Laminar burning velocities of rich ethylene / air flames

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This work investigates premixed ethylene / air flames under fuel lean and rich conditions over the equivalence ratio range of $\Phi = 0.7 - 2.5$. The laminar burning velocities were measured with the heat flux method at atmospheric pressure and unburnt gas temperatures of 298 K. The experiments were compared against predictions using two different kinetic models. The experimental and simulated laminar flames do confirm to the fuel lean conditions, but there are some notable discrepancies under fuel rich conditions.

Introduction

The laminar burning velocity S_L of a given mixture of fuel and oxidizer is an important parameter to characterize premixed flames. S_L is not only a fundamental parameter to calculate properties of turbulent flames, it is also an important target for the development of chemical kinetic mechanisms. Under fuel rich conditions it has relevance when simulating soot formation in burner stabilized flames. Many experiments on soot formation have been conducted in fuel-rich burner stabilized ethylene flames. Therefore an interest exists in experimental data for laminar burning velocity, in particular in fuel-rich ethylene flames. Botha and Spalding [1] had proposed to determine the adiabatic burning velocity of a burner stabilized flat flame by means of extrapolation to zero heat loss. In 1993, de Goey and van Maaren [2, 3] improved the method and developed the heat flux method for determining the adiabatic burning velocity by means of interpolation to zero heat loss. The advantage of the heat flux burner is that an unstretched, radially one-dimensional and adiabatic flame can be investigated [4, 5]. In the present work, ethylene / air flames were measured in the heat flux setup. Subsequently, the experimental data were compared against existing data and modelled using two kinetic models.

Experimental setup

The laminar burning velocity of premixed ethylene / air flames at atmospheric pressure and initial gas temperatures of T = 298 K were determined using the heat flux method. The flames were investigated over the equivalence ratio range of $\Phi = 0.7 - 2.5$. The experimental burner was prepared by the Department of Mechanical Engineering, Eindhoven University of Technology. It mainly consists of a perforated plate burner, where the flame stabilizes above a 2 mm thick brass burner plate. The plate has a diameter of 30 mm and is perforated with small holes of 0.5 mm diameter at 0.7 mm pitch [4, 5]. From the upstream side, eight type-T thermocouples are precisely soldered into selected, radially positioned small holes on the perforated burner plate. The thermocouples measure the temperature distribution which determines the net heat flux [5] and help to verify the axis-symmetry of the temperature distribution on the burner plate. The burner head and plenum chamber has heating and cooling jackets respectively to keep the temperature constant. During experiments, the hot water temperature flowing through the heating jacket was retained at 358 K and the water flowing through the cooling jacket of the plenum chamber was retained at 298 K by different thermostat water bath supplies. The flame stabilizes on the burner by losing heat to the burner surface and this

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loss of heat is compensated by the unburnt gas mixture. If the unburnt gas velocity U_G, is higher than the adiabatic laminar flame speed S_L (super-adiabatic condition), the net heat flux is negative and temperature at the centre of burner plate is cooler than the heating jacket temperature [6]. If U_G is lower than S_L (sub-adiabatic condition), the heat flux is positive and temperature at the centre of the burner plate is higher than the heating jacket temperature. For adiabatic conditions, the temperature distribution over the perforated burner plate is uniform and equal to temperature of heating jacket, thus the net heat flux become zero. The laminar burning velocity can be found by varying the velocity of the unburned gas for a given gas mixture until a constant temperature distribution is reached. We follow the procedure suggested by Bosschaart et al. [5] to find the laminar burning velocity.

We analysed the possible sources of data inaccuracy. The largest error in the measured laminar flame speeds results from errors in measuring the fuel-air equivalence ratio. The error in the fuel-air equivalence ratio is defined by the accuracy of the mass flow controllers. This is in agreement with prior estimations by other research teams.

Modelling

The experimental results in the present work were simulated using two kinetic models: the latest reaction scheme developed at the BTU [7] and Aramco 2.0 [8]. The first model is based on a series of previous developments [9, 10, 11]. In the BTU model the n-Heptane submechanism has been removed and the scheme contains 249 species and 1505 reactions. The model "Aramco 2.0" [8] contains 493 species and 2716 reactions. The modelling was performed with LOGEsoft 1.08.00 [12] using the premixed laminar flame speed module.

Results and discussion

The experimental and simulated laminar burning velocities of ethylene / air mixtures are shown in figure 1. The laminar burning velocities obtained in this studies, along with there uncertainties, are compared against other published experimental data for $\Phi = 0.7 - 1.8$ at the same conditions in figure 1 (a).

In general there is a good agreement between the present velocities and those presented by Park et al. [13] using the counterflow method (CF). For fuel-lean conditions our data show lower flame velocities than other measurement. For fuel rich conditions from 1.0 - 1.3 there is a close match with experiments by Jomaas et al. [14] and Hassan et al. [15], which were using the spherically expanding (SE) method. The experimental data are slightly lower compared to those presented by Kumar et al. [16]. Experimental and simulated S_L for C_2H_4 / air flames are shown in Figure 1 (b). The computed S_L using the BTU Mechanism are in good agreement with the present data for $\Phi < 1.6$. For fuel rich conditions the deviation increase between the computed results of both mechanism and experimental data. The Aramco mechanism agrees for fuel-lean conditions better with data from [16], and for fuel-rich conditions with the data presented in this work.

The error in the laminar flame velocity is most sensitive on the error in the fuel-air equivalence ratio. The sensitivity of the equivalence ratio on the flame velocities is highest at the fuel-lean and fuel rich turning points of the bell shaped curve. For fuel rich conditions, with very low mass flow velocities – especially for air – we observe very high errors in the fuel / air equivalence ratio. However, the sensitivity of this error on flame velocity is low. The relative error in burning velocity is however still high. A better calibration of the mass flow controllers is needed for these conditions to make the data conclusive.
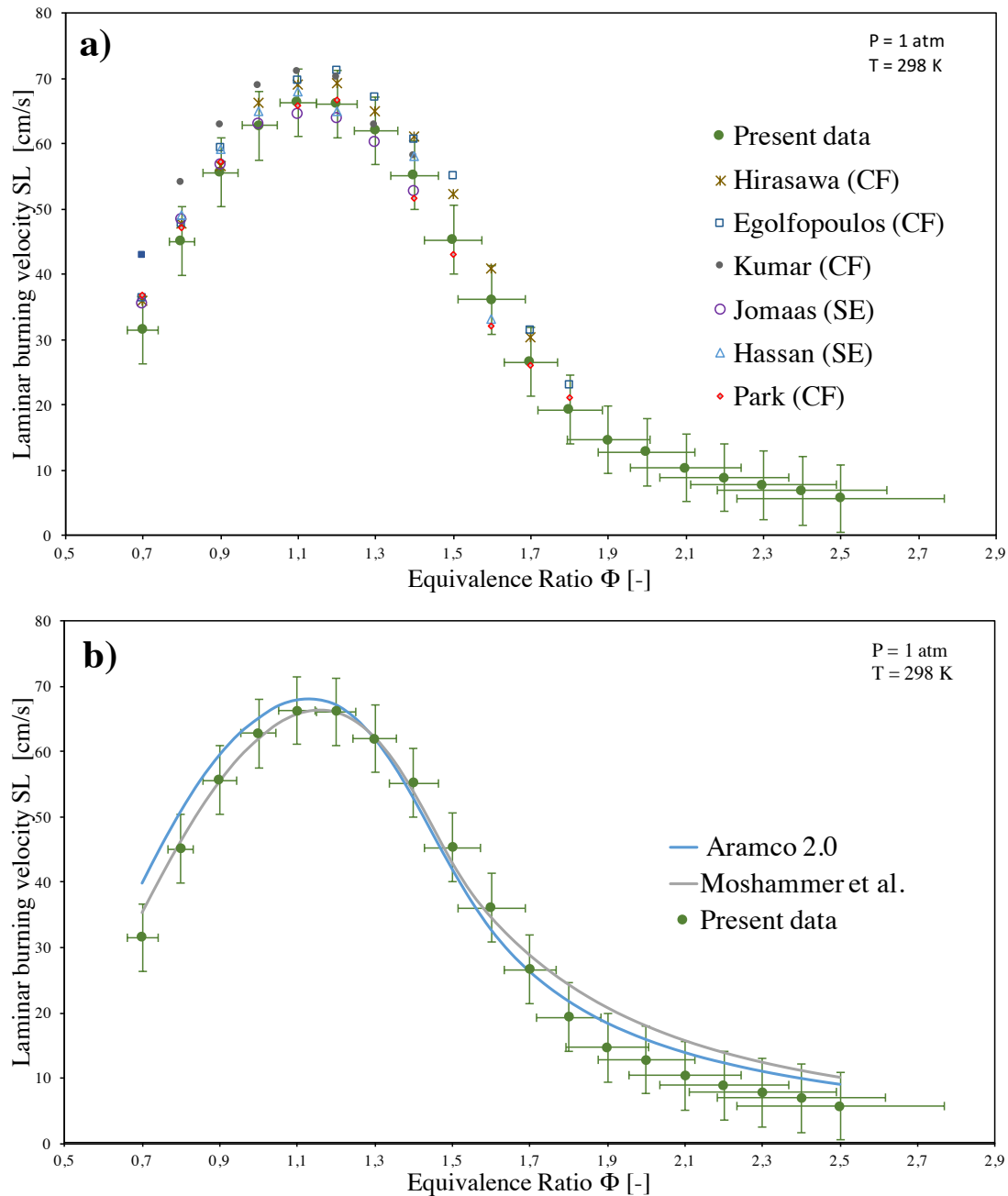
Fig. 1 Laminar burning velocity S_L of premixed ethylene / air flames at temperature T = 298 K and atmospheric pressure P = 1 atm with error bars. Fig. (a) shows the comparison with published experimental data and (b) with predictions of the kinetic models from [7] and [8].

Conclusion

The laminar burning velocities of ethylene / air flames at P = 1 atm and initial gas temperatures of 298 K were determined using the heat flux method. Comparison of the new experimental data, data from literature and different kinetic models was carried out. For fuel lean conditions, there is a good agreement between literature data, the present results and both models. Both models are within the experimental uncertainty for rich flames. The obtained laminar flame speed in particular for rich conditions are associated with a high uncertainty which will be reduced in the near future.

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