Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 26 (2011) 1563 – 1570

Procedia Engineering

www.elsevier.com/locate/procedia

First International Symposium on Mine Safety Science and Engineering

Numerical Simulation on the Gas Explosion Propagation Related to Roadway

Yan Aihua[a] , Nie Baisheng[b], Dai Linchao[b],

Zhang Qinqin[b], Liu Xinna[b], Yang Hua[b], Liu Zhen[b],Hu Tiezhu[b] a*

[a]*Research Center of State Administration of Work Safety P.R.C, Beijing 100713,China*
[b]*Faculty of Resource and Safety Engineering, China University of Mining & Technology, Beijing 100083, China*

Abstract

Based on the combustion, explosions and air dynamics and related theory etc, this paper describes the mathematical model of gas explosion in detail, combined with the gas explosion transmission mechanism, make a research on two wave-three area structure of gas explosion and the energy change rule of the array face of precursor wave and the array face of flame wave, with the fluid dynamics analysis Fluent software, this paper makes a numerical simulation and analysis on the overpressure transmission rule when gas explosion takes place in different types roadways. The results of the study show that: Fluent software can be used to accurately simulate gas explosion condition, when explosion wave spreads in the roadway turns, the bigger of the overpressure value in corner, the stronger of the destructive power; when tunnel has bifurcation, the overpressure will release in bifurcation, but explosions wave with flame wave will produce more powerful destruction effect. The research results can be used as a certain reference for how to prevent and control the gas explosion, and how to reduce the power of the gas explosion etc.

Selection and/or peer-review under responsibility of China Academy of Safety Science and Technology, China University of Mining and Technology(Beijing), McGill University and University of Wollongong.

Keywords: Gas explosion; Fluent software; Roadway; Numerical simulation

1. Introduction

Underground mining accounts for 95% in our country's coal mining. Because of the complex geological conditions, major disaster accidents occurred from time to time in the course of resources

* Corresponding author. Tel.:01082375620
E-mail address: bshnie@163.com

1877-7058 © 2011 Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
doi:10.1016/j.proeng.2011.11.2339

exploitation [1]. According to the statistics, in these accidents, the gas explosion happens at most, and the harm and loss caused by them also is the most serious. The destruction of the underground ventilation system, the turbulence of atmospheric, and the spread of the poisonous and harmful gas are caused by the gas explosions, and sometimes even lead to continuous gas explosion, it makes great difficulties and dangers to the underground staff's personal safety and the rescue work at the later period [2].

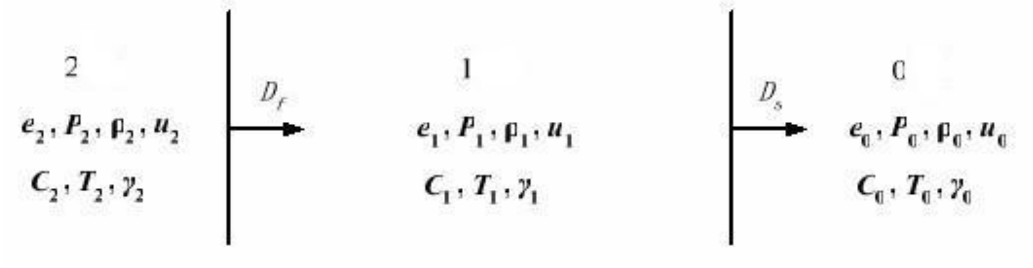
In order to research how to effectively prevent and control the gas explosion, through the experiment means, a large number of studies about the gas explosion mechanism and characteristics were made by the scholars at home and abroad. Faireweathe etc. [3]make an gas explosion experiment in a pipe, the pipe with two ring shape obstacles diameter for 288mm and long 84mm. Xu Jingde et al [4] make a number of related gas explosion experiments utilize the roadway model, it section 7.2 m^2 semicircle arch and long 710m which is available for the experiment. He Xueqiu et al [5,6] used a pipe which section for 80mm×80mm and long 24m make a gas explosion experiments, take a research on the flame microstructure and flame propagation mechanism in the process of gas explosion. Due to the numerical simulation method can save the expensive cost for some experiments, therefore, it gets attention from people. At present many domestic and foreign scholars have done some simulation works related to all aspects of gas explosion process, but simulation mainly is numerical simulation which is based on the experiment in the pipe [7-15]. Because of the geological factors and the needs of production, tunnels arrangement in the mine is very complex, the roadways are related with each other more, the tunnel turns and roadway bifurcation can be seen everywhere in the underground tunnel pipeline network system. Therefore, it is very significant to research on the spread change rule of gas explosion that happened in some place which tunnel physical construction is complex.

