

Measurements of the laminar burning velocities of ethanol-water-air flames

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Introduction

Next to the use of fossil fuels, other fuels are increasingly becoming the focus of public discussion. Reasons for the search for alternatives are the limited crude oil reserves, but also the environmental pollution and emissions that occur during the combustion of mineral oil products and their additives. An alternative to diesel or gasoline offer bio-alcohols such as ethanol. The production by distillation of pure ethanol is very costly. Furthermore, ethanol, such as other alcohols, absorbs water from the air contained moisture. To understand the impact of water content in ethanol, either due to long term storage or due to water injection strategies during combustion, extensive laminar flame velocity (S_L) experiments have been performed.

At the present time, the combustion society is concerned with the development of mechanisms to make the most accurate predictive responses possible. Liang et al. [1] determined laminar flame speeds for ethanol-water-air mixtures and investigated the effect of water on S_L . Liang et al. [1] studied different water contents (10 – 30% water) in premixed ethanol-air flames at initial temperature of 383 K using a combustion chamber with central ignition. Currently, the dissertation by Haas-Wittmüß [2] provides results for premixed ethanol-water flames containing up to 20% water by volume. The experiments of Haas-Wittmüß [2] were carried out using the heat flux method and at different temperatures.

The aim of the present work is to measure S_L of ethanol-water-air flames using the heat flux method and to provide the newly obtained experimental data. Furthermore, these data are used to compare with predictions of three models: the mechanism developed by Moshhammer et al. [3], Shrestha et al. [4] and the model of the group of Konnov [5]. This work is a cooperation between the BTU and the Lund University. Experiments have been performed at Lund University.

Experimental details

The laminar burning velocity of ethanol-water-air flames at atmospheric pressure and initial gas temperatures of $T = 358$ K was measured with the heat flux method. The mixture of ethanol-water-air contained 0%, 10%, 20%, 30% and 40% water by mole and the equivalence ratio (ϕ) range was varied from 0.7 to 1.4. The purity of the ethanol was above 99% (absolute ethanol from VWR Chemicals) and the oxidizer was synthetic air (21% O_2 + 79% N_2). The experimental burner consists of a perforated plate burner, where the flame stabilizes above a 2 mm thick brass burner plate. The perforated burner stabilized the flat adiabatic flames on the 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. The burner head and plenum chamber has heating and cooling jackets, respectively, to keep the temperature constant that was achieved using two water baths. Mass flow controllers have been used to regulate the flow rates of the oxidizer and the fuel.

The liquid fuel mixture (ethanol and water) was vaporized using an evaporator. The laminar burning velocity was found by varying the velocity of the unburned gas for a given gas mixture until a constant temperature distribution in the burner plate is reached.

Modeling details

Detailed kinetics models have been compared to the experimental data from this study. The experimental data were simulated using three kinetic models: the reaction scheme developed by Moshhammer et al. [3], Shrestha et al. [4] and a model derived from the group of Konnov [5]. The first model is based on a series of previous developments [6–8]. The model of Shrestha et al. [4] focused on the oxidation of methanol and ethanol and their fuel interaction with NO_x (NO and NO_2) chemistry. The modelling of both were performed with LOGEresearch [9] using the premixed laminar flame speed module. The last model, a mechanism of Konnov and coworkers [5] based on the Konnov mechanism version 0.6 [10] and include extensive updates and validation for methanol. The numerical calculations for this model were conducted with CHEMKIN-PRO software package.

Results and discussion

The laminar flame speeds of ethanol-air at $T = 358 \text{ K}$ and at atmospheric pressure were measured. The S_L are measured for different equivalence ratios from $\phi = 0.7$ to 1.4, as present in Figure 1 (left). Figure 1 (left) compares the present data including error bars with published data and shows good agreement. The overall accuracy for S_L was around $\pm 1 \text{ cm/s}$. At lean and near stoichiometric conditions the obtained S_L is slightly faster in comparison to other experiments. The S_L measured by Sileghem et al. [11] agrees very good for lean and rich mixtures with the present measurements. At stoichiometric mixtures it is observed that the present S_L are (systematically) higher, by about $2 - 3 \text{ cm/s}$ at between $\phi = 0.9 - 1.1$. For rich conditions the results of Dirrenberger et al. [12], Bradley et al. [13] and Sileghem et al. [11] are within the present measurements. At equivalence ratio of 1.3 the present data found to be close to the data of Dirrenberger et al. [12] and Sileghem et al. [11] with a difference below 1 cm/s . Data from Bradley et al. [13] are in good agreement with the data of Dirrenberger et al. [12] for rich conditions. The S_L of Liao et al. [14] are generally slower at all conditions than the presented results. On average, the speed is about 6 cm/s slower than the present data and at $\phi = 0.9$, there is an underprediction by around 10 cm/s . It should be noted that Liao et al. [14] used a different method (combustion bomb) to determine the S_L . The Figure 1 (left) shows also that the repetition of the S_L of ethanol-air flames are in the range of error bars, the difference between the S_L is not more than $\pm 0.7 \text{ cm/s}$.

