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LAMINAR BURNING VELOCITIES OF METHYL FORMATE + AIR AT ROOM AND ELEVATED TEMPERATURES

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Summary

Laminar burning velocities of methyl formate + air were measured using the heat flux method in an initial gas mixture temperature range of 298-348 K and at atmospheric pressure. Good agreement to previous experimental data of Wang et al. [1] was found at lean and rich conditions. Modelling performed by Wang et al. [1] using the mechanism of Dooley et al. [2] is in good agreement with the present data at lean conditions with increasing deviations towards stoichiometric and richer flames. The temperature dependence of the laminar burning velocity is also reported.

Introduction

With the increasing concerns related to global warming the search for fuels with lower emissions of greenhouse gases, particulates, nitrogen oxides and carbon monoxide, is of importance.

Biodiesel are fuels produced from renewable sources as vegetable oil or animal fat. The United States Environmental Protection Agency found that the use of biodiesel from soy oil and waste grease lowered the greenhouse emissions on average by 57 and 86% compared to ordinary diesel [3].

As biodiesel consist of methyl-esters of varying lengths it is challenging to develop chemical kinetic mechanisms for these fuels. These mechanisms are of hierarchal structure and to successfully reproduce experimental results the sub-mechanisms of intermediate species must be appropriately designed.

Methyl formate ($C_2H_4O_2$), has gained attention throughout the years as it is the smallest methyl ester and thus the foundation to a biodiesel fuel mechanisms. Research investigating the processes of its oxidation and pyrolysis, using experiments and modelling, have been performed by a few groups, e.g. [1, 2].

The laminar burning velocity of methyl formate has previously been investigated by Wang et al. [1] and Dooley et al [2]. Wang et al. used a counter flow setup with unburned gas mixture temperatures of 298 K and 333 K. Flow velocity measurements were made using particle image velocimetry and nonlinear extrapolation to zero strain rates were made to derive the laminar burning velocity. Measurements of Dooley et al. were performed using a high pressure chamber at 295 K. Spherically expanding flames were monitored using high speed Schlieren photography. Linear extrapolation to zero stretch rate was performed to derive the laminar burning velocity.

Comparison of the datasets of Wang et al. and Dooley et al. at room temperature clearly shows a good agreement for lean and stoichiometric conditions but an increased deviation is apparent at richer conditions.

To investigate this deviation further and evaluate the temperature dependence, the laminar burning velocities of methyl formate and air were measured at several temperatures in the range 298-348 K and atmospheric pressure, using the heat flux method. This method generates a stretch free flame and the laminar burning velocity is determined directly. The new experimental burning velocities are compared to previously published data [1, 2] and modelling performed by Wang et al [1].

Experimental details

The laminar burning velocities were measured at atmospheric pressure using the heat flux setup seen in Fig. 1. As shown in the figure the setup consists of a mixing panel for gases and liquid, an evaporator to transfer the fuel to the gas phase, and a burner where burner head temperature and plenum chamber temperature are set by separate thermostated water baths. The unburned gas temperature was set to 298, 318, 338 and 348 K over a wide range of equivalence ratios, typically from 0.7 till 1.6.

The heat flux burner generates a flat, stretch-free flame that is ideal for burning velocity determination as it compensates for the heat loss required for flame stabilization [4]. This is achieved by heating the burner plate to a temperature higher than the unburned gas, in the present study 368 K. The unburned gas mixture is

heated as it passes through the plate and the heat loss of the flame is compensated for.

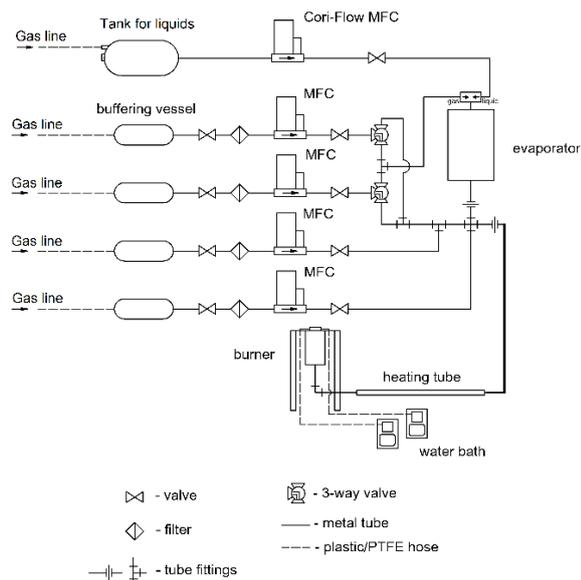


Figure 1. A schematic of the heat flux setup

To measure the laminar burning velocity, the flame must be adiabatic which is indicated by zero net heat loss of the flame to the burner plate. By measuring the temperature distribution in the plate the adiabatic conditions are found by carefully adjusting the unburned gas velocity while monitoring the temperature profile. The shape of the profile is generally parabolic and the adiabatic state is found when the profile is flat.

