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Research on the temperature field of unconfined gas cloud explosion

Hemispherical finite element model of combustible gas was created by Fluent software to simulate the gas cloud explosion. The temperature field of unconfined gas cloud explosion was studied by data fitting. The result shows that, each monitoring point experienced four stages: rose to peak temperature; dropped to a high temperature quickly; maintained in this high temperature and lasted some time; declined slowly. Double fold line model can fit the curves of temperature change, and get the temperature-time functions finally.

Keywords: Gas cloud explosion; temperature field; fitting function; CFD

1.0 Introduction

In recent years, with the wide use of natural gas pipelines, gas accidents caused significant casualties and damage to the surrounding environment in China. Severe disasters urged the researchers to determine the scope of damage, predict the intensity of gas explosions, and put forward reasonable antiknock programmes in the process of building design and installation. The deflagration of gas cloud consists of the overpressure wave and flame wave. High temperature flame will affect the mechanical properties of building materials, causing warping or damage of building structures and burn nearby persons. Therefore, the research on temperature field of the gas cloud explosion is particularly important.

Liu Qingming [1] did some experiments with different concentrations of propane-oxygen gas mixture in a spherical combustion chambers, he used the sensors sticking on the inner wall of the combustion chamber to record the room temperature and studied temperature change regularity; Nie Baisheng et al. [2] based on radiation theory, proposed a method to obtain flame temperature by analysis of gas explosion in high-speed photography. Compared to experimental method, numerical method has been adopted by many researchers for lower cost and higher security. Bi Mingshu et al.[3] did a one-dimensional numerical simulation of flammable gas explosions in pipeline; Jiang Bingyou [4] studied the effect of the initial ignition temperature on flame propagation and distribution rule of temperature field in the long pipeline by numerical simulation method.

Smith, et al filled an enclosed space with methane-hydrogen gas, carried out a series of large gas cloud explosion tests [5].Yang Yi did some experiments and found that: if the flame wave encountered obstacles, it would bypass the obstacles, produce turbulence, flame speed and overpressure would increase [6]. The paper [7] used CFD method to calculate the possible overpressure in onshore and offshore facilities under the action of gas cloud explosion. The paper [8] simulated the explosion of liquefied natural gas in a refinery by CFD method. The paper [9] obtained the radiation damage effects and the determination of the damage radius by CFD method.

This article simulates methane-air premixed gas cloud explosion in open space by CFD software Fluent, and studies the temperature field by data fitting.

2.0 Verification of the numerical method

Hemispherical finite element model of combustible gas was created by FLUENT software to simulate the gas cloud explosion. The radius of gas cloud is 0.5m or 1m, the first monitor 1 is set from the hemispherical gas edge, and a number of equally spaced points are set respectively in the radial direction, spacing is 0.4m, as shown in Fig.1. The ignition region is set in the center of hemispherical gas cloud to trigger a chemical reaction, the radius is 2mm and

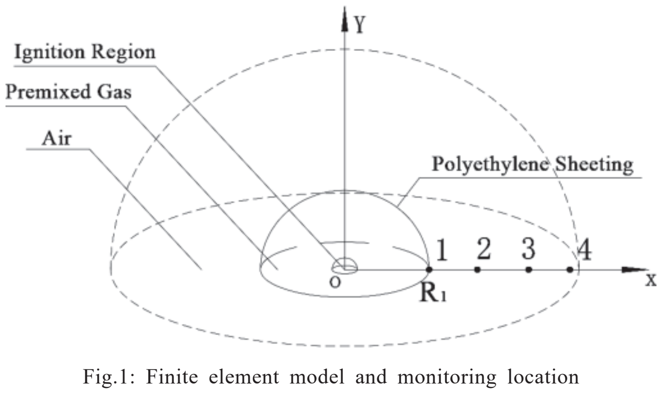

Fig.1: Finite element model and monitoring location

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TABLE 1: COMPARISON OF PEAK OVERPRESSURES BETWEEN NUMERICAL CALCULATION AND EXPERIMENTAL RESULTŸKPA

Radius of gas cloud/m		Distance from the explosion center r/m				
		1.4	1.8	2.2	3	5.4
0.5	Experimental result	3.326	2.958	1.952	0.947	0.419
	Numerical calculation	3.629	3.44	2.216	1	0.376
	Relative error/%	9.1	16.4	13.5	5.6	-10.36
1	Experimental result	4.528	3.937	2.811	1.513	0.704
	Numerical calculation	4.9	4.5	3.2	1.536	0.636
	Relative error/%	8.2	14.3	13.8	3.3	-9.66

TABLE 2: NUMBER AND LOCATIONS OF MONITORING POINTS

Number	1	2	3	4	5	6	7	8	9	10
Distance r/m	0.5	0.6	0.7	1	1.2	1.5	2.4	2.7	3.2	3.6

temperature is 1300K. The gas mixture region is full of acetylene-air gas, the volume fraction of acetylene is 13.3%, and the chemical reaction equation is a single and irreversible step:

$$2C_2H_2+5O_2=4CO_2+2H_2O \qquad \text{... (1)}$$

The overpressure peaks of each monitoring points are recorded and compared to experimental data [10], the calculated relative error is listed in Table 1. The maximum relative error is 16.4%, and the average relative error is 11%.

