various time instants. The numerical solver uses a 9 species and 22 reactions kinetic model for H_2-air combustion. The numerical results are in good agreement with the experimental results in producing different stages of the flame propagation. The results show the generation of pressure waves from the initial ignition due to the high temperature ignition zone. The pressure front travels faster than the flame front and it transmits and reflects repeatedly from the top and bottom walls, and end walls of the channel. The reflected pressure front when interacting with the flat flame front generates additional pressure waves near the walls. These waves are of significant strength and move backward in the burned gas. The interaction of the additional pressure front and the flame front is found to be one of the reasons for the shape of the tulip flame.

The effect of inclined walls of the channel on the flame dynamics and the formation of the tulip flame is investigated with the angular chamber having a $4°$ planar converging (C–C) and diverging channel (D–C). Flame propagation is studied for different equivalence ratios to understand the flame behaviour and the tulip flame formation. The location and speed of the flame tip propagation and the cusp are plotted for different ϕ for both channels. The flame propagation in both convergent and divergent channels showed all the stages of flame development that occurred in the straight channel including the classical tulip flame formation. Distorted tulip flame (DTF) is observed at different equivalence ratios. The DTF creates a corrugated flame surface and increases the flame surface. It also helps in maintaining the shape of the tulip flame. At $\phi < 1.0$ for the C–C and $\phi < 1.2$ for the C–C, the tulip flame loses the symmetric shape and turns into a concave flame. It is observed that the flame speed increases with increasing ϕ and the time of flame inversion decreases with increasing ϕ. The flame speed is higher in the D–C compared to the C–C. The flame inversion position and time are compared for different ϕ and for all the channels (D–C, C–C, and straight channel). The flame inversion occurs at approximately halfway of the channel and takes about 1/3rd of the total time of the flame propagation. The flame front during the early stage, in the C–C, takes an elliptical shape and adapts to the shape of the combustion chamber.