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Investigate on hydrogen dispersion of complex air supply and exhaust system in large underground garage

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ABSTRACT

With the improvement of energy consumption level in China, environmental pollution and energy shortage are becoming more and more prominent. Hydrogen energy as a clean and efficient new energy has gradually entered the public's field of vision, H_2 was developed rapidly. Hydrogen fuel cell vehicles (HFCVs) is an important development direction of H_2 energy application as a net zero carbon emission transportation form. However, the development of H_2 energy has been hindered by H_2 storage, transportation and other problems in practical applications. H_2 is lighter than air and will dissipate rapidly while existing leakage in open environment. But H_2 will accumulate and cause incalculable damage while existing accidental leakage in semi-enclosed or enclosed space (i.e., garage or tunnel). The study to leakage of high pressure H_2 is the necessary prerequisite for the promotion of hydrogen fuel cell vehicles. In this paper, the effects of atmospheric stability conditions and source term variations on confined space dispersion scenarios were systematically evaluated by using the coupled integral model and computational fluid dynamics (CFD) method.An integral model was used to simulate the process of source term formation after 3.5kg high pressure hydrogen was released. This paper also studied the influence of the existence of obstacles and the arrangement of vents on H_2 concentration distribution in the leakage process emphatically. Combined with the simulation results at the initial stage of leakage, a feasible method was provided for the risk assessment of hydrogen fuel cell vehicle garages.

Keywords: Hydrogen dispersion; Integral models; Computational Fluid Dynamics modeling; Air supply and exhaust system

1. INTRODUCTION

Hydrogen gas (H_2) is a potential clean and renewable energy source which has features of zero carbon emission and wide application in the near future[1, 2].Among various H_2 applications, there has been considerable interest in applying H_2 on automobiles, which has the broadest development prospects, and is also conducive to building a net-zero carbon emission transportation system. H_2 is indeed inferior to traditional energy sources in terms of safety (wider combustion range (4%–74%)[3], wider volumetric explosion range (11%–59%)[4] and lower minimum ignition energy (0.02MJ)[4]), which revealed the high possibility of flammable and combustible and high risk to cause more serious medical and economic loss. Some security problems are raised for the production, transportation and storage of H_2 due to these features. Presently, the primary way of H_2 storage in HFCV is high-pressure H_2 tank. In the event of an accidental leakage in relatively closed spaces， H_2 tends to accumulate. Hence, the underground garage can be regarded as one of the most dangerous places while existing leakage of HFCV tanks.

The 3-dimensional equations were solved by CFD based models. CFD techniques discretized the control differential equations of fluid flow to perform complex mathematical descriptions and accurate, intuitive models. An innovative coupling with integral source terms models was developed by using the output of an integral model as the inlet boundary condition of the CFD model. The innovative coupling can achieve lower computational cost compared with using CFD alone, and more reliable analysis with compared with using the integral model alone. There are potential dangerous during releasing and accumulating of H_2.H_2 will move upward rapidly after released, known as exceeding leak point, due to the extremely low density.

At present, there have been many studies investigating H_2 leakage and dispersion experiments, but H_2 leakage is different in different application scenarios, and the danger situation is also different. To reduce a dangerous situation, so need to know the H_2 distribution in that situation. Here in, several safety analyses are performed in the case of accidental H_2 leakage in a real large underground garage by the coupled integral model and computational fluid dynamics (CFD) method , which attempt to estimate the source strength and subsequent dispersion under real ventilation conditions. The research results have positive significance for promoting the application of hydrogen fuel cell vehicles.

2. METHODS

2.1 *coupled integral model*

Process Hazard Analysis Software Tool (PHAST) is a petrochemical project hazard consequence analysis tool launched by DNV, which can perform quantitative risk analysis, including material leakage rate, and calculation of fire and explosion consequences. This paper uses a medium atmospheric stability of A. PHAST is used to simulate H_2 dispersion conditions. The H_2 storage tank contains high-pressure H_2 with a mass of about 3.5kg. When the ambient temperature is 15℃, the H_2 leakage occurs and the release state is gas phase. The leakage height is 1m above the ground. Fig 1 show the dispersion distance of combustible gas cloud leakage.

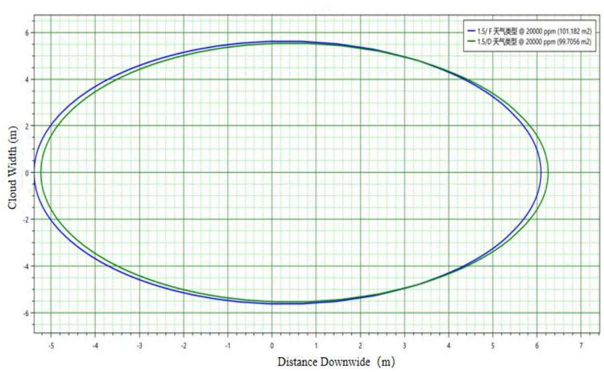


Fig. 1. The dispersion distance of combustible gas cloud leakage

2.2 *CFD model*

The commercial CFD code Ansys Fluent 15.0 (Fluent in the following), based on the finite volume methods, was used to solve the governing equations.

The overall size of the computing domain is 74.6 m × 44.5 m × 4 m (X × Y × Z) The actual air duct layout car and support pillars were also considered in this simulation. Three exhaust pipes were arranged with 15 exhaust outlets and 4 wind inlets. The positions of the one hypothetical H_2 leakage sources S1 is also shown in Fig. 2.

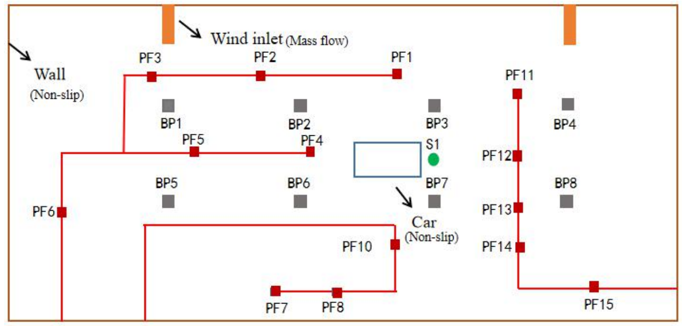


Fig. 2. Schematic of computational domain

The dispersion process of H_2 leakage is the process of high pressure and material transportation. Based on the Realizable *k*–*ε* model and component transportation model, the Realizable *k*–*ε* model is improved on the basis of standard *k*–*ε* model. The content related to rotation and curvature is introduced, which can be applied to simulate turbulent flow of gas.

The equations used for continuity, energy conservation, and momentum were as follows:

Continuity Equation

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0, \tag{1}$$

Energy Equation

$$\frac{\partial(\rho E)}{\partial t} + \nabla \cdot [\vec{v}(\rho E + p)] = \nabla \cdot \left[k_{eff} \nabla T - \sum_i h_i \vec{J_i} + (\overline{\tau}_{eff} \cdot \vec{v}) \right], \tag{2}$$

Momentum Equation (Navier-Stokes Equation)

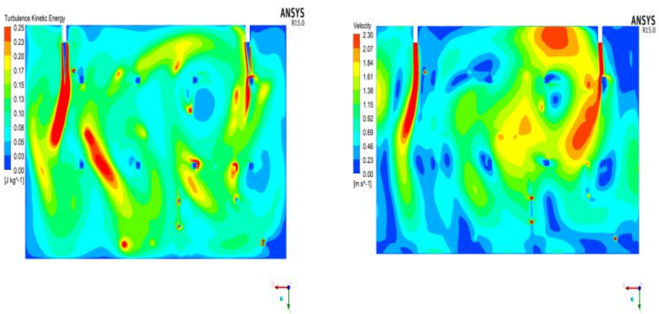
$$\frac{\partial(\rho \vec{v})}{\partial t} + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla p + \nabla \cdot (\overline{\tau}) + \rho \vec{g} + F_d, \tag{3}$$

$$\overline{\tau} = \mu \left[\left(\nabla \vec{v} + \nabla \vec{v}^T \right) - \frac{2}{3} \nabla \cdot \vec{v} I \right], \tag{4}$$

where ρ, $\vec{v}$ and *p* are the density, velocity vector and pressure, respectively; $\rho \vec{g}$ represents the gravitational force per unit volume; $\overline{\tau}$ is the stress tensor (described in Equation (4)), where, μ is the dynamic viscosity; *E* represents the total energy; k_{eff}, *T*, h_i, and $\vec{J_i}$ are the effective thermal conductivity, temperature, specific enthalpy of species *i*, and dispersion flux, respectively.

3. RESULTS AND DISCUSSION

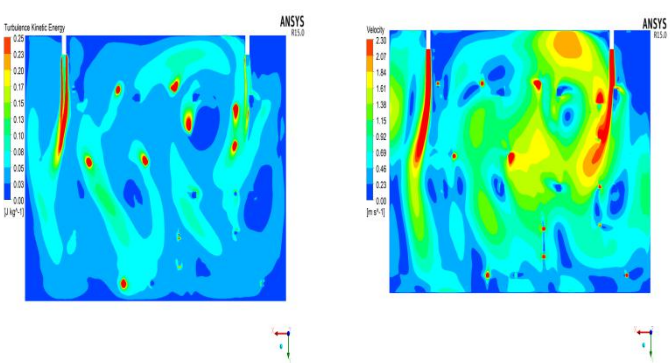
Fig.3 shows the cloud images of high turbulent kinetic energy and velocity at 3 m away from the release source S1 which continuously leaked for 10 s. The velocity around outside of release source increase while the velocity around the release source does not decrease and the turbulent kinetic energy along the direction of flow increase.At this time, the velocity at 2.5 m directly above the release source S1 is 1.12 m/s and the velocity at coordinates (13,18,3) is 2.23 m/s. The velocity increases under the influence of the fan.



(a) Turbulent kinetic energy cloud (b) Velocity cloud

Fig.3 The cloud images of high turbulent kinetic energy and velocity at 3 m away from the release source S1which continuously leaked for 10 s.

Fig.4 shows the cloud images of turbulent kinetic energy and velocity at 3.9 m away from the release source S1 which continuously leaked for 10 s.It can be seen from figure that the velocity around the release source is somewhat weakened compared to the above.The volume of released H_2, the turbulent kinetic energy around the release source and the turbulence velocity are small due to the short release time.At this time, the flow rate at 3.4 m directly above the release source S1 is 1.03 m/s.Overall, the changes of spatial velocity directly above release source is little under the influence of obstacles and exhaust air.At this time, the velocity at coordinates (13,18,2) is 2.37 m/s which indicated the velocity along the air supply direction of fan is relatively high.



(a) Turbulent kinetic energy cloud (b) Velocity cloud

Fig.4 The cloud images of high turbulent kinetic energy and velocity at 3.9 m away from the release source S1which continuously leaked for 10 s.

Take the flow velocity at S1 (27.2,18,0.5), A (13,18,0.5) close to downwind of the blower and different heights above the two points.The changes of flow velocity at each point are shown in the figure below.Under the influence of air supply and the close distance directly above point S1, the velocity at 1 m point above S1 changes greatly and the trend fluctuates greatly. Although the air supply is still affecting, the velocity distribution is similar and the change is gentle with the increase of height when exist certain height from the release point.The initial release velocity at point A and points above A at different heights fluctuate, change gently with the increase of time and the difference of velocity distribution is little. Fig.4 show the diagram of flow rate variation at S1 and nearby points .

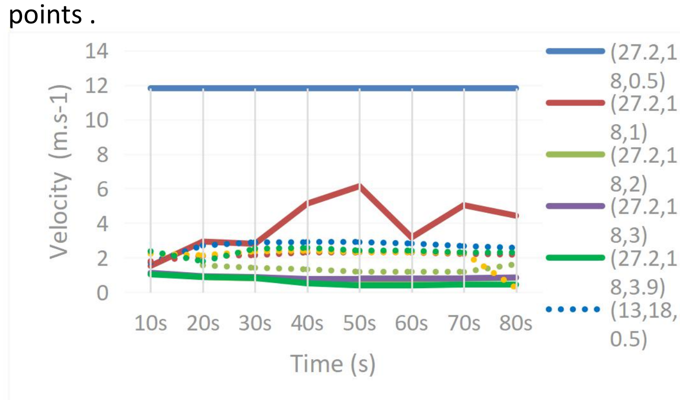


Fig.4 Diagram of flow rate variation at S1 and nearby points

4. CONCLUSIONS

Hydrogen energy vehicles are getting more and more attention under the premise of severe climate change and tense international oil situation.In this paper, a garage and its exhaust system were mainly taken as model background, the dispersion trajectory of high-pressure compressed H_2 after leakage is studied which can predict the far-field characteristics of H_2 dispersion in a the large underground garage. It is also helpful to provide reference for firefighters to predict the actual complex flow field environment. A reliable method for assessing the risk of H_2 leak can be provided by the emergency plans which based on this research.The specific conclusions are as follows:

The dispersion of H_2 will gather near the ceiling under the influence of buoyancy, and the buoyancy will push the light H_2 upward, and the increased momentum will improve the dispersion of gas from the leakage source through advection transport, and the flow trajectory is related to the velocity of the flow field.

In this study, the simulation of H_2 dispersion with different air distribution forms in underground garage is insufficient. In future studies, the influence of air distribution on H_2 dispersion and emission can be compared conveniently by simulating the H_2 dispersion under different air supply and exhaust modes.

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