NUMERICAL SIMULATION ANALYSIS ABOUT THE EXPLOSION PROPAGATION PROCESS OF PIPELINE GAS ON THE EFFECT OF COMPLEX OBSTACLES

XU Jing-de; LI Hui; HAO Xu; DUAN Xiao-ping

(North China Institute of Science and Technology, Yanjiao Beijing-East 101601)

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ARTICLE DETAILS

ABSTRACT

Article History:

Received 02 october 2017
 Accepted 06 october 2017
 Available online 11 october 2017

Keywords:

obstacles; natural gas explosion;
 FLACS; numerical simulation

Natural gas explosion seriously endanger social stability and public life property safety, study the pipeline gas explosion is high importance of the safety enterprise production and social stability. Through the theoretical analysis of the process of pipeline gas explosion, using FLACS software, and set up three control groups to compare the effects of obstacles with different size, different arrangement on the explosion propagation law of natural gas. It was discovered through the research of explosion parameters: obstacle has incentive effect on explosion propagation, the size is larger; the arrangement is more closely, the obstacles have greater impact on the flame front, propagation speed and explosion power of pipeline gas explosion. The production provide theoretical basis for the prevention and control of gas explosion accident.

1. INTRODUCTION

The completion of Sichuan Chongqing transmission gas pipeline in 1963 marked the beginning of China's development of natural gas pipeline engineering. Up to year 2015, China has already built 9 million kilometres natural gas pipeline, the total gas transport capacity of trunk pipeline network is more than 2000 billion steers each year. In the past ten years, there are about 0.5 million kilometre long natural gas pipeline built every year in China.

At present, natural gas pipeline industry still maintain the rapid growth momentum, pipeline transportation has become the basic way of natural gas transmission. However, due to lots of gas transmission pipeline has served for a long time and the working environment is very bad, besides, sweet natural gas without purification was allowed to be transferred directly through the pipeline, therefore, the pipeline has suffered serious corrosion; in addition, due to the limit of construction condition, welding level and many other reasons, there are more or less different size, different shape and different distribution of obstacles. Once the explosion occurred, these obstacles will have a profound impact on the explosion.

In recent years, a lot of research about the explosion propagation process of pipeline gas has been carried out both at home and abroad. Oh has done a series of experiments in a square container with obstacles in it. The experimental results show that the final explosion pressure and total pressure rise rate is not affected by the obstruction rate in closed container, and is only related to the concentration of mixed gas [1]. Lin Baiquan and others did gas explosion experiment in a pipeline with obstacles, the experiments show that the presence of obstacles accelerate the DDT process (deflagration and detonation transition) [2]. Professor Lu Shouxiang and Fan Baochun carry out a related gas explosion experiment in a 1.5m*0.1m*0.1m transparent pipe and get the result that gas explosion flame will produce different acceleration while meet obstacles with different shapes and different sizes [3].

However, the study on the effects of explosion propagation process by obstacles with different sizes, different distribution is still very lack. This paper based on natural gas pipeline explosion propagation characteristics, using professional gas explosion propagation simulation software FLACS, simulate the effect of different size, different arrangement of obstacles on gas explosion propagation law,

providing certain theoretical basis for further study of the natural gas pipeline explosion propagation characteristics, the formulation and implementation of explosion prevention and control technologies and measures.

2. Theoretical Analysis of Natural Gas Explosion Propagation

The main component of natural gas is methane and a small amount of ethane, propane and butane. Moreover, there are hydrogen sulfide, carbon dioxide, nitrogen and water vapor and traces of carbon monoxide and rare gas such as helium and argon. Therefore, in the numerical study, generally take natural gas explosion as the severe reaction of the mixture of methane gas and air in the high temperature and produce a large number of heat. The reaction equation is: $\text{CH}_4 + 2\text{O}_2 \rightarrow 2\text{CO}_2 + 2\text{H}_2\text{O}$ [4].

In the pipeline, when the natural gas reached the explosion conditions and lighted by incendiary source, a small fireball with the ignition source as the center will rapidly formatted, the fireball propagate abroad in the form of a layer by layer Concentric spherical wave. In the reaction process, the combustion products keep expanding, the unburned gas is compressed and produce pressure wave (precursor shock wave), the wave continue to spread to the unburned area and ignite unburned gas. It can be seen that the gas explosion propagation is the process of flame and pressure wave propagation. In figure 1, assume that the explosion occurred in a tubular space, the ignition is at the center of the left boundary, so the whole explosive region is divided into three: the burned area, the reaction zone and the non combustion zone

Fig.1 Methane-air explosion propagation structural diagram

On the propagation of explosion flame and explosion pressure wave, if encounter obstacles, then the flames will form high-gradient viscous boundary layer which results turbulence. Small scale turbulence enhances the exchange rate of local heat and mass, large scale turbulence twists flame front and increases the flame area, so the turbulent flow will increase combustion area and causing the flame acceleration, flame

acceleration will strengthen the turbulence which leads to further distortion of flame front, turbulence further aggravated, so turbulence and flame form a mutual incentive work and will produce DDT process when condition is mature^[5].

3. Model Building And Meshing

3.1 Mathematical Model

The explosion process in pipeline of natural gas is a fast combustion reaction process and satisfies the mass conservation, momentum conservation, conservation of energy and chemical group points balance equation, at the same time, the standard k - E model is used to describe the turbulent, the specific equations are as equation (1) to (6)^[6].

Mass conservation equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u_i}{\partial x_i} = 0 \quad (1)$$

Momentum conservatio equation:

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial}{\partial x_i} (\rho u_i u_j) = \frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} + \rho g_i + F_i \quad (2)$$

Energy conservatio equation:

$$E = h - \frac{p}{\rho} + \frac{u_i^2}{2} \quad (3)$$

Chemical group points balance equation:

$$\frac{\partial (\rho Y_{fu})}{\partial t} + \frac{\partial}{\partial x_i} (\rho u_i Y_{fu}) - \frac{\mu_e}{\sum_{fu}} \frac{\partial Y_{fu}}{\partial x_i} = R_{fu} \quad (4)$$

Standard K-ε turbulence model euqation :

$$\frac{\partial \rho k}{\partial t} + \frac{\partial (\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_i} \left[\mu + \frac{\mu_t}{\sigma_k} \frac{\partial k}{\partial x_i} \right] + G_k + G_b - \rho \epsilon - Y_M + S_k \quad (5)$$

$$\frac{\partial \rho \epsilon}{\partial t} + \frac{\partial (\rho u_i \epsilon)}{\partial x_i} = \frac{\partial}{\partial x_i} \left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon} \right) \frac{\partial \epsilon}{\partial x_i} \right] + C_{1\epsilon} \frac{\epsilon}{k} (C_k + C_{3\epsilon} G_b) - C_{2\epsilon} \rho \frac{\epsilon^2}{k} + S_\epsilon \quad (6)$$

t—Time, s; ρ —Density; X_i —Pipeline axial coordination, m; U_i —Kinetic Viscosity, Pa•s; P —Static Pressure, Pa; τ_{ij} —Stress Tensor; g_i —Gravity Force on i direction; F_i —external volume force on i direction; E —momentum, J; h —Enthalpy, J/mol; Y_{fu} ; R_{fu} —Chemical reaction rate.

3.2 Physical Model

The 5m*0.3m*0.3m pipeline was filled by 9.5% methane-air premixed gas the ignition is arranged in the left, ignoring the pipe wall thickness. Obstacles is set in model 2 to model 4, and make sure that all obstacles is set between 1.5m - 4m, which assure the simulation results is easy to compare. In the second and third model, five 0.1m*0.1m*0.1m size obstacles were set up, which were arranged by 0.6m equal distance in model 2 and in model 3 were scattered arranged. In model 4, five 0.05m*0.05m*0.05m size obstacles were set up in scattered arrangement. The specific

(b) Model 2: Big obstacles arranged in uniform distributed

(b) Model 3: Big obstacles uniformly distributed

(c) Model 4: Small obstacles non-uniformly distributed

Fig.2 Physical model of pipeline gas with different condition of obstacles(x-y direction)

3.3 Numerical Simulation Parameters Setting

Numerical simulation parameters in explosion process are set as follows:

In order to observe the change of the flame propagation speed in detail, each observation point was arranged at every 0.5m distance in the pipeline, which are totally 9, the monitor points are: (0.5,0.15,0.15); (1.0,0.15,0.15); (1.5,0.15,0.15); (2.0,0.15,0.15); (2.5,0.15,0.15); (3.0,0.15,0.15); (3.5,0.15,0.15); (4.0,0.15,0.15); (4.5,0.15,0.15).

Set the output variables for the pressure and reaction rate. Select the Single Field Scalar Time Output: P,T and VVEC(including U,V,W), and do the same setting in the Field 3D Output Single.

Set boundary conditions. All parameters in the Boundary Conditions are "EULER".

Set the initial conditions. In the Initial Conditions, Set the initial temperature for 20 degrees; set the initial pressure for 1000pa.

Set gas group. In the Gas Composition And Volume, set the Position Of Fuel Region is (0,0,0); set the Dimension Of Region is (5,0.3,0.3); set the Volume Fraction, because this time, only simulate methane-air mixture combustion gas, so set the volume fraction of methane is 0.0095.

