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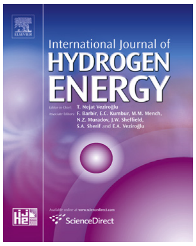

Comparison of explosion characteristics between hydrogen/air and methane/air at the stoichiometric concentrations

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ABSTRACT

Hydrogen and methane that are largely different in gas activity are two common explosion hazards. Understanding their explosion characteristics is the foundation for acknowledging explosion hazard effects of hydrogen and methane. In this study, the explosion experiments of hydrogen/air and methane/air for different gas volumes have been carried out in a closed tube. The objectives of this study are to examine the explosion characteristics of hydrogen and methane at the stoichiometric concentrations and to acknowledge explosion hazard effects based on the experimental data in the tube. According to the experimental results, the flame propagation speed of hydrogen/air explosion is higher than that of methane/air, while the flame duration of methane/air is longer than that of hydrogen/air. It is indicated that the higher reactive hydrogen can cause massive burst damage, while the lower reactive methane can lead to a lasting harm. In the experimental tube, peak overpressures and maximum rates of pressure rise $(dp/dt)_{max}$ of hydrogen/air explosion for different gas volumes change greatly along the axial direction of the tube and reach the maximums at the end of the obstacles region. The pressure maximums are up to more than 1.5 MPa. While peak overpressures and $(dp/dt)_{max}$ of methane/air explosion change relatively slowly along the axial direction of the tube and their maximums appear beyond the original premixed gas zone. The pressure maximums just reach about 0.38 MPa. For all premixed zones, peak overpressures, maximum rates of pressure rise $(dp/dt)_{max}$ of hydrogen/air explosion and speeds of shock wave are significantly larger than those of methane/air, except for 1.5 m premixed zone for which peak overpressures, $(dp/dt)_{max}$ and speeds of shock wave of hydrogen/air and methane/air are very close relatively beyond the premixed gas zone due to too little combustible gas volume. As the combustible gas volume increases, maximum pressures and maximum rates of pressure rise of hydrogen/air explosion rise more significantly than those of methane/air because of different gas activity and flame acceleration characteristic.

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Introduction

Gas explosion accidents often cause mass death and casualty. The combustible gas explosion intensity varies according to the combustible gas activity in the same environment. The gas activity reflects how easily the chemical reaction goes on. The chemical reaction absorbs energy called activation energy from the environment to make the chemical bonds broken and recombined. For the higher reactive combustible gas, the activation energy is lower and the molecular diffusion is faster, resulting in the chemical reaction taking place more easily and developing more rapidly, and even the detonation is more likely to occur.

Hydrogen and methane that are largely different in gas activity are two common explosion hazards. The explosion accident consequences of hydrogen and methane are significantly different, indicating that their explosion propagation process and characteristics are very different. A lot of researches on their ignition energy [1,2], explosion limits [3–8] and explosion indexes [9–11] have been reported. Le et al. [3] studied the relationship of lower flammability limits (LFLs) of hydrogen/air, methane/air, ethane/air, n-butane/air, and ethylene/air with the different initial pressures in a closed cylindrical vessel, and found that the LFL of hydrogen initially decreased with pressure from 1.0 to 0.3 atm, and then increased with the further decrease of pressure, while the LFLs of the hydrocarbons increased with the pressure decrease from 1.0 to 0.1 atm, except for methane for which the LFL did not change with pressure. Kuznetsov et al. [4] experimentally evaluated the upper and lower flammability limits and laminar flame velocity in the range of 4–8% hydrogen in air at initial pressures 25–1000 mbar in a spherical explosion chamber with a volume of 8.2 dm^3. Cashdollar et al. [9] experimentally studied the flammability for methane, propane, hydrogen and deuterium gases in air in 20 L and 120 L closed explosion chambers under both quiescent and turbulent conditions and presented lower and upper flammable limits, maximum pressures, and maximum rates of pressure rise, which illustrated the complications associated with buoyancy, turbulence, selective diffusion, and igniter strength versus chamber size. Ma et al. [12] examined the effect of hydrogen addition on methane/air explosion in the 20 L vessel. Liu and Zhang [13] studied influence of initial pressure and temperature on flammability limits of hydrogen/air. Zhang et al. [14] measured the critical concentration of helium making hydrogen/oxygen with various fractions nonflammable.

In addition, a huge amount of studies have been focused on the evaluation of the flammability and explosion parameters of hydrogen, methane and their mixtures. Gu et al. [16] experimentally and numerically studied the effects of stretch on laminar burning velocities of methane-air mixture at initial temperatures between 300 and 400 K, and pressures between 0.1 and 1.0 MPa at equivalence ratios of 0.8, 1.0 and 1.2. Sarli et al. [17] studied the laminar burning velocities of hydrogen-methane/air mixture for different equivalence ratio and fuel composition at normal temperature and pressure using the CHEMKIN PREMIX code with the GRI kinetic mechanism and found that the values of the blends laminar burning velocities were always smaller than those obtained by averaging the laminar burning velocities of the pure fuels. Salzano et al. [18] conducted experimental tests in a 5 L closed cylindrical vessel for explosions of different compositions of hydrogen-methane in stoichiometric air at varying initial pressure (1, 3 and 6 bar) and found the quantification of the combined effect of both mixture composition and initial pressure on the maximum pressure, maximum rate of pressure rise and burning velocity. Jiang et al. [19,20] carried out hybrid mixtures explosions in a 36 L dust explosion apparatus including mixtures of methane/niacin, methane/cornstarch, ethane/niacin and ethylene/niacin in air and proposed a new formula to improve the prediction of the LFL of the mixture by utilizing basic characteristic of unitary dust or gas explosion and discussed the effect of varying the ignition energy and turbulence intensity to the formula. Benedetto et al. [21] performed explosion tests for mixture with stoichiometric CH_4/O_2 ratio in a non-adiabatic 5 L cylindrical vessel and found the oscillating pressure could be attributed to the occurrence of cycles of condensation and vaporization of the water produced during combustion.

However, under the same experimental conditions, the comparative study on the characteristics of the flame acceleration and the deflagration to detonation transition in a confined space is still very little, which is the foundation for acknowledging explosion hazard effects of hydrogen and methane.

In this study, the explosion experiments of hydrogen/air and methane/air for different premixed zones have been carried on in the closed tube. The objectives are to compare the explosion characteristics and the flame propagation of hydrogen and methane at the stoichiometric concentrations filled in the local zone of closed tube under the experimental conditions, in order to acknowledge different explosion hazard effects based on the experimental data in the tube. The appropriate preventive and control measures of accidents for hydrogen and methane can be taken corresponding to the both different combustible gases. In addition, this study can provide a basis for the development of preventive and control measures for explosion accidents of hydrogen and methane and the further study of gas activity.

Experimental apparatus and conditions

The experimental apparatus used in this study consisted of the explosion tube, an electric ignition system, a high speed photography sub-system, a data acquisition system, a transient pressure measurement sub-system and a transient temperature measurement sub-system. Experimental tests were conducted in an 8.9 m long tube with an internal diameter of 10.8 cm, with both ends closed, as shown in Fig. 1. The ignition point was located at the left end of the tube. Tests were conducted with obstacles placed inside the first 1.5 m of the tube from the left closed end. This obstacles zone included several orifice plates with even spacing of 10 cm. The obstacles area blockage ratio (BR), defined as the ratio of the cross-sectional area [15], was 0.34. Explosions were monitored using 8 Kistler pressure gauges and 5 temperature transducers