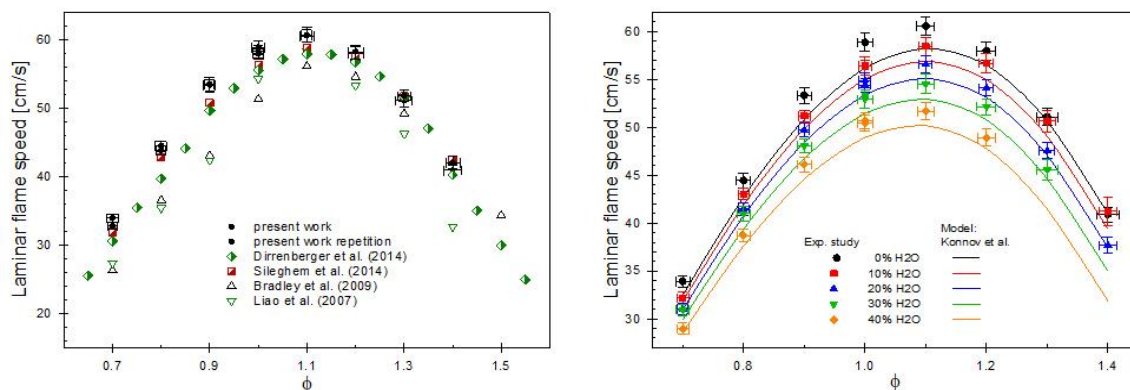


Figure 1: S_L of ethanol-water-air flames at $T = 358 \text{ K}$ and atmospheric pressure in comparison with published experimental data [11–14] (left) and modelling results (right). The simulations are performed with the Konnov mechanism version 0.7 model [5]. Symbols: experiments, lines: modeling.

The laminar burning velocities obtained in this study, along with their uncertainties, are compared against the predictions of three models, seen in Figure 1 (right) and Figure 2. It is seen that the experimental laminar flame speed (S_L) for ethanol-water-air mixtures decrease with increasing the water content 10 – 40%. General the experimental data for S_L show a better agreement with the model of Konnov et al. [5]. The model of Konnov et al. [5] leads to a slight underestimation of the S_L in particular at rich conditions by below 2 cm/s. A very close agreement is observed for lean mixtures. The largest deviation is seen close to the stoichiometric mixtures and the maximum S_L for the equivalence ratio of 1.1 for pure ethanol by around 2.5 cm/s.

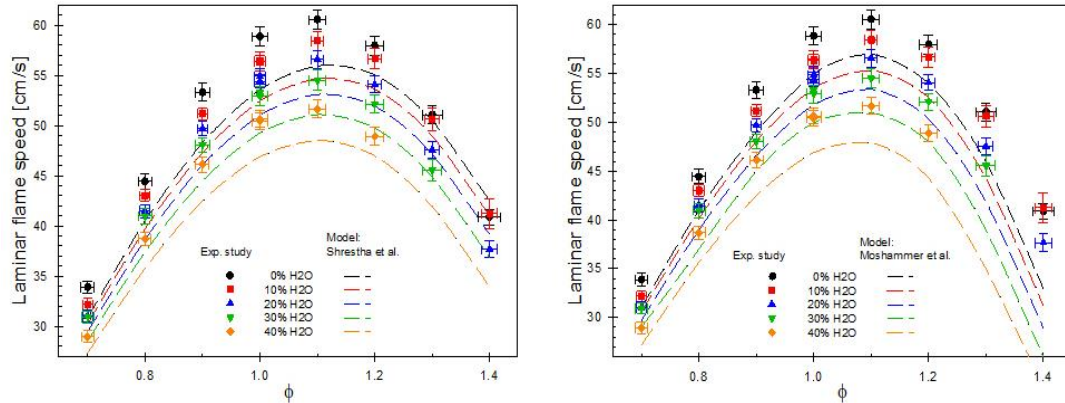


Figure 2: S_L of ethanol-water-air flames at $T = 358\text{ K}$ and atmospheric pressure in comparison to the simulation data of Moshhammer et al. [3] (left) and Shrestha et al. [4] (right). Symbols: experiments, lines: modeling.

Figure 2 (left) displays the experimental results for ethanol-water-air flames, which are in good agreement with the model [3] at lean conditions with a underprediction of around 3 cm/s. For the dilution of 10 % water the model tends to underpredict the experimental S_L by around 10 cm/s. For equivalence ratio above 0.9 the deviation between the model of Moshhammer et al. [3] and experimental data increases. Note that the model of Moshhammer et al. [3] shows the largest deviation compared to the other models. Finally, Figure 2 (right) compares the present data with the model of Shrestha et al. [4]. The model of Shrestha et al. [4] predicts the experimental results very well at rich mixtures with the difference in S_L being around 2 cm/s. At lean- and stoichiometric conditions this model shows larger deviations than the model of Konnov et al. [5].

Conclusions

The laminar burning velocities of ethanol-water-air flames at atmospheric pressure and initial temperatures of 358 K were determined using the heat flux method. The present measurements were performed on the experimental setup at the Lund University. Comparison of the present experimental data, data from literature and different kinetic models was carried out. The present data were compared to published data and predictions of three detailed reaction schemes developed by Moshhammer et al. [3], Shrestha et al. [4] and a model derived from the group of Konnov [5]. The S_L measured by Sileghem et al. [11] and Dirrenberger et al. [12] shows a close match with present experiments, which were obtained using the same method (heat flux method).

The kinetic model of the group of Konnov et al. [5], which contains updated methanol sub-mechanism agrees best with present data. The model of Shrestha et al. [4] displays good agreement at lean and rich conditions with a underprediction at stoichiometric mixtures and the prediction of Moshhammer et al. [3] shows the worst match with the present data. All models show an underprediction of S_L at stoichiometric conditions.

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