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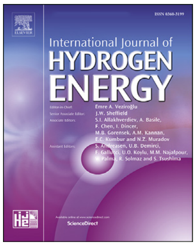

Effect of vent size on vented hydrogen-air explosion

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ABSTRACT

In this paper, the effect of vent size on vented hydrogen-air explosion in the room was studied by numerical simulation. Analysis of the explosion temperature, overpressure, dynamic pressure and wind velocity under different vent sizes indicate that these explosion parameters have different change rules inside and outside the room. Inside the room, the vent size has little effect on the explosion temperature, dynamic pressure and wind velocity, but it has a significant impact on the explosion overpressure. As the scaled vent size K_v ($A_v/V^{2/3}$) increases from 0.1 to 0.3, the difference between the maximum internal peak overpressure is 87.8%. Outside the room, as the vent size increases, the high-temperature range (above 800 K) first decreases and then increases, while the explosion dynamic pressure and hurricane zone caused by explosion wind gradually decrease. The maximum high-temperature range (32.5 m for $K_v = 0.1$) and hurricane zone (41.1 m for $K_v = 0.1$) can reach 7.0 times and 8.9 times the length of the room, respectively. The explosion dynamic pressure can reach the same order of magnitude as the explosion overpressure under the same vent size. Therefore, these damage effects outside the room cannot be ignored. During the change of vent sizes, for $K_v \le 0.3$, the explosion parameters change drastically and the disaster effect is significant. For example, external explosion that affect the discharge of internal explosion overpressure occur; explosion that occurs in masonry structures can destroy the structural integrity of the brick walls. Therefore, $K_v = 0.3$ can be used as a reference for hydrogen-air venting safety design.

Introduction

As a kind of clean energy source, hydrogen can effectively solve the problems such as greenhouse effect, air pollution and energy crisis [1]. However, due to the wide explosion limit and low MIE (Minimum Ignition Energy), resulting in the explosion safety problems of hydrogen energy in the process of production and use [2,3].

When hydrogen-air mixture explodes in a confined space, it will produce high overpressure and temperature, causing great personnel and property losses [4]. Explosion venting can release the energy generated during the hydrogen-air explosion quickly, it can be an effective method to protect equipment and buildings against explosion damage [5–8]. For the safety design of vented explosion, the National Fire Protection Association (NFPA) in US has developed the standard NFPA 68 [9]. However, this standard is mainly applied to hydrocarbon such as natural gas and cannot be directly used for hydrogen [10–12]. Hydrogen has a higher reactivity than hydrocarbon, so the process of vented hydrogen-air explosion tends to

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Nomenclature

A_v	vent area (m^2)
C_t	dimensionless constant
C_v	the constant volume specific heat (J/kg/K)
C_μ	constant of $k-\varepsilon$ model (m^2/s)
C_1, C_2	constant of $k-\varepsilon$ model
E	energy (J)
H_c	the heat of combustion (kJ/mol)
k	turbulent kinetic energy (m^2/s^2)
K_v	scaled vent size, $K_v = A_v/V^{2/3}$
L_t	turbulent length scale (m)
m_{fu}	the fuel mass fraction
p	the static pressure (Pa)
P_{max}	maximum peak overpressure (kPa)
R_{fu}	volumetric combustion rate (kg/m^3/s)
R_{min}	minimum mass fraction
S_l	laminar burning velocity (m/s)
S_t	turbulent burning velocity (m/s)
t	flame arrival time (s)
T	temperature (K)
u_i	the flow velocity in the direction of i (m/s)
u_t	turbulence intensity (m/s)
V	volume of the room (m^3)
x	the space coordinate
Greeks	
δ_{ij}	the Kronecker δ
ε	dissipation rate of turbulent kinetic energy (m^2/s^3)
ε_{c0}	quasistatic strains under uniaxial compression
ε_{t0}	quasistatic strains under uniaxial tension
Γ	turbulent diffusion coefficient (m^2/s)
μ	poisson ratio
μ_t	turbulence viscosity coefficient
ν	kinematic viscosity (m^2/s)
ρ	mixture density (kg/m^3)
σ_{sc0}	quasistatic strengths under uniaxial compression (MPa)
σ_{sttt0}	quasistatic strengths under hydro-tension (MPa)
σ_{st0}	quasistatic strengths under uniaxial tension (MPa)

occur in a shorter time with a more complicated phenomenon. Therefore, a full understanding of the characteristic of vented hydrogen-air explosion can provide important reference for the structural safety design of vessels and buildings, and it is also of great significance for the protection of individuals and property.

The vent size is an important factor during the vented hydrogen-air explosion. Cooper et al. [13] found that there are four major peaks in the pressure-time curve during the vented explosion process. For the first, third and fourth pressure peaks, the corresponding peak pressure increases as the vent size decreases. The second pressure peak is related to the external combustion. As the vent size decreases, the second pressure peak first increases and then decreases. In the small volume vented hydrogen-air explosion experiment of Rocourt et al. [14], the measured overpressure increases as the vent size decreases. Through a series of vented explosion experiments, Kuznetsov et al. [15] found that the maximum vented explosion pressure increases as the vent size decreases. However, when the hydrogen concentration is lower than 10%, the maximum vented explosion pressure will be independent of the vent size due to the occurrence of a local quench. The numerical simulation results of Vyazmina and Jallais [8] also show that under the same ignition position and hydrogen concentration, the hydrogen-air venting pressure increases as the vent size decreases. Liang [16] studied the effect of vent size on the vented hydrogen-air deflagration near the lean flammability limit under quiescent and turbulent conditions, respectively. Under quiescent condition, the peak overpressure increases with the decrease of vent sizes for a given hydrogen concentration and vessel volume.

During the vented hydrogen-air explosion, some unburnt gas diffuses out and forms a combustible gas cloud [17,18]. When the internal flame spreads out of the vent, the gas cloud will be ignited. A few research has been done on this phenomenon, but the topics are mainly on the effect of vent size on the formation of external combustible gas cloud. Proust and Leprette [19] conducted a series of vented hydrogen-air explosion tests in vessels with a volume ranging from 1 to 100 m^3. The data shows that the radius of the combustible gas cloud is more closely related to the vent size compared to the volume of the vessel. In addition, the formation of the gas cloud is also affected by the flame expansion rate and flow velocity. Daubech et al. [20,21] conducted vented hydrogen-air explosion experiments in a 4 m^3 cuboid chamber. They found that the vent size has a significant influence on the formation of external combustible gas cloud. As the vent size decreases, the shape of the gas cloud appears a jet structure.

Among the research mentioned above, the effect of vent size on the vented hydrogen-air explosion was mainly focused on the overpressure. The effect of vent size on external combustible gas cloud was only focused on the formation of external gas cloud. The explosion of the external combustible gas cloud will not only cause harm to the surroundings, but also a violent external explosion will affect the interior of the vessel. In addition, the temperature rise caused by high-temperature combustion products during the venting process, the impact of the explosion dynamic pressure and wind velocity [22] on the surrounding equipment and people, and the interaction between the blast wave and the building structures [23], are all safety concerns that cannot be ignored during the vented hydrogen-air explosion. However, studies on these aspects have been overlooked.

In this paper, the effect of vent size on vented hydrogen-air explosion in the room was studied by numerical simulation. Inside the room, the quantitative relationship between the vent size and the explosion peak overpressure was discussed, so that the explosion peak overpressure of different vent sizes can be quantitatively predicted. Outside the room, the safety concerns in the venting process were discussed, including: the effect of vent size on high-temperature range; the relationship between the external explosions and vent size, and its effect on internal overpressure; the affected area of explosion dynamic pressure and wind velocity under different vent sizes; the interaction