Based on the above analysis, this paper uses fluid dynamics and fluent software to make numerical simulation and analysis the overpressure propagation rule when gas explosion happens in some complex roadways, such as turns, bifurcation, etc, thereby studies the influence of the roadways on gas explosion.

2. The mechanism analysis of propagation process of gas explosion

2.1 The theory analysis of gas explosion propagation

Premixed gases, short for the mixture of methane and air, could be referred to as the fuel gas. If the explosive premixed and the high temperature source of ignition coinstantaneous exist, then the gas will be lit by the source of ignition and form first flame, at the condition of atmospheric pressure, the thickness of the flame is very thin, only 0.1 ~ 0.01 mm, it is a burning belt and spread in the premixed gas. In the combustion process, if the flame restrained, or spread accelerate gradually caused by the disturbance in the premixed gas, then it will produce some pressure, forming the pressure wave, this process is called deflagration. Deflagration is a kind of combustion with pressure wave, burning flame spread in subsonic, the pressure wave is spread in local speed, it marched in the front of flame face, also be called precursor wave. So, a deflagration wave in the process of march forward forms three flow field area [6] (see figure 1).



e :Specific energy; P :pressure; ρ :density; u :velocity; c :velocity of sound; T :temperature; γ :isentropic exponent
area 0—The initial state of combustible mixture; area 1—The state after the precursor wave through ;area 2—The condition after flame surface through

Fig.1 Three flow field areas of deflagration wave

2.2 The mathematical model of gas explosion

Gas explosion is a quick combustion reaction process, meets the mass conservation equation, momentum conservation equation ,energy conservation equation and the chemical composition of balance equation, and meanwhile use the standard $k-\varepsilon$ model to describe the turbulence, equation such as type (1) ~ type (6) shows, including specific symbol meaning see literature [16,17] as shown.

Mass conservation equation：

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

Momentum conservation equation：

$$\frac{\partial \rho u_i}{\partial t}+\frac{\partial}{\partial x_i}\left(\rho u_i u_j - \mu_e \frac{\partial u_i}{\partial x_j}\right)=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu_e \frac{\partial u_j}{\partial x_j}\right)-\frac{2}{3}\frac{\partial}{\partial x_j}\left[\delta_{ij}\left(\rho k+\mu_e \frac{\partial u_k}{\partial x_k}\right)\right] \qquad (2)$$

Energy conservation equation：

$$\frac{\partial \rho h}{\partial t}+\frac{\partial}{\partial x_j}\left(\rho u_j h-\frac{\mu_e}{\sigma_h}\frac{\partial h}{\partial x_i}\right)=\frac{Dp}{Dt}+S_h \qquad (3)$$

The chemical composition of balance equation：

$$\frac{\partial\left(\rho Y_{fu}\right)}{\partial t}+\frac{\partial}{\partial}\left(\rho u_j Y_{fu}-\frac{\mu_e}{\sigma_{fu}}\frac{\partial Y_{fu}}{\partial x_i}\right)=R_{fu} \qquad (4)$$

The standard $k-\varepsilon$ model equation：

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

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

In the equation, the model constants value is：

$C_{1s} = 1.44, C_{2s} = 1.92, C_{\mu} = 0.09, \sigma_k = 1.0, \sigma_s = 1.3$.

2.3 The mathematical equations description of gas explosion wave

(1)The array surface of precursor wave

As shown in fig.1, the interface from area 1 to area 0 is the array surface of precursor wave, there are mixed gas which is undisturbed in the area 0, the state on both sides of a planar precursor wave can list three conservation equation [15]:

Mass conservation equation:

$$\rho_1(D_s - u_1) = \rho_0 D_s \qquad (7)$$

Momentum conservation equation:

$$p_1 + \rho_1(D_s - u_1)^2 = p_0 + \rho_0 {D_f}^2 \qquad (8)$$

Energy conservation equation:

$$e_1 + \frac{p_1}{\rho_1} + \frac{(D_s - u_1)^2}{2} = e_0 + \frac{p_0}{\rho_0} + \frac{{D_s}^2}{2} \qquad (9)$$

（2）The Array face of flame wave

The state on both sides of a planar flame wave in figure 1 can show as the following equation:

Mass conservation equation :

$$\rho_1(D_f - u_1) = \rho_2(D_f - u_2) \qquad (10)$$

Momentum conservation equation:

$$p_1 + \rho_1(D_f - u_1)^2 = p_2 + \rho_2(D_f - u_2)^2 \qquad (11)$$

Energy conservation equation:

$$e_1 + \frac{p_1}{\rho_1} + \frac{(D_f - u_1)^2}{2} = e_2 + \frac{p_2}{\rho_2} + \frac{(D_f - u_2)^2}{2} \qquad (12)$$

The specific symbol meaning in the equations see literature [15] as shown.