Set the value of equivalent. Equivalence Ratios, refers to ER, in this software, the fraction of O₂ in the air was 20.95%, according to the definition of ER: Divided by the actual concentration ratio of combustible gas and oxygen in reaction and the concentration ratio of combustible gas and oxygen when the reaction is completely carried out. In this simulation:

$$ER = \frac{C_{CH_4}}{(100 - C_{CH_4}) * 20.95\%} \sim 1.002$$

Set the ignition conditions. Set the Position of Ignition Region is (0.01,0.15,0.15); set the Dimension of Ignition region) is (0,0,0); set the Time Of Ignition is: 0.

2.4 Grid Division

In order to improve the calculation speed of the software, set the grid size for 0.05m*0.05m*0.05m. Set the mesh region from (-0.5,-0.1,-0.1) to (5.5, 0.4, 0.4) in the pipeline. 120 grids is divided in the X direction, 10 is divided in both the Y and Z direction. So totally 12000 grids is divided in the

pipeline. Figure 3 is the model grid division result:

Fig.3 Grid Division

4. Numerical Simulation Results Analysis

4.1 Influence of Obstacles on The Pressure of Explosion Propagation

(a) Model 1: Without obstacles

(b) Model 2: Big obstacles arranged in uniform distributed

(c) Model 3: Big obstacles uniformly distributed

(d) Model 4: Small obstacles non-uniformly distributed

Fig.4 P-T Diagram of pipeline gas explosion propagation with different condition of obstacles

Through observing the change of explosion propagation pressure in four cases, one conclusion can be get that obstacles have little effects on the peak explosion pressure. The peak pressure maintain at 7.87P with or without obstacles, besides, through comparing different pressure-time diagrams, we can find that the explosion pressure situations are familiar with each other. So, it can be confirmed that the existence of obstacles has very little effect on explosion pressure.

4.2 Influence of Obstacles on The Explosion Temperature and Flame Propagation

Obser vation points	Highest Temperature/K				Time to Reach the Highest Temperature/s			
	Mo del 1	Mo del 2	Mo del 3	Mo del 4	Mo del 1	Mo del 2	Mo del 3	Mo del 4
1	278	278	279	278	1.1	0.6	0.6	0.9
	3.94	7.87	1.52	3.07	6	2	6	5
2	270	269	270	271	1.1	0.6	0.6	0.8
	2.97	3.56	5.23	8.82	8	2	1	9
3	264	263	263	263	1.2	0.5	0.6	0.9
	5.68	9.47	9.53	9.50	0	8	5	1
4	259	258	258	259	1.1	0.4	0.6	0.9
	4.44	1.40	2.79	7.84	6	6	8	5
5	255	256	254	255	1.1	0.6	0.6	0.9
	9.16	8.52	9.73	9.06	5	2	6	0
6	251	252	251	253	1.2	0.6	0.6	0.9
	7.60	1.27	6.59	2.97	5	2	8	5
7	247	247	249	246	1.2	0.6	0.6	0.9
	0.04	9.63	3.50	8.37	5	2	8	5
8	243	243	243	243	1.2	0.6	0.6	0.9
	6.49	7.92	7.40	6.29	5	2	8	5
9	241	241	241	241	1.1	0.6	0.6	0.9
	3.94	4.03	4.56	4.28	5	0	6	1

Table 1 Comparison of Pipeline Gas Explosion Temperature With or Without Obstacles

According to the comparison of pipeline gas explosion temperature with or without obstacles, it can be seen that obstacle has little effect on the highest explosion temperature, the highest explosion temperature measured under various conditions are very close. However, the time to reach the highest temperature is of great difference under different conditions. The time to reach the highest temperature of each observation points without obstacles greatly exceeds the time with obstacles. The time to reach the highest temperature is the shortest in model 2 when all obstacles are arranged in continuous equal distance. Comparing model 3 and model 4, we can find that the volume of obstacles in pipeline is bigger, the time to reach the highest temperature is shorter. Therefore, it can be inferred that the existence of obstacles has incentive effect, it can accelerate the flame propagation, when there are obstacles in large size and are continuously arranged, the time to reach the highest explosion temperature will be greatly increased.

(a) Model 1: Without obstacles

(b) Model 2: Big obstacles arranged in uniform distributed

(c) Model 3: Big obstacles uniformly distributed

(d) Model 4: Small obstacles non-uniformly distributed

Fig.5 Temperature cloud of pipeline gas explosion propagation with different condition of obstacles

Through the temperature cloud picture of explosion field under different conditions, the flame front can be found stretched just before obstacles. Compared with model 2 and model 3. It is found that compared to the decentralized arrangement, obstacles which are continuously arranged has more violent effect on the tensile deformation of flame front. Compared to model 3 and model 4, it can be found that larger obstacles make the tension deformation of flame front more violent. Therefore, it can be considered that the size is larger, the arrangement is more compact, the flame front will be stretched more violent when explosion occurred^[7].