Results and discussions

Laminar burning velocities

Figure 2 presents the laminar burning velocity of methyl formate and air at 298 and 338 K compared to the experimental values of Wang et al. [1] and Dooley et al. [2]. The experimental data of Dooley et al. were obtained at 295 K and the measurements of Wang et al. were performed at 298 and 333 K.

At the lower temperatures there is a relatively good agreement between the present experimental results and those of Wang et al. for lean and rich conditions. Close to stoichiometric there are some discrepancies but the results are within overlapping error bars.

The laminar burning velocities presented by Dooley et al. are in good agreement at equivalence ratios lower than 1.1 but there is an increased deviation towards richer conditions. At equivalence ratio 1.6 the discrepancy between the present results and Dooley et al. is roughly 6.5 cm/s.

At 338 K the laminar burning velocities are compared to the experimental data of Wang et al., determined at 333K. There is a good agreement throughout the equivalence ratio range with only a slight tendency of Wang et al. data to be lower at lean conditions.

The model of Dooley et al. [2], implemented by Wang et al. [1], is in good agreement with the present experimental results at 298 K at lean conditions. As the flame becomes richer there is an increased deviation and the model over-predicts the burning velocities. It should be noted that the model do reproduce the laminar burning velocities experimentally determined by Dooley et al. also at rich conditions.

At 338 K there is a similar trend as the model successfully reproduces experiments at equivalence ratios below 1.2. However as the conditions becomes richer the model over predicts the experimental results.

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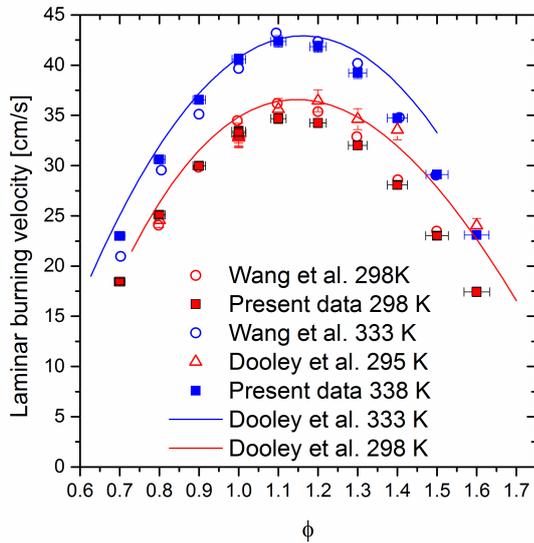


Figure 2. Laminar burning velocities of methyl formate + air. Symbols: experiments, lines: modelling using the mechanism of Dooley et al. [2]. Red and blue squares are present data at 298 K and 338 K; red and blue circles, Wang et al. [1] at 298 K and 333K. Red triangles Dooley et al. [2] at 295 K.

Temperature dependence

As previously mentioned the laminar burning velocity was determined at temperatures between 298 and 348 K. The temperature dependence of the laminar burning velocity can be described by the equation

$$S_L = S_{L,0} (T/T_0)^\alpha$$

where $S_{L,0}$ is the burning velocity at temperature T_0 , defined as the reference temperature, 298 K in the present work.

By plotting the laminar burning velocity as a function of temperature on a log-log scale the power exponent α was obtained. Figure 3 presents the power exponent α as a function of equivalence ratio. A local minimum is observed close to stoichiometric conditions.

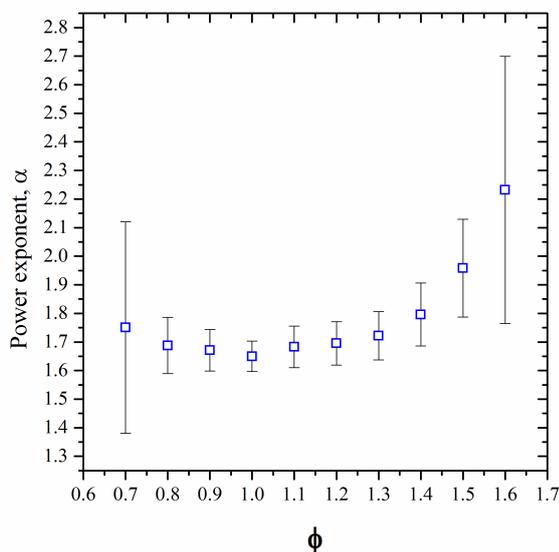


Figure 3. The power exponent as a function of equivalence ratio.

Conclusions

The laminar burning velocities of methyl formate and air have been determined at temperatures in the range 298-348 K. Good agreement with previous experimental results of Wang et al. [1] was observed.

The model of Dooley et al. [2] over predicts the laminar burning velocities at rich conditions, but is in good agreement with experimental results from lean flames.

Acknowledgements

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