3. The influence of the roadway turn to the spread of gas explosion

3.1 The roadway model

Supposing that the specification of the two-dimensional tunnelling roadway is 100m×2m, and there is a 90° turn in the roadway whose length is 50m, 100m away from the driving surface, besides, the roadway is evenly full of the gas whose concentration is 9.5%.The schematic diagram of the roadway model is shown in Fig.2.

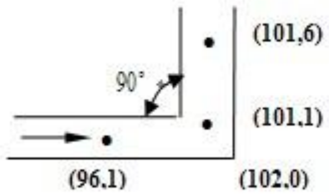


Fig.2 Schematic diagram of the turning roadway model

3.2 Numerical simulation result

Conduct the numerical simulation of the gas explosion of the roadway model shown in the Fig,1 using the Fluent software, then the explosion overpressure law of the 1# feature point (96,1), 2# feature point (101,1), 3# feature point (101,6) can be gained, as it shows in Fig.3.

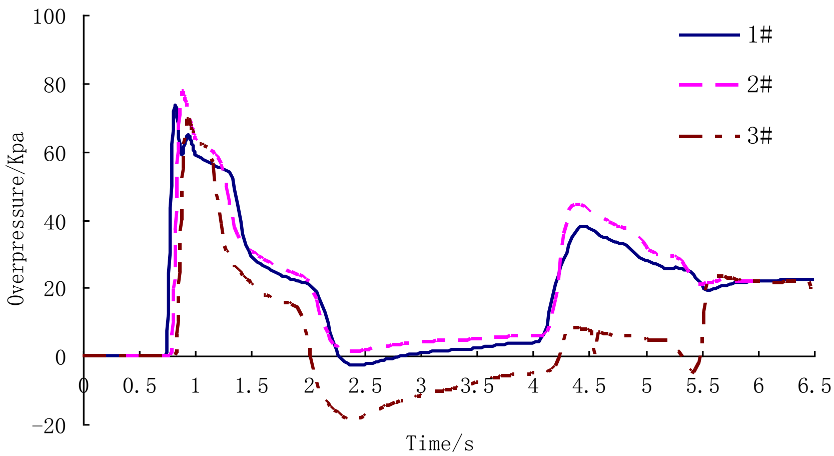


Fig .3 Overpressure-time curve of characteristic point

It can be known from Fig.3 that the maximum overpressure value of the 2# feature point is a little bigger than that of the 1# and 3#. In the meantime, the gas explosion wave in each point has appeared the quite obvious structure of two-wave and three-district, among that, the first pressure crest wave value appears earlier in the time about 0.8s~1.0s. It is caused by the precursor pressure surge of front flame which condenses the unracted gas. And the second pressure peak appears approximately in the time period of 4.3s~6s, it is caused by the rapid expansion of the product gas when the flame wave of the gas explosion arrives.

In order to analyze the influence of the turning roadway to the spread of the explosion pressure wave deeply, take the overpressure value of the feature point（96,1）as the reference data(denoted as P_o), then calculate the ratio of the overpressure value with its pressure respectively of the other feature point in the roadway, and the result is shown in Tab.1.

It can be seen from the chart1 that the overpressure values of the feature point (101,1) and (102,0) in the roadway turn can reach 77.66KPa and 85.37 KPa respectively, and it is bigger than that of the horizontal feature point (96,1) obviously. What's more, the overpressure value of feature point(102,0) in the turn reaches the maximum. Therefore, it can be illustrated that the turn in the underworkings can reinforce the effect of the gas explosion, thus warning the operating persons under the pit not to deposit or deposit less equipments around the corner. So the unnecessary loss caused by the gas explosion accidents can be avoided.

Tab.1 Overpresssure of characteristic points

Number	1#	2#	3#	4#	5#
Coordinate/m	(96,1)	(101,1)	(101,6)	(100,2)	(102,0)
The maximum overpressure/KPa	73.58	77.66	69.51	58.13	85.37
Corresponding time/s	0.82	0.885	0.93	0.925	0.87
The change rate P/P_0)	1	1.06	0.94	0.79	1.16

4. The influence of the bifurcation in the roadway to the spread of the gas explosion

4.1 Physical model

Supposing that there is a two-dimensional roadway with bifurcation, and the schematic diagram of its physical model is shown in Fig.4. Both the intersection angle of the roadway with bifurcation and the tunnelling roadway is 90° .The corresponding coordinates in the figure is the feature points selected correspondingly. Just the same, it is considered that the roadway is evenly full of the gas whose concentration is 9.5%.