4.3 Influence of Obstacles on The Explosion Propagation Speed

(a) Model 1: Without obstacles

(b) Model 2: Big obstacles arranged in uniform distributed

(c) Model 3: Big obstacles uniformly distributed

(d) Model 4: Small obstacles non-uniformly distributed

Fig.6 Velocity Vector Diagram of pipeline gas explosion propagation with different condition of obstacles

The explosion velocity vector can be observed that, without obstacles, the explosion propagation is very normal: explosion propagation velocity increase first to reach the peak in the middle of the explosion field, after that, it gradually decreases; and in the existence of obstacles, the velocity change is more complex: because of the existence of obstacles, the flame front is stretched in front of them, so the flame propagation turbulence present near the obstacles and the turbulence level varies directly with the size of obstacles and made disturbance of flame propagation velocity. The flame velocity increases before arriving obstacles and rapidly decreases after passing them, and then sharply increase again^[8]. So, it can be considered that, the explosion speed changes more complex, the flame is stretched more serious.

Table 2 Comparison of The Pipeline Gas Explosion Velocity and The Change With and Without Obstacles

Observation points	Maximum Speed/m/s				Time to Reach the Maximum Speed/s			
	Mode 1	Mode 1	Mode 13	Mode 14	Mode 1	Mode 12	Mode 13	Mode 1
	1	1	13	14	1	12	13	1
	1	2			1			4
1	23.43	23.34	23.41	23.47	0.054	0.055	0.055	0.054
2	44.12	42.89	43.40	44.02	0.081	0.081	0.081	0.081
3	52.32	57.25	57.41	54.84	0.089	0.090	0.090	0.089
4	39.48	39.02	39.21	39.75	0.089	0.090	0.090	0.090
5	34.09	33.90	33.33	33.83	0.088	0.089	0.089	0.089
6	28.26	28.27	30.97	29.12	0.087	0.088	0.088	0.088
7	21.99	22.49	22.67	22.38	0.086	0.087	0.087	0.087
8	15.14	16.56	17.05	15.54	0.086	0.086	0.086	0.086
9	7.76	7.67	8.08	7.70	0.086	0.086	0.086	0.086

The explosion speed change can be more observed more intuitively through table 2: the maximum transmission speed is highest when the obstacles is in big size and continuously arranged, next came the situation which big obstacles arranged discontinuously. When the obstacles are in very small size, the explosion speed changes little compared with the situation without obstacles. Without obstacles, the explosion speed changes regularly: increases from 2.677m/s at 1 observation point to 10.895m/s at 3 observation point, and then slowly decreases to 0m/s; in model 2, the obstacles are arranged continuously and compactly from 3 observation point to 8 observation point, in this region, the explosion spread rapidly increased while it violent decrease in 9 observation point after pass the obstacles; in model 3, the obstacles are in dispersive arrangement, the explosion speed firstly increased sharply passing by the first obstacle and then gradually down to normal because of the long distance to the next obstacles and reaccelerate in face of the second obstacle. However, if the obstacle size is very small, the speed changes very gentle. Therefore, it can be thought that obstacles have great influence on explosion propagation speed, furthermore, the size is bigger and the arrangement is more close, the speed changes more complex.

4 Conclusion

(1) The existence of obstacles has little effects on the pipeline gas explosion peak pressure, but obviously affects the shape of the flame front and the distribution of the velocity field.

(2) Obstacle has incentive effect, it will cause flame fronts tensile deformation, flame acceleration, besides, the size is bigger, the arrangement is more compact, the influence on flame fronts tensile deformation surface tension and velocity change is larger. It reveals the positive feedback mechanism which obstacles and turbulence causes flame acceleration.

(3) The pipeline situation should be regularly maintained when the natural gas is transported to prevent pipeline rupture and cause explosion. At the same time, it should consider optimize pipeline welding, reinforcement technology to avoid the existence of pipeline obstacles and ensure that the inside of the pipe is smooth without obstacle as far as possible.

(4) Next step, considering research the influence of obstacles on the pipeline gas explosion propagation in different blockage ratio and analysis obstacles' blocking limits to seek in which blockage ratio will the effect of obstacles to the pipeline gas explosion propagation reaches a maximum.

This work are financial supported by Natural Science Foundation of China a General Program (Grant NO. is 51374108) and the Fundamental Research Funds for the Central Universities (Grant NO. is 3142015122, 3142015118).

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