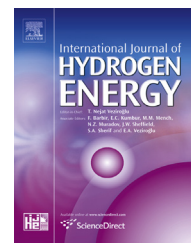


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Influence of initial pressure and temperature on flammability limits of hydrogen–air



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ABSTRACT

This paper presents data on the lower and upper flammability limits of hydrogen–air mixtures at elevated temperature and pressure. A 5-L explosion vessel, an ignition system, and a transient pressure measurement sub-system were used in this study. Through a series of experiments carried out, the lower and upper flammability limits of hydrogen–air mixtures at different initial pressures and temperatures have been studied and the influence of initial temperature and pressure on the lower and upper flammability limits of hydrogen–air mixtures has been analysed and discussed. It was found that the decrement of the LFLs of hydrogen–air with the initial temperature from 21 to 90 °C at the initial pressure of 0.1 MPa is less than 1%, the decrement of the LFLs with the initial temperature from 21 to 90 °C at 0.2 MPa is less than 1%, the decrement of the LFLs with the initial temperature from 21 to 90 °C at 0.3 MPa is less than 0.66%, and the decrement of the LFLs with the initial temperature from 21 to 90 °C at 0.4 MPa is less than 0.25%. The lower flammability limits of hydrogen–air mixtures at the pressures of 0.1 and 0.4 MPa are 4 and 1.25%(V/V), respectively. The upper flammability limits of the hydrogen–air mixtures increase with the initial pressure and temperature. The upper flammability limit of the hydrogen–air mixtures at 90 °C and 0.4 MPa reaches 93%(V/V) which is much higher than that (76%(V/V)) at 21 °C and 0.1 MPa.

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Introduction

Hydrogen has been proposed as a potential fuel to replace fossil fuels and to reduce carbon emissions. The future widespread use of hydrogen brings safety issues that have to be addressed before public acceptance can be achieved [1]. There has been a significant amount of research on hydrogen safety and the design of mitigation measures [2]. A great deal of data on the combustion parameters of hydrogen–air mixtures has been reported in previous literature [3–5]. Jo and Crowl [3] measured the maximum explosion pressure of hydrogen–air mixtures in a 20-L sphere.

The lower and upper flammability limits of a fuel are key parameters for predicting fire, assessing the possibility of explosion, and designing protection systems. The flammability limits of hydrogen in air mixture are 4–75.6% at atmospheric pressure and normal temperature [4]. Ng and Lee measured the upper flammability limits of hydrogen–air at room temperature (20 °C) and initial pressure of 1.0, 0.7, 0.5, 0.3, 0.1, and 0.05 atm [1].

While the upper and lower flammability limits of the hydrogen–air mixtures at elevated pressure and temperature are essential for safe and reliable operation in the process industry, they are nevertheless hardly available in the literature. Knowledge of the flammability limits of

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hydrogen–air at elevated pressure and temperature is an important prerequisite for safe usage. Although a great deal of research effort has been directed towards determining the explosion parameters of hydrogen–air [6–18], the flammability limits of hydrogen–air mixtures [19], and the limiting oxygen concentration of fuel–air–inert mixtures at elevated temperatures [20], unfortunately, few researchers have paid attention to the effects of the initial temperature and pressure on the upper limits and lower limits of the hydrogen–air mixtures.

Consequently, in this work, we have used a limiting (minimum) concentration measurement system consisting of a 5-L explosion vessel, an ignition sub-system, and a transient pressure measurement sub-system. Through a series of experiments carried out in this system, the flammability limits of the hydrogen–air mixtures at elevated initial pressure and temperature have been studied.

Combustible gas at the pressure of 0.1–0.3 MPa is frequently used [21]. The examined range of initial pressures is 0.1–0.3 MPa in this study which was based on an actual process of chemical engineering which is an advanced process to be developed. The experimental conditions in this work were completely identical to that of the production.