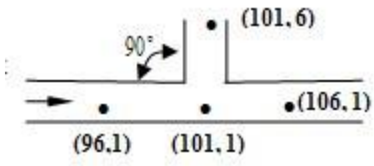


Fig.4 schematic diagram of the roadway model with bifurcation

4.2 Numerical simulation result

Conduct the numerical simulation analysis of the gas explosion in the roadway with bifurcation shown in the Fig.3 respectively, select the feature points to monitor, then the law that the explosion pressure of the feature points in the roadway with bifurcation changing with time can be reached. The result is shown in Fig.5.

Just as the idea using in the 3.1 when we analysis the roadway with turn, take the pressure of the feature point（96，1）as the benchmark. Then calculate the overpressure value of each feature point in the roadway with bifurcation. The result is shown in Tab.2.

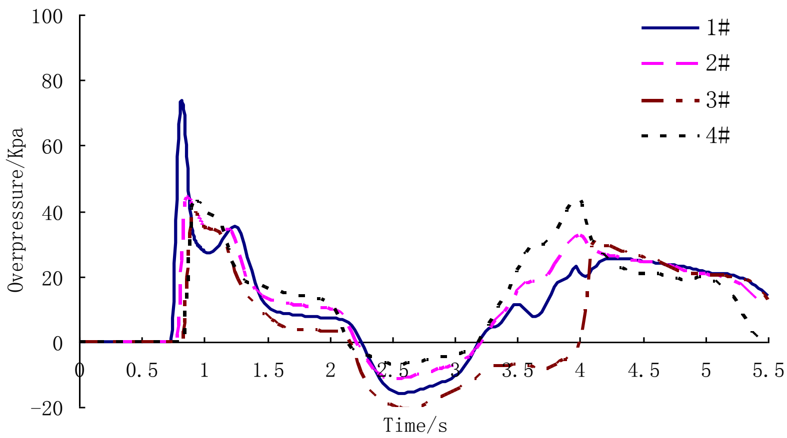


Fig.5 Overpressure-time curve of feature points

Tab 2 The maximum pressure of the feature points

Number	1#	2#	3#	4#	5#	6#
Coordinate/m	(96,1)	(101,1)	(101,6)	(106,1)	(100,2)	(102,2)
The maximum overpressure/KPa	73.57	44.24	40.02	43.91	40.17	45.83
Corresponding time/s	0.82	0.865	0.92	0.935	0.84	0.88
The change rate (P/P_0)	1	0.60	0.54	0.59	0.55	0.62

It can be known from the Fig4 and Tab2 that the gas explosion wave in each point has appeared the quite obvious structure of two-wave and three-district. And the maximum overpressure value of the feature points 2#、3#、4# and 5# is obviously low than that of the feature points 1# and 6#, which illustrates that the obvious decompression effect of the roadway with bifurcation to the spread process of the gas explosion. However, the maximum overpressure value of the gas explosion appeared the second time in the roadway with bifurcation everywhere is higher than that in the straight roadway. In this way the damage degree caused by it will be more serious.

5. Conclusion

From the point of view of explosion wave energy, make a research on change rule of explosion wave in two wave-three area structure, describes the energy change rule of the array of precursor wave and flame wave surface in the process of gas explosion. Using Fluent software to makes a numerical simulation and analysis on the overpressure transmission rule when gas explosion takes place in different types roadways. The results of the study show that: when the explosion wave spread in tunnels, the overpressure in the corner is higher than the overpressure in other position; when tunnel has bifurcation, the overpressure will release in bifurcation. Through the above analysis, the results can be used as the theoretical reference for prevent and control the gas explosion.

Acknowledgements

Financial support by the opening project of Henan key laboratory of coal mine methane fire prevention HKLGF(200907).

References

[1] YU Bufan. Prevention of coal-mine gas hazards and utilization manual(revised edition) [M]. Beijing: Coal Industry Press,2005.

[2] ZHOU Shining, LIN Boquan. The prevention theory and control technology of coal gas dynamic disaster[M].Beijing: Science Press,2007.

[3] FAIR Weather M.Studies of premixed flame propagation in explosion tubes[J].Combustion and Flame, 1996,116: 504-518.

[4] XU Jingde, XU Shengli, YANG Gengyu. Experiment study on mine gas explosion transmission [J]. Coal Science and Technology, 2004,32 (7): 55-57.(In Chinese)

[5] HE Xueqiu ,YANG Yi, WANG Enyuan, et al. Effects of obstacle on premixed flame microstructure and flame propagation in methane/air explosion [J].Journal of China Coal Society, 2004, 29(2):186-189 . (In Chinese)

[6] Baisheng Nie, Xueqiu He, Ruming Zