DEFLAGRATION-TO-DETONATION TRANSITION IN AIR MIXTURES OF PROPANE–HYDROGEN FUEL

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Abstract: The previously proposed experimental method for evaluating the detonability of fuel–air mixtures, based on measuring the run-up distance L_{DDT} and/or run-up time τ_{DDT} of deflagration-to-detonation transition (DDT) in a standard pulsed detonation tube, was applied to study the DDT in stoichiometric air mixtures of blended propane–hydrogen fuel with a volume fraction of hydrogen x_{H_2} ranging from 0 to 1 under the fixed thermodynamic and gasdynamic conditions. Based on the known data on combustion and self-ignition of such a fuel, it was expected that the DDT run-up distance and time should gradually decrease with hydrogen concentration x_{H_2} and the corresponding dependences should be close to linear. Contrary to expectations, the observed dependences turned out to be nonlinear and, in some cases, nonmonotonic: they exhibit local maxima. Analysis of the results suggests that the observed dependences are a manifestation of the physicochemical properties of the fuel mixtures under study. A change in the design of the flame acceleration section in the detonation tube as a whole does not affect the nature of the obtained dependences: they remain nonlinear, although the nonmonotonicity degenerates. Like other critical phenomena in chemical kinetics, nonmonotonicity can manifest itself only near critical conditions and is obscured by other effects when moving away from the critical conditions.

Keywords: propane–hydrogen fuel; methane–hydrogen fuel; fuel–air mixture; detonability; standard pulsed detonation tube; deflagration-to-detonation transition

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Figure Captions

Figure 1 Three configurations of standard pulsed detonation tube with indication of measuring segments: (*a*) K1; (*b*) K2; and (*c*) K3; $*$ — location of spark plug. Dimensions are in millimeters

Figure 2 Detonation velocity – distance plots for the development of DDT process in detonation tubes of configuration K1 in 5 successive shots in a stoichiometric air mixture of propane–hydrogen fuel with $x_{\mathrm{H}_2} = 0$ (*a*), 0.2 (*b*), 0.4 (*c*), 0.6 (*d*), 0.8 (*e*), and 1 (*f*)

Figure 3 Detonation velocity – distance plots for the development of DDT process in detonation tubes of configuration K2 in 5 successive shots in a stoichiometric air mixture of propane–hydrogen fuel with $x_{\mathrm{H}_2} = 0$ (*a*), 0.2 (*b*), 0.4 (*c*), 0.6 (*d*), 0.8 (*e*), and 1 (*f*)

Figure 4 Detonation velocity – distance plots for the development of DDT process in detonation tubes of configuration K3 in 5 successive shots in a stoichiometric air mixture of propane–hydrogen fuel with $x_{\mathrm{H}_2} = 0$ (*a*), 0.2 (*b*), 0.4 (*c*), 0.6 (*d*), 0.8 (*e*), and 1 (*f*)

Figure 5 Detonation velocity – distance plots for the development of DDT process in detonation tubes of configuration K2 in 5 successive shots in a stoichiometric air mixture of propane–hydrogen fuel with $x_{\mathrm{H}_2} = 0.95$ (*a*), 0.96 (*b*), 0.97 (*c*), 0.98 (*d*), and 0.99 (*e*)

Figure 6 Averaged over 5 successive shots dependences of flame acceleration on the traveled distance during DDT in stoichiometric air mixtures of propane–hydrogen fuel with $x_{\mathrm{H}_2} = 1.0$ (*1*) and 0.99 (*2*) in the detonation tube of configuration K2

Figure 7 Time–distance diagram of DDT process in a stoichiometric air mixture of propane–hydrogen fuel with $x_{\mathrm{H}_2} = 0.4$ in 5 successive shots in the detonation tube of configuration K3

Figure 8 Primary records of pressure sensors (solid curves) and ionization probes (dotted curves) in measuring sections 4 to 17 for one of the shots with a stoichiometric air mixture of propane–hydrogen fuel with $x_{\mathrm{H}_2} = 0.2$ in the detonation tube of configuration K1

Figure 9 Measured DDT run-up distance L_{DDT} (*a*) and run-up time τ_{DDT} (*b*) as functions on hydrogen volume fraction x_{H_2} in stoichiometric air mixtures of propane–hydrogen fuel: *1* — K1; *2* — K2; and *3* — K3. Error bars correspond to the shot-to-shot scatter

Figure 10 Measured DDT run-up distance L_{DDT} (*a*) and run-up time τ_{DDT} (*b*) as functions on hydrogen volume fraction x_{H_2} in stoichiometric air mixtures of methane–hydrogen fuel: *1* — K1; *2* — K2; and *3* — K3

Figure 11 Dependences of the shock wave velocity (left scale) and the time lag of the reaction front from the shock wave (right scale) at the measuring segments upstream the helical section (6–7 (*a*) and 7–8 (*b*)) and inside the helical section (7–8 (*a*) and 8–9 (*b*)) on the hydrogen volume fraction in stoichiometric air mixtures of propane–hydrogen fuel in the detonation tube of configurations K1 (*a*) and K2 (*b*)

Figure 12 Calculated dependences of the self-ignition delays on x_{H_2}, P, and T for stoichiometric air mixtures of propane–hydrogen (solid curves) and methane–hydrogen (dashed curves) fuels

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