Physics and chemistry behind laminar flame propagation

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Combustion is by far the most important energy conversion process. According to recent figures >70% of the global energy utilization involves combustion. The adiabatic laminar burning velocity is a fundamental parameter of any combustible mixture, which depends on the stoichiometric ratio, pressure and temperature. The laminar burning velocity at standard conditions, i.e. atmospheric pressure and initial temperature of 298 K is invaluable for characterization of combustion properties of the given fuel, for understanding of the underlying chemistry, validation of kinetic models, calibration of turbulent flame models, etc. However, in general applications, from domestic appliances to engines and gas turbines, pressure and initial temperature of the mixture are often higher than standard ones. It is therefore important to quantify the effects of pressure and initial temperature on the adiabatic laminar burning velocity of practical fuels.

An exhaustive literature survey was performed to study the numerous existing laminar burning velocity correlations for its temperature and pressure dependence. The effect of temperature on the adiabatic laminar burning velocities was often interpreted using correlation $S_L = S_{L0} (T/T_0)^{\alpha}$. Experimental data and proposed empirical expressions for α as a function of equivalence ratio were summarized. They were compared with predictions of detailed kinetic models in hydrogen, methane, methanol, ethanol and other flames. Unexpected non-monotonic behavior of α was found in rich methane + air flames. Modeling results are further examined using sensitivity analysis to elucidate the reason of particular dependences of the power exponent α on equivalence ratio.

In spite of the large amount of research devoted to the evaluation of the high pressure dependence of methane + air flame burning velocity, there still exists a large uncertainty in the data for various reasons. It is indicated from the literature that many of the deduced correlations use stretched laminar burning velocity results. The effect of pressure on the adiabatic laminar burning velocities was often interpreted using correlation $S_L = S_{L0} (P/P_0)^{\beta}$. Its rationale is based on early theories of flame propagation. The power exponent β depends on the mixture composition and is different for different pressure ranges. Numerical simulations were performed using two detailed chemical mechanisms and compared with available measurements. Both recent experimental results and modelling show non-monotonic behavior of β in rich methane + air flames, which is related to similar peculiarities of the temperature dependence. An interplay of physical and chemical aspects in the flame propagation is highlighted.