THE INFLUENCE OF PRESSURE ON THE SELF-IGNITION DELAY OF METHANE–HYDROGEN–AIR MIXTURES

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Abstract: Experimental study by the static reactor method and kinetic modeling of self-ignition delay of stoichiometric methane–hydrogen–air mixtures of different composition in the temperature range 700–1000 K and initial pressures of 1–15 atm corresponding to the possibility of undesirable self-ignition in spark-ignition internal combustion engines were carried out. It was found that hydrogen additives to methane less than 50% do not significantly affect the ignition of such mixtures, that is, their resistance to the occurrence of detonation combustion modes. A strong difference in the behavior of mixtures with high and low hydrogen content is shown which is a consequence of significant differences in the low-temperature ($T < 900$ K) mechanisms of ignition and oxidation of methane and hydrogen. In the region of $T_0 = 800$–1000 K for mixtures with hydrogen content of less than 50%, increasing the pressure monotonously reduces the ignition delay. For mixtures with high hydrogen content, this dependence becomes nonmonotonic with a maximum at $P_0 \approx 3$ atm: the pressure increase to 3 atm leads to increase of ignition delay, and upon further pressure increase, the ignition delay begins to decrease monotonically.

Keywords: methane; hydrogen; self-ignition delay; internal combustion engine

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Figure Captions

Figure 1 Temperature dependences of self-ignition delay time of stoichiometric methane–hydrogen–air mixtures: (*a*) $P_0 = 1.0$–1.1 atm; (*b*) $P_0 = 3.0$–3.2 atm; *1* — 100% CH_4; *2* — 97.5% CH_4 + 2.5% H_2; *3* — 95% CH_4 + 5% H_2; *4* — 90% CH_4 + + 10% H_2; *5* — 80% CH_4 + 20% H_2; *6* — 70% CH_4 + 30% H_2; *7* — 60% CH_4 + 40% H_2; and *8* — 50% CH_4 + 50% H_2

Figure 2 Comparison of ignition delays of stoichiometric methane–hydrogen–air mixtures at an initial pressure of 1 atm (solid lines) and 3 atm (dashed lines): (*a*) hydrogen concentration 0%–10% (*1* — 100% CH_4; *2* — 97.5% CH_4 + 2.5% H_2; *3* — 95% CH_4 + 5% H_2; and *4* — 90% CH_4 + 10% H_2); and (*b*) hydrogen concentration 20%–50% (*5* — 80% CH_4 + 20% H_2; *6* — 70% CH_4 + 30% H_2; *7* — 60% CH_4 + 40% H_2; and *8* — 50% CH_4 + 50% H_2)

Figure 3 The dependence of the ignition delay time of stoichiometric methane–hydrogen–air mixtures at pressures of 1 (*1*) and 3 atm (*2*) and temperature of 900 K on the concentration of hydrogen

Figure 4 Dependence of effective activation energy E_{ef} (*a*) and preexponential factor A of the ignition delay time (*b*) of stoichiometric methane–hydrogen–air mixtures at pressures of 1 (*1*) and 3 atm (*2*) on the hydrogen concentration

Figure 5 Comparison of experimental data (symbols) and calculations (lines) of self-ignition delay time for stoichiometric mixtures of CH_4–H_2–air at $P_0 = 1$ atm and $\alpha_{\mathrm{H}_2} = 30\%$ (*1*) and at $P_0 = 3$ atm and $\alpha_{\mathrm{H}_2} = 10\%$ (*2*)

Figure 6 The dependence of the self-ignition delay time of stoichiometric mixtures CH_4–H_2–air on the initial temperature at $\alpha_{\mathrm{H}_2} = 20\%$ (*a*) and 80% (*b*): $P_0 = 1$ atm (*1*); 3 (*2*); and $P_0 = 15$ atm (*3*)

Figure 7 The dependence of the self-ignition delay time of stoichiometric mixtures CH_4–H_2–air on the initial temperature at $\alpha_{\mathrm{H}_2} = 0\%$ (*1*), 2% (*2*), 5% (*3*), 10% (*4*), 20% (*5*), and 30% (*6*): (*a*) $P_0 = 1$ atm; (*b*) 3; and (*c*) $P_0 = 15$ atm

Figure 8 The dependence of self-ignition delay time of stoichiometric mixtures CH_4–H_2–air on the initial pressure at $T_0 = 900$ K and different α_{H_2}: *1* — 0%; *2* — 2%; *3* — 5%; *4* — 10%; *5* — 20%; *6* — 30%; *7* — 50%; *8* — 80%; and *9* — 100%

Figure 9 The dependence of the activation energy of the self-ignition delay time of stoichiometric methane–hydrogen–air mixtures on the concentration of hydrogen at $P_0 = 1$ atm: *1* — experimental results ($T_0 = 900$ K); *2*–*4* — calculation at $T_0 = 850$–900 (*2*), 900 (*3*), and 950–1000 K (*4*)

Figure 10 The dependence of the maximum concentration of hydrogen peroxide on the initial temperature at different values of α_{H_2}: *1* — 0%; *2* — 40%; *3* — 70%; *4* — 90%; and *5* — 100%

Figure 11 The dependence of hydrogen concentration (mole fractions X_{H_2}) on time at $T_0 = 900$ K and different values of α_{H_2}: *1* — 10%; *2* — 20%; *3* — 30%; and *4* — 50%

Figure 12 Temperature dependence of the activation energy of the self-ignition delay time of stoichiometric mixtures CH_4–H_2–air at $P_0 = 3$ (*a*) and 15 atm (*b*): *1* — $\alpha_{\mathrm{H}_2} = 20\%$; *2* — 50%; and *3* — $\alpha_{\mathrm{H}_2} = 80\%$

Figure 13 The dependence of the activation energy of the self-ignition delay time of stoichiometric mixtures CH_4–H_2–air on the initial pressure at $\alpha_{\mathrm{H}_2} = 20\%$ (*a*) and 80% (*b*): *1* — $T_0 = 800$ K; *2* — 900; and *3* — $T_0 = 1000$ K

Figure 14 Dependence of the self-ignition delay time of stoichiometric H_2–air mixtures on the initial pressure at $T_0 = 800$ (*1*), 900 (*2*), and 1000 K (*3*)

Table Caption

The effective activation energy of the self-ignition delay time of methane–hydrogen–air mixtures at pressures of 1 and 3 atm

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