EFFECTS OF H_2 CONCENTRATION AND MIXTURE PRESSURE ON PROPAGATING LAMINAR AND TURBULENT H_2-CH_4-AIR AND H_2-CO-AIR PREMIXED FLAMES

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論 文 名　：Effects of H_2 Concentration and Mixture Pressure on Propagating Laminar and Turbulent H_2-CH_4-Air and H_2-CO-Air Premixed Flames
（水素の濃度と混合気圧力が H_2-CH_4-Air と H_2-CO-Air の層流および乱流予混合伝播火炎に及ぼす影響）

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論　文　内　容　の　要　旨

Alternative fuels for internal combustion engines have attracted growing interests in recent years due to the demand to reduce overdependence on conventional fossil fuels and reduce pollutant emission associated with fossil fuel combustion. Hydrogen-methane and hydrogen-carbon monoxide binary fuels are considered alternative fuels. Because hydrogen has a large burning velocity in comparison to conventional fossil fuels and no carbon content, an increase in the hydrogen concentration in the binary fuels leads to an increase in their burning velocity and an increase in their H/C ratio. The fundamental flame properties such as the burning velocities and the Markstein length affect the performance of internal combustion engines. Therefore, there has been a series of studies on the fundamental combustion characteristics of H_2-CH_4-air and H_2-CO-air mixtures in order to evaluate their potentials as alternative fuels in engines. However, most of the studies examined the effects of a small concentration of hydrogen in the binary fuels. Some studies that examined a wide range of hydrogen concentration in H_2-CH_4-air flames observed that the flame characteristics may vary non-linearly with hydrogen concentration. For instance, the Markstein length was found to vary non-monotonically with hydrogen concentration but this behaviour has not been fully understood. Furthermore, there are few studies on the effect of mixture pressure on the outwardly propagating flames of these binary fuels, consequently variation of the fundamental flame properties with mixture pressure has not been fully understood.

This dissertation presents new data on the laminar and turbulent burning velocities and Markstein lengths of outwardly propagating H_2-CH_4-air and H_2-CO-air flames at 350 K that cover a range of conditions where data in literature is sparse. Experiments, numerical simulations and theoretical analysis were conducted to understand the studied characteristics of the flames. The mole fraction of hydrogen in the binary fuels was varied from 0 to 1.0 at mixture pressures of 0.10, 0.25 and 0.50 MPa in order to clarify the effects of hydrogen concentration and mixture pressure on the propagation of the flames.

This dissertation consists of 7 chapters which can be summarized as follows.

In chapter 1, the background of the study is introduced. Furthermore, a review of past literature is presented in order to show the extent of work that has already been done and clarify the motivations of the present study. Finally, the objectives of this study is discussed.

In chapter 2, the research methodology is elaborately explained. This involves a description of the experimental and numerical methodologies and methods of data processing and analysis.

In chapter 3, the experimental and numerical results of the laminar burning velocities of the flames are presented and discussed. The laminar burning velocity of H_2-CH_4-air flames was evaluated at equivalence ratios, ϕ, of 0.8, 1.0 and 1.2 and found to increase non-linearly with hydrogen concentration. The laminar burning velocity at ϕ = 0.8 was further evaluated at 0.10, 0.25 and 0.50 MPa and found to decrease with mixture pressure. As for H_2-CO-air flames, the laminar burning velocity of the stoichiometric mixtures were obtained at the three mixture pressures and found to increase linearly with hydrogen concentration and decrease with mixture pressure. Normalized sensitivity analysis showed that reactions involving H and OH radicals were the most important reactions to the laminar burning velocity in the lean H_2-CH_4-air flames.

In chapter 4, the sensitivities of the flames to stretch are presented. The Markstein lengths, the Zel'dovich numbers and the effective Lewis numbers of H_2-CH_4-air flames were evaluated. An asymptotic expression for the Markstein length was slightly modified for the binary fuel by modifying the effective Lewis number. The non-monotonic variation in the Markstein length with hydrogen concentration was found to be predominantly due to a non-monotonic variation in the effective Lewis number, while the change in the sign of the Markstein length of the lean flames at elevated pressure was found to be due to an increase in the Zel'dovich number. Furthermore, the chapter presents and discusses the variation of the Markstein length and the Markstein number of H_2-CO-air flame with hydrogen concentration and mixture pressure.

In chapter 5, cellular instability in the flames are discussed. The variation of the propensity of flame instability with hydrogen concentration in H_2-CH_4-air flames at ϕ = 0.8 and 1.0 was found to vary non-monotonically, corresponding to the variation in the Markstein lengths. It was deduced that thermo-diffusive effects may contribute to the enhancement of cellular instability with an increase in mixture pressure in the lean flames in this study as indicated by the increase in the Zel'dovich number. Cellular instability also was found to increase with mixture pressure in the stoichiometric H_2-CO-air flames.

In chapter 6, measurements of turbulent burning velocities of the stoichiometric flames are presented. The unstretched laminar burning velocities of H_2-CH_4-air and H_2-CO-air flames were found to predominantly influence the increase in their turbulent burning velocities with hydrogen mole fraction at a constant turbulence intensity. Thermo-diffusive effects on the turbulent burning velocity was found to be less significant than the effect of relative turbulence intensity with variation in hydrogen fraction. The turbulent burning velocity of H_2-CO-air flames was found to increase with mixture pressure.

In chapter 7, the summary and conclusions are presented.