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# CFD simulation study on gas dispersion for risk assessment: A case study of sour gas well blowout

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ABSTRACT

Compared with general blowout, the process of sour gas well blowout is more complex. The exchange of gas state is affected by many factors, and the consequences of the accident are serious. It is difficult to find out the rule of gas dispersion and predict the distribution of toxic gas. Fluent code was used to model the sour gas dispersion in the atmosphere after well blowout. The "12.23" sour gas well blowout, which was happened in Kai County, Chongqing, Sichuan, China, was the research background. The blowout accident model was set up to simulate the real process. Models were built based on real topography. Wind speed and atmospheric stability of the day which the accident happened were set as the operation conditions, and the composition, injection rate, and temperature of the gas at the actual time were set as the boundary conditions of numerical simulation. The analysis of gas dispersion based on simulation results conducted from two aspects, height and dispersion time. A comparison of field data with simulation data demonstrated that CFD technology can be an effective aid to describe the process of sour gas dispersion and can also predict the tendency of gas dispersion and gas distribution. Furthermore, it can provide guidance on design emergency response zone (ERZ).

## 1. Introduction

Accident simulation is an effective way to do risk analysis and also do help to build precaution strategy. The study of accident models and numerical simulation is necessary day by day to help people to analyze all kinds of accidents, such as fire, leaking, and explosion to avoid the hazard and decrease the loss.

Several computational fluid dynamics (CFD) programs are currently available to the industry for this very purpose (Gavelli et al., 2008). CFD techniques are increasingly being applied to model environmental source and dispersion problems. CFD models are based upon the underlying principles of fluid dynamics which govern the physics of the flow problem. Advances in the speed of modern computers, and more significant updated advances in CFD techniques, have made CFD modeling tractable for complex environmental problems. The use of CFD for the simulation of LNG vapor cloud dispersion was strongly recommended by the Sandia National Laboratories 2004 report (Hightowe et al., 2004). Qi provided the prediction results of downwind gas concentrations close to ground level were in approximate agreement with the test data (Qi et al., 2010).

Large natural gas fields with content of high hydrogenate sulfide were discovered in China's western region. But these gas fields located in hills with very complex geological structures, densely populated, and buried depth of gas reservoirs. These fields are called "three high" gas fields due to high containing $H_2S$ or $CO_2$, high pressure and high capacity ("three high "characteristics). There are significant safety risks of natural gas exploration.

Compared with the normal well blowout event, the blowout in the high-sulfur content well can cause enormous danger to public health and environment because of toxic gas and complex turbulence phenomena. Currently, the blowout well with high hydrogen sulfide content cannot conduct field test, on-line detection of blowout is very difficult, leading to emergency evacuation after the accident based on the lack of guidance.

This paper provides a case study of sour gas well blowout to show how the risk simulation works in risk assessment.

## 2. Background of accident

Accident occurred at 21:15, 23 December, 2003. The sour gas well was located in Xiaoyang village, Gaoqiao Town, Kai County, Chongqing City, northeastern Sichuan Gas Field, Luo 16H well. At that time, overflow happened suddenly from the well bottom. Some causes leaded to the well out of control. A large amount of sour gas burst from the hydrophthalmus of drilling tool, spray height was up to 30 m. Toxic gas spreaded rapidly with the air along the mountain to valley. Twenty-eight towns around the well were covered by poison gas in a short time. Because the accident took place at night, plus the area with complex terrain, and rescue

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facilities were backward, emergency notification and evacuation were not timely, nearly ten thousand of people were faced with hydrogen sulfide poisoning, of which up to 243 deaths. Nearly 10,000 people urgently evacuated. Economic losses was about 100 million RMB (wei et al., 2009). According to the soil and environment report after accident, soil was acidificated and some heavy metal activation was found (Xu et al., 2005). The region's soil curing serious. The plants and animals had to suffer the sustained damage.

## 3. Simulation code and workflow

### 3.1. Simulation software

There are many simulation softwares used in industry area, such as HYSIS, ASPEN PLUS, and ANSYSc. Different softwares have their advantage in different area.

Fluent is a general purpose CFD code that has been in use since 1983. It was mainly applied to simulate complex fluid flow problems. It is especially appropriate for simulating the complex physics process. Fluent solving steps were shown in Fig. 1.

