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Turbulence influence on explosion characteristics of stoichiometric and rich hydrogen/air mixtures in a spherical closed vessel

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A R T I C L E I N F O

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A B S T R A C T

Explosion always occur in turbulent ambience, but few researches focusing on the effects of turbulence on explosion characteristics has been performed in the current. In the present investigation, the effects of initial turbulence on the explosion characteristics of stoichiometric and rich hydrogen-air mixtures were experimentally studied and analyzed on the basis of explosion pressure traces. Maximum explosion pressure, explosion duration, maximum rate of pressure rise, fast explosion duration, deflagration index, and the averaged heat flux through the wall during explosion were systematically examined. The results indicated that, turbulence will reduced the corresponding equivalence ratio to maximum rate of pressure rise but won't change the corresponding equivalence ratios to maximum explosion pressure and two explosion durations. In turbulent ambience, two explosion durations will decline for the accelerated propagation of pressure wave, the values of maximum explosion pressure and maximum rate of pressure rise will be raised for the reduced heat flux through the vessel's wall during explosion. In addition, turbulence raises the value of deflagration index, namely it raises the hazardous level.

1. Introduction

There is no doubt that the development and progress of human society relies on the exploitation and utilization of fuels and energy; however, facing to the depletion of fossil fuels on a global scale, a sound oppugns the sustainability of such development model has been widely raised (as systematically discussed by Sun and his co-workers [1,2]). Compared to abandon the development, exploring and utilizing new alternative (especially renewable) fuel(s) are more in line with the reality of human being. As well-known, hydrogen is the most abundant element of earth and hydrogen gas is a renewable fuel could be obtained from various substances in various ways, and hydrogen can be taken as addition fuel into various traditional fuels (such as gasoline [3], *n*-butanol [4], ethanol [5], and diesel [6]); therefore, a viewpoint about taking hydrogen energy as the dominant energy in the next era has attracted great concern in the worldwide, relevant studies about the fundamental combustion characteristics of hydrogen gas has also correspondingly received enthusiastic attention.

As a fuel in practical utilization, explosion characteristics are essential and crucial: to an expected combustion in thermal devices (such as internal combustion engine, gas turbine, and power plant), advancing explosion performance could bring positive and beneficial efforts on the conversion of heat into power [7]; while, to an unexpected explosion (such as accidental explosion in the process of transportation and storage), suppressing explosion intensity could reduce the degree of harmful damage [8]; therefore, relevant studies on explosion characteristics are always hot topic in the field of energy conversion and management.

Since explosion often occurs in confined space, the relevant experimental studies are always performed in closed explosion vessels. Heretofore, fundamental explosion characteristics have been widely studied on hydrocarbon fuels (such as methane [9], propane [10], octane [11], ethylene [12], propylene [13], n-alkane [14], biogas [15], and syngas [16]) in the past few decades, and various factors (such as ambient pressure and/or temperature [17], equivalence ratio [18], dilution ratio [19], moist [16], even ignition position [20]) influencing explosion characteristics have been systematically studied. It seems that the studies relevant to fundamental explosion characteristics have been very comprehensive on hydrocarbon fuels, but the experimental studies about explosion characteristics on hydrogen gas is relative insufficient albeit some scholars obtained some brilliant achievements (such as the effects of nitrogen dilution on hydrogen explosion [21], the explosion limitation under different ambient conditions [22], even the effects of ignition position on explosion pressure [23]) in recent years. Actually, practical combustion and/or explosion always happens in turbulent environment, especially in

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Nomenclature

A	the area of the vessel's inner surface, m^2
dp/dt	the rate of pressure rise, 0.1 MPa/ms
$(dp/dt)_{max}$	the maximum rate of pressure rise, 0.1 MPa/ms
K_G	deflagration index of mixtures, MPa·m/s
p_e	adiabatic explosion pressure, 0.1 MPa
p_{max}	the maximum explosion duration, 0.1 MPa
q	the averaged heat flux per are unit through the vessel during the explosion, J/m^2
t_a	the time when 50% pressure rise rate is attained, ms
t_b	fast burn period, ms
t_c	explosion duration, ms
u'_{rms}	turbulent intensity, m/s
V	the net volume of the vessel, m^3
φ	equivalence ratio, –
γ	the adiabatic coefficient of burned mixtures, –

weak turbulent regime for the most common. However, nearly all the previous experimental studies about explosion characteristics of gaseous fuels were performed in laminar environment, which makes the effects of turbulence on explosion characteristics are absent from the current knowledge. Therefore, making studies on the explosion characteristics of hydrogen gas, especially considering the influence of turbulence is necessary and significant to a wider utilization of hydrogen as one expected alternative fuel in the coming era.