Experimental apparatus and procedures

The experimental set-up used in this study consisted of a 5-L cylindrical vessel coupled with an electric ignition system and a data acquisition system. Experiments were performed in a cylinder explosion vessel with central ignition. The height h of the vessel was 340 mm and the inner diameter $2R$ was 160 mm. In the experimental vessel, ignition was achieved by means of an inductive-capacitive spark produced between stainless steel electrodes with rounded tips, separated by a spark gap of 1 mm. The electrode diameter used in the experiments was 1 mm. At the condition of high temperature and high pressure, it is difficult to achieve homogeneous mixture composition in the vessel using a stirrer which cannot work well under the higher initial temperature and pressure. So we determined the ignition positions based on the reported data on the LFL and UFL of 4% and 76% at room temperature and atmospheric pressure, respectively. The ignition position in the experiments of UFL, was set at 1/5 height of the vessel (for all of the initial temperatures and pressures), as shown in Fig. 1. The ignition position in the experiments of LFL was set at 4/5 height of the vessel (for all of the initial temperatures and pressures), as shown Fig. 2. We assumed that by this way, the LFLs measured under the various initial temperatures and pressures are comparable each other. Similarly, the UFLs measured by this way under the various initial temperatures and pressures are comparable each other also.

Explosions of the mixtures were monitored by means of Kistler pressure gauges mounted on the wall of the experimental vessel. All results were stored through a data acquisition device. The data acquisition system was triggered by the control unit, and recorded pressure data at sampling frequencies of 1 MHz.

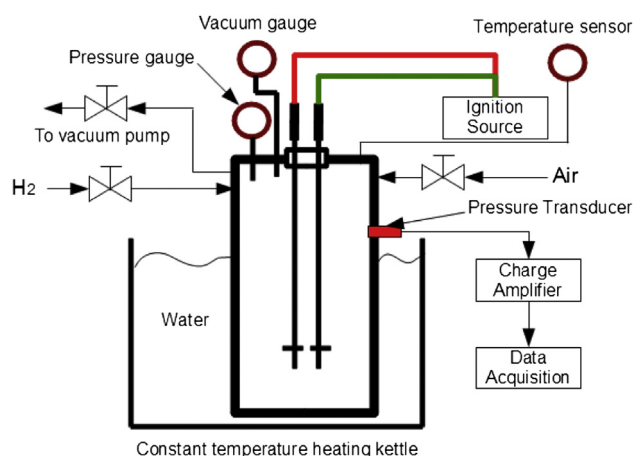


Fig. 1 – Ignition position at 1/5 height of vessel (for experiments of UFL under the various initial temperatures and pressures).

The lower part of vessel was placed in a thermostatic water container and its upper part was wound by a constant temperature heating kettle to heat the outer surface of the vessel to the specified temperatures (40 °C, 60 °C, 75 °C, or 90 °C). Air and hydrogen were successively filled into the vessel in the experiments. The filled air and hydrogen concentrations of the mixtures were evaluated by partial pressures. The hydrogen–air mixture was then ignited by an electric spark generated by a spark generator. After the ignition occurred within the mixture, a combustion wave formed and propagated from the position of ignition to the wall of the vessel. The histories of pressure resulting from the hydrogen–air mixture explosion were recorded by the pressure transducer connected to the data acquisition system. The pressure changes with time describe a given pressure history, and the maximum pressure represents the peak value of a given pressure wave.

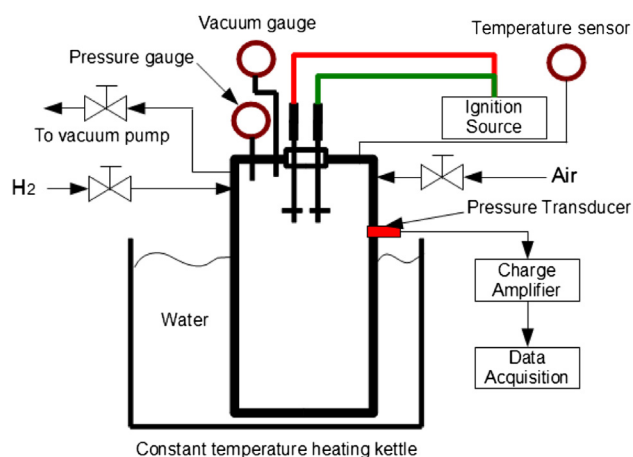


Fig. 2 – Ignition position at 4/5 height of vessel (for experiments of LFL under various initial temperatures and pressures).

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