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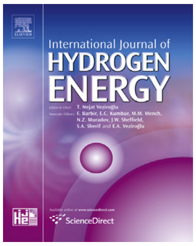

Experimental investigation of influence of methane additions on spontaneous self-ignition of pulsed jet of hydrogen

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ABSTRACT

The influence of addition of methane on the self-ignition of a hydrogen jet was studied experimentally for the pulse discharge into an open channel filled with air. During the pulse discharge from a high pressure chamber a shock wave is formed, which heats the surrounding air and a contact surface. The self-ignition of the jet occurred at the contact surface of the jet with air. A mixture of hydrogen with methane was preliminary prepared in a vessel of 40 L. The initial pressure of the mixture was varied from 3 to 15 MPa. During the discharge of the binary mixture ignition delays were measured relative to the moment of a breaking of the diaphragm. Ignition delays were determined by a photomultiplier tube. The delays were measured for different initial pressures and the methane addition. A molar concentration of the methane addition varied from 5% to 18%. Analysis of the effect of impurities on the thermodynamic parameters of the pulsed jets was carried out.

Introduction

One of type of self-ignition of gases is a spontaneous self-ignition of compressed hydrogen or another combustible gas at a pulse discharge from a vessel under high pressure into air. At this release a shock wave is formed in air which heats air to a temperature more than one thousand degrees. It creates sufficient conditions for igniting of the combustible gases if it are in contact with hot air. In Ref. [1] we have shown experimentally that the ignition delay at the contact surface of hydrogen with air can reach minimum value of 23 μs. The conditions in which self-ignition occurs have been studied in detail since 1972 [2]. The experimental and numerical minimum values of the pressures and temperatures which cause the ignition of hydrogen are presented in Refs. [3–7]. The influence of the diameter of the orifice through which the hydrogen discharges on the possibility of ignition is presented in Refs. [5,8,9]. The actions of obstacles, channel cross-section and channel length are presented in Refs. [10–12]. The kinetic mechanisms of the ignition of hydrogen with different boundary conditions are given by Refs. [4,13,14]. The

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modelling and large-eddy simulation (LES) of the spontaneous ignition dynamics of hydrogen in a tube with a non-inertial rupture diaphragm is described in Ref. [15]. The ignition delays for the non-premixed mixtures were measured experimentally in Ref. [16], and numerically in Ref. [17]. Great importance is given to the influence of the Lewis number and expansion on jet ignition [18]. The influence of the initial shape of the hydrogen jet on the dynamics of self-ignition was investigated numerically in Ref. [19]. Numerical study of spontaneous ignition was investigated in a tube with local contraction in Ref. [20], with an obstacle plate in Ref. [21], and in a T-channel in Ref. [22]. When discharging the pulsed jet of hydrogen into a long channel of length 4200 mm, the self-ignition of hydrogen occurs at the contact surface with the air inside the channel [23]. Until the moment when the contact surface is moved to the outlet of the long channel, the combustion has stopped.

The fact that the ignition delay of hydrogen can reach values of 23 μs certainly suggests that the storage and operation of compressed hydrogen can be highly explosive, even when there are no external ignition sources. Self-ignition of a hydrogen jet cannot be fully inhibited or prevented by the use of channels and safety valves of special geometric construction. The latter is due to the fact that a non-stationary hydrogen jet discharged from the vessel generates a system of compression waves and shock waves. The interaction of the system of these waves can lead to an increase in temperature at local points and to the appearance of additional points of inflammation [11,24].

One method to increase the ignition delay of hydrogen is by using an admixture of other combustible gases. Wherein, the ignition delay of a binary mixture is several times higher than the delay of ignition of pure hydrogen. In the paper methane was used as the admixture.