Aiming at providing more basic and beneficial information on fundamental explosion characteristics of hydrogen-air mixtures, series of experiments have been performed in weak turbulent environment (since it is the most common condition in practical devices) in the present investigation. Learnt from previous works on explosion of hydrogen-air mixtures in laminar conditions [21], the inflexion of explosion pressure exists in rich conditions; for examining whether turbulence influence could vary the inflexion of explosion pressure and other indicator or not, stoichiometric and rich hydrogen-air mixtures have been taken as the objects in the present investigation. For obtaining systematic analysis, the variations of six important indicators (including maximum explosion pressure p_e, explosion duration t_c, the maximal rate of pressure rise $(dp/dt)_{max}$, deflagration index K, fast explosion duration t_b, and the heat lost to the surface unit of wall q) have been discussed, the combined influence effects of equivalence ratio (φ, from 1.0 to 2.5) and initial turbulent intensity (u'_{rms}, from 0 m/s to 1.309 m/s in root mean square turbulent fluctuation) on explosion characteristics have been thoroughly considered and discussed.

2. Methodology

2.1. Experimental apparatus and procedure

Experiments were performed in a premixed turbulent explosion bench, as shown in Fig. 1(a). The bench consists a stainless-steel closed explosion vessel, a turbulence generation system, an ignition system, and a pressure data acquisition system. The explosion vessel is designed into a spherical cavity, the vessel's inner diameter is 380 mm and the corresponding net volume is 28.73 L.

The turbulence generation system consists four independent fan-motor sets, each fan-motor set consists one axial-flow fan, one circular porous plate, one magnetic coupling, one electric motor, and one frequency converter. In each fan-motor set, the fan is linked with the electric motor by the magnetic coupling, the porous plate is installed over ahead the fan, and the operation condition of the motor is controlled by the frequency converter outside the vessel. The four fan-motor sets are orthogonally installed on the vessel in a Pyramidal configuration, and the geometric centre of pyramidal coincides with vessel's centre. The principle of turbulence generation has been described in our previous literatures [8,24] as that, once four fan-motor sets are synchronously trigged by frequency converter with a designated speed, the axial-flow fans will rotate with the same speed to form moving-ahead swirl flow, the swirl flow would be transferred into flow jets once it advances through the porous plate, then the jets from four directions would collide at the vessel's centre (also the geometric centre of four fan-motor sets) to form near isotropic turbulence. The turbulent intensity can be controlled by the speed of fan (as in all the fan-stirred vessel, such as Leeds-type [25], Princeton-type [26], CNR-type [27], etc.), the structure of fan, and the structure of porous plate. In the present investigation, the four fans have the same structure, each fan has five tetrahedron blade and one central install hole, the gross diameter is 90 mm, the blade's width is 15 mm, and the hole's diameter: 14 mm, as shown in Fig. 1(b); the four circular porous plates also have the same structure, each porous plate has 37 holes in the circular plate with a gross diameter of 110 mm, the hole's diameter is 12 mm, and the distance between two neighbouring hole is 3 mm, as shown in Fig. 1(c). With the mentioned fan-motor sets, the nexus between fan rotation

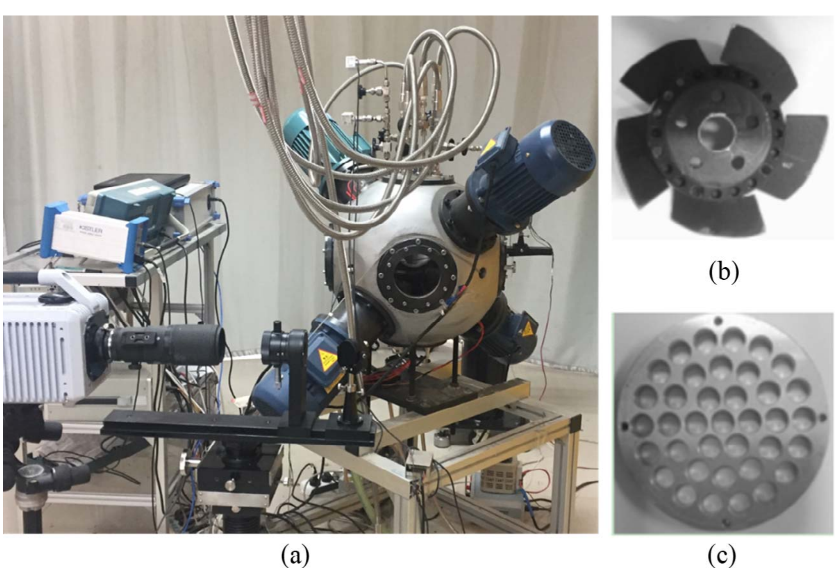

Fig. 1. Premixed turbulent explosion bench: (a) explosion vessel and other subsystem; (b) fan; and (c) porous plate.