Simulation results agree with the experimental values, the relative errors may be caused by such reasons: a simplified reaction mechanism is chosen to reduce computation, which is different from the actual combustion process; some systemic errors of the model exist in Fluent software. The analysis of the results shows that the numerical modelling and simulation methods used in this paper are reasonable and feasible.

3.0 Numerical simulation and analysis of results

Extensive research shows that when flammable gases are mixed with air with the stoichiometric ratio, it will burn the most severely and have a maximum temperature. Therefore, gases are stoichiometric mixtures with air in the simulation.

Hemispherical finite element model is established, the computational domain is full of methane-air mixtures, the monitoring points are in the range of mixtures, the number and locations of monitoring points are listed in Table 2, and the ignition temperature is 1300K.

Fig.2 is temperature histories with time of each monitoring point, you can find that:

(1) The temperature of all monitoring points experienced 4 stages. Stage 1, "peak": as soon as the flame wave arrived, temperature rose to peak temperature suddenly; Stage 2, "drop": when the flame wave passed, temperature dropped to a high temperature quickly; Stage 3, "constant": temperature maintained in this high temperature and lasted some time; Stage 4, "decline": temperature declined slowly.

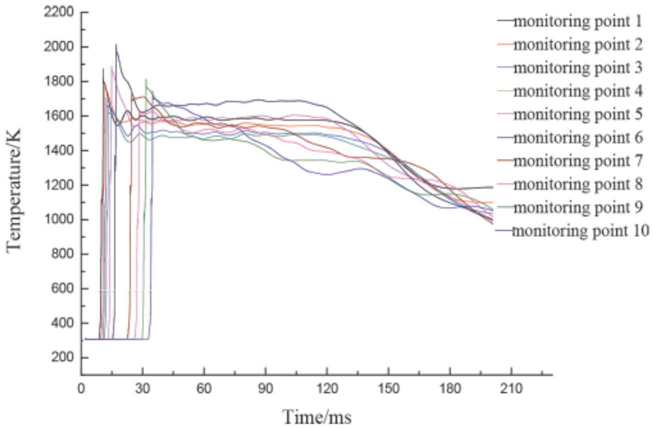

Fig.2: Temperature-time histories of all monitoring points

(2) The time when each monitoring point arrived at the peak temperature increased with the increase of the distance to the center of the explosion, the monitoring point at 1.5m reached the maximum peak temperature, about 2000K, peak temperatures of the other monitoring points were similar, about 1700K~1900K.

(3) Each monitoring point lasted similar time at Stage 3, about 85ms; constant temperature of the monitoring point at 1.5m was maximum, about 1670K, constant temperature of the others decreased with the increase of the distance to the center of the explosion.

(4) The temperature of each monitoring point declined after 120ms, and the declined rate were similar.

4.0 Temperature calculation formula of unconfined gas cloud explosion

According to temperature-time histories of all monitoring points, the curves can be simplified as a double fold line, as shown in Fig.3. Temperatures rise as a perpendicular and reach peak temperatures. Line AB is a horizontal line, line BC is an oblique line. The mean temperatures of each monitoring point at stage 3 are shown in Fig.4.

Table.3: The fitting function of line BC for each monitoring point

r/m	Fitting function	Coefficient A	Coefficient B	R^2
0.5	$T = -8.4453t + 2625.5$	-8.4453	2625.5	0.9594
0.6	$T = -7.5196t + 2483.9$	-7.5196	2483.9	0.9846
0.7	$T = -7.156t + 2442$	-7.156	2442	0.9481
1.0	$T = -7.1348t + 2406.4$	-7.1348	2406.4	0.9906
1.2	$T = -6.8383t + 2347.4$	-6.8383	2347.4	0.991
1.5	$T = -6.197t + 2263.8$	-6.197	2263.8	0.8995
2.4	$T = -5.679t + 2224.9$	-5.679	2224.9	0.8807
2.7	$T = -4.1531t + 1835$	-4.1531	1835	0.8986
3.2	$T = -3.9634t + 1865.8$	-3.9634	1865.8	0.8936
3.6	$T = -3.6477t + 1784.7$	-3.6477	1784.7	0.8798