### 3.2. Model selection

The large-eddy simulation can give a high-accuracy description of gas expansion (Meng et al., 2006; Ying-wen and Jian-xing, 2005), but it also has a high requirement for the computer performance. As we know, a proper model should gain the balance between "the computation precision" and "the computing time".

By applying the TOPSIS method to six RANS models (RSM, standard k–ε, RNG k–ε, standard k–ω, SSTk-ω) simulation provided by Fluent (Jianfeng et al., 2008), the comparison result shows that the standard k–ε model was the best suitable model under the simulation of heavy gas dispersion for hill-shaped terrains.

$$\frac{\partial}{\partial t}(\rho\phi) + div(\rho\mu\phi) = div(\Gamma grad\phi) + S_\phi \tag{1}$$

The four items from left to right on the style times were non-stationary items, convection, and diffusion and source terms. And $\phi$ is the general variable, $\Gamma$ is a generalized diffusion coefficient.

The wind velocity and potential temperature gradient functions along the height $z$ were given as follows (Brown et al., 1990):

$$\frac{\partial U}{\partial z} = \frac{U_*}{k \cdot z} \cdot \phi_m\left(\frac{z}{L}\right) \tag{2}$$

$$\frac{\partial U}{\partial z} = \frac{\theta_*}{k \cdot z} \cdot \phi_h\left(\frac{z}{L}\right) \tag{3}$$

where $L$, $U_*$, and $\theta_*$ are the Monin–Obukhov length, friction velocity, and scaling potential temperature, respectively, and $k$ is the vonKarman constant (0.41).

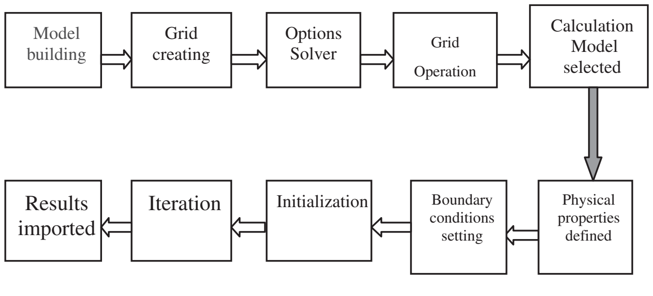

**Fig. 1.** Solving steps diagram of fluent code.

## 4. Geometry and scenarios

### 4.1. Scenarios

Kai County is located in the eastern mountainous, edge of Sichuan Basin, the southern slope and the north is DaBa Mountain, parallel to the canyon. The north and northeast are the high mountains, south is strip of low valley; northwest side is often isolated mountain plateau. This kind of complicated topography would likely leads to accumulation of harmful gases.

Objectively, as well blowout occurred in the night, most people already went to bed (Li et al., 2009). The well site was not far away from the surrounding residents, as shown in Fig. 2. In addition, the gas stability that day was not helpful to $H_2S$ spread, with traffic here was extremely inconvenient, poor communications, which increased the difficulty of evacuation assistance. After the blowout occurred, the lack of an emergency evacuation plan and without monitoring equipment, no ignition of spray pipes or broken source measures on time resulted in a large amount of $H_2S$ leakage, expansion, and deterioration of blowout.

According to the actual terrain surrounded 16H well, three-dimensional model of topography was built by simplified structure of real terrain in this paper. Because the complete spatial structure based on real terrain was too complex and there are several highly distorted elements, they easily lead to numerical divergence problem during initialization. To simplify the complicated topography, we did pretreatment that was based on the real terrain, the extraction of height, and a larger range of topographic features; the rest part and wellhead area was set to flat ground, simplified structure was shown in Fig. 3. Location of villages near the wellhead which blowout was marked in the map.

In order to study the law of gas dispersion affected by nearby villages and undulating terrain, different size rectangular platform structure was selected to characterize the local topography according to local terrain features. The rectangular specific size and coordinates of platform were shown in Table 1.

Based on the distribution of the terrain, the entities model was constructed in the Gambit. Because the wind environment was considered during the numerical simulation, enough space outside the terrain structure was set aside to ensure the atmospheric stability, so to construct the final topographic boundary conditions: 2500 m × 2500 m × 500 m hexagon prism, wellhead center coordinates was (0, 0, 0).

### 4.2. Geometry and grid

Hexahedral grid was used to mesh models. Computational domain was very large, at the same time sufficient accuracy needs to be considered, so it is necessary to make mesh of key parts

**Fig. 2.** The layout of Luojia 16H well site.