Ignition delays and flame characteristics for the hydrogen–methane jets depending on the composition are presented in Refs. [25–27]. It is worth noting that the mixture of compressed hydrogen and natural gas is quite common, and is known as HCNG (hydrogen-compressed natural gas) [28]. The addition of hydrogen into compressed methane increases the energy efficiency of engines and devices using compressed methane [29,30]. Effects of hydrogen additives on the ignition delay for engines and chambers of constant volumes are presented in Refs. [31–33], for turbines in Ref. [34], and in the review [35]. The values of the ignition delays for preliminary premixed hydrogen–methane mixtures behind the shock wave can be found in Refs. [36–39], for CO- hydrogen–-methane mixtures in Ref. [40].

The aim of the present paper is the experimental determination of the ignition delays of the pulse jet of a binary mixture of hydrogen with methane for the different initial pressures of the hydrogen–methane mixture.

Experimental technique: mixture

For producing of the spontaneous discharge of hydrogen into the channel, rupture of the diaphragm between the chamber and channel was used. Fig. 1 shows the schematic of the experimental set-up, organized according to the principle of a shock tube. The methodology is described in detail in Ref. [1]. The length of the channel was 185 mm, the distance from the diaphragm to the pressure gauge in the channel was 135 mm, and the internal diameter of the channel was 5 mm.

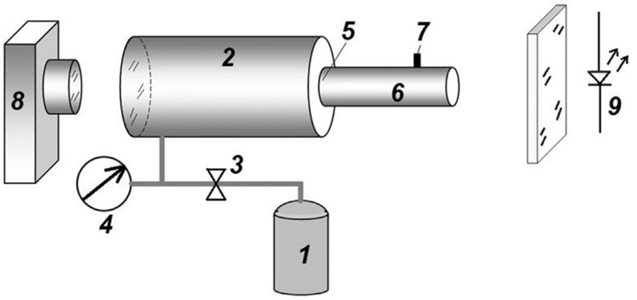

Fig. 1 – Schematic of experimental set-up. 1, compressed binary mixture; 2, high pressure chamber (initial pressure P_4); 3, regulating vent; 4, manometer; 5, diaphragm; 6, open channel (initial pressure P_1); 7, piezoelectric pressure transducers PCB 113A; 8, photomultiplier tube (PMT); 9, light diode (LED).

A photomultiplier tube 18A (PMT) (8) and light diode BL-L314UWC (LED) (9) arranged along the axis of the channel were used to register the initial moment of rupture of the diaphragm and to register the moment of ignition. The light diode created a light, directed along the axis of the channel. At the closed end of the chamber a transparent window and photomultiplier tube were installed. The moment of opening the diaphragm was registered by the intensity of light passing through the diaphragm. The supply voltage to the photomultiplier tube is not less than 3 kV. The voltage of the light diode was 2 V. The distance from the outlet of the channel to the diode was approximately 1 m. For this location of the diode, the intensity of its glow does not exceed the emission intensity of the combustion of the hydrogen–methane mixture in air (see Section Ignition delay). After the disclosure of the diaphragm the PMT registers the hydrogen self-ignition in any location along the channel. PMT registers the fact of the self-ignition and ignition delay relative to the rupture.

The diaphragms were made of aluminium of different thicknesses and depths of incision to provide a wide range of initial pressures. The thicknesses of the diaphragms were changed from 0.10 to 1.00 mm. The error of the determination of the initial pressure of hydrogen was 0.05 MPa.

For registration of the shock waves, piezoelectric pressure transducers PCB 113A (7) were used, located in the channel. The pressure transducer could not register the moment of the rupture, since it is protected against lateral wave disturbances propagating through the metal. Additionally, the pressure transducer was used for triggering of the digital oscilloscope 100 MHz Tektronix TDS3014B.

The hydrogen–methane mixture was prepared by partial pressures in a 40 L vessel. The total pressure did not exceed 15 MPa. Table 1 shows the parameters of the binary mixtures used in the experiments.

Considering the shock wave propagation in the channel of 5 mm in diameter it is necessary to take into account the effect of an boundary layer. The thickness of the boundary layer can be estimated using [41]. For example, for a pressure behind the