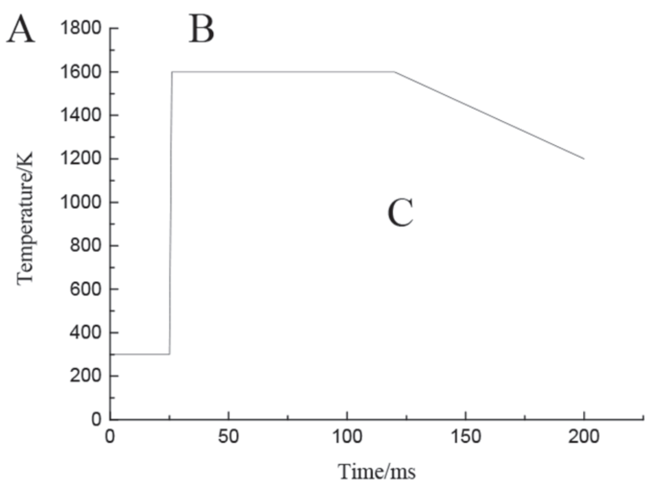

Fig.3: double fold line model of temperature

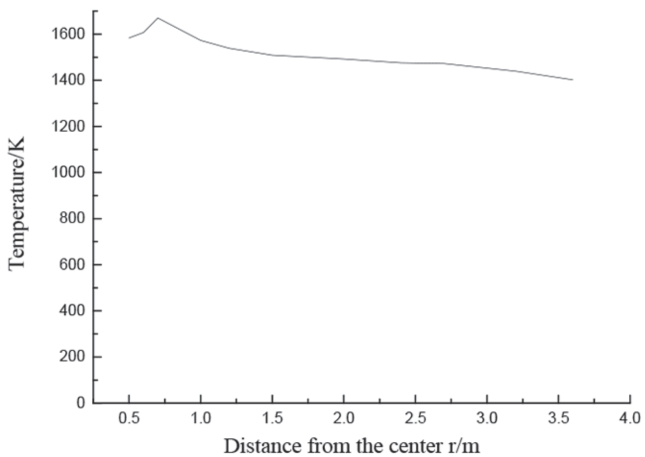

Fig.4: The mean temperatures of each monitoring point at stage 3

Use a linear function to fit line AB and BC. From Fig.4 you can see that, the mean temperature of monitoring point at 0.6m is maximum and then decreases with the increase of the distance to the center of the explosion. Use a linear function to fit line AB:

$$T_1 = -65.893 + 1638.7 \quad (2)$$

$$R^2 = 0.8982 \quad (3)$$

T_1 is the temperature of monitoring points/K, r is the distance from monitoring point to the center/m, R is correlation coefficient.

Use the formula (4) to fit line BC:

$$T_2 = At+B \quad (4)$$

The fitting functions of line BC for each monitoring point are shown in Table 3. The relationship between coefficient A and r is shown in Fig.5.

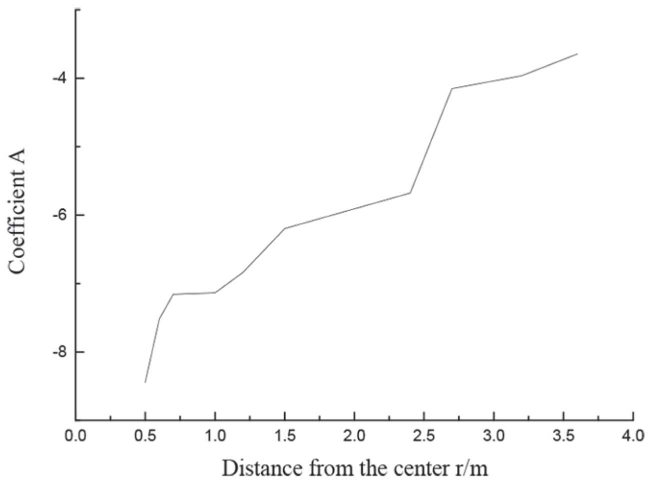

Fig.5: The relationship between coefficient A and r

So the relationship between coefficient *A* and distance *r* can be fitted as a linear function, the fitting equation is shown in formula (5). The relationship between coefficient B and distance r can be fitted by the same way, as shown in formula (7).

$$A=1.4145r-8.5346 \quad ...(5)$$

$$R^2 = 0.9493 \quad ...(6)$$

$$B = -250.34r + 2663.5 \quad ...(7)$$

$$R^2 = 0.9229 \quad ...(8)$$

5.0 Conclusions

This article simulates methane-air premixed gas cloud explosion in open hemispherical space using CFD software Fluent, monitors the temperatures of points at different distances, and studies gas explosion on the distribution rule of temperature field. The main conclusions are as follows:

(1) The temperature of all monitoring points experienced 4 stages. Stage 1, "peak"; Stage 2, "drop"; Stage 3, "constant"; Stage 4, "decline".

(2) Using double fold line model to fit the curves of temperature change, get the temperature-time functions.

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