Abstract

Laminar burning velocity is a fundamental property of a fuel-air mixture at a given pressure, temperature and equivalence ratio. Many practical combustion appliance designs are based on the laminar burning velocity. It is also a strong candidate to validate or develop chemical kinetic models. The laminar burning velocity is also an important input in modelling turbulent premixed combustion in spark ignition engines. Therefore, its accurate measurement is necessary. The constant volume method is the only technique suitable for determining laminar burning velocity at engine-relevant thermodynamic conditions. Values of laminar burning velocity obtained by the conventional constant volume method suffer from the inaccuracies induced by the weak burned gas mass fraction model and the effect of flame stretch. Direct measurement of the flame radius along with pressure-time trace can result in accurate determination of laminar burning velocity in constant volume method. This motivates the present work to look closely at the constant volume method with a view to improve its accuracy/eliminate its weaknesses.

A spherical chamber would be the best choice for the constant volume method, as in such chambers, the flame remains spherical throughout the combustion. However, full optical access in a spherical chamber may produce lens effect due to the curvature of chamber walls, and would need an optical correction to get the correct flame radius. Spherical transparent chambers are also difficult to fabricate. The remedy for this is the use of flat optical windows. Use of flat optical windows in a spherical chamber restricts the useful range of the flame radius-time data. The other alternative is to the use a cylindrical chamber with full flat optical windows. Such a combustion chamber gives direct visual access to the entire range of flame radii in the chamber, and can also help in detecting the onset of cellularity. A cylindrical combustion chamber with full optical access is also easy to fabricate.

Since the flame in a cylindrical vessel does not remain spherical throughout the period of propagation, the end-view radius obtained during the experiment cannot be used directly to compute the actual burned gas volume and flame surface area. The current work proposes a new methodology for determining accurate values of laminar burning velocity in a cylindrical vessel using constant volume method. A comprehensive numerical simulation of constant volume combustion in a cylindrical and spherical chamber is performed using computational fluid dynamics (CFD). Two normalized relations in a cylindrical vessel are developed using CFD simulations. The relationship obtained by numerical simulation between the normalized

radius of the end-view of the flame, $\left(R_{f,end-view}/R_c\right)$ and the normalized burned gas volume (V_b/V_t) as well as the normalized flame surface area $\left(A_f/A_t\right)$ in a cylindrical chamber is found to be purely geometric, and hence is independent of the fuel-air mixture and chamber size, so long as its aspect ratio is unity. Using these relationships, end-view of flame radius, $R_{f,end-view}$, can be mapped to correct burned gas volume and flame surface area in a cylindrical vessel of any size. Then, using burned gas volume, flame surface area and pressure-time trace, laminar burning velocity can be accurately calculated at each location of the flame without the need for a model for burned gas volume.

Firstly, the pressure-time trace and end-view flame radius obtained from numerical simulations, in combination with the mapping approach, are used to calculate laminar burning velocity using constant volume method. The obtained values of laminar burning velocity in a cylindrical vessel are identical to those obtained numerically in a spherical vessel. Second, using the proposed method, obtained values of laminar burning velocity are also corrected for flame stretch. A stretch-correction methodology requires the values of laminar burning velocity with different stretch rates at a given target state (p, T) of the mixture, for extrapolating the laminar burning velocity to zero stretch. Stretch-corrected values of laminar burning velocity obtained in a cylindrical vessel for a $H_2 + O_2$ −diluent mixture at various equivalence ratios are in good agreement with those obtained in a spherical chamber.

The new methodology proposed using numerical simulation is demonstrated for experimental data for methane-air mixture. This starts with developing a new cylindrical combustion chamber of volume 10.86 litre with full optical access and heating arrangement. Using the experimentally recorded pressure-time trace, end-view of flame radius and mapping methodology, the laminar burning velocity for a stoichiometric methane-air mixture is determined using the constant volume method, and the results agree well with those of a previously published study. The present work also demonstrates the stretch-correction method, originally proposed by the author's research group, for methane-air flames for pressures up to 2.5 bar, for equivalence ratio 0.8 – 1.2. Thus, the present work significantly reduces the main drawbacks of the constant volume method, making the method a candidate for accurate determination of laminar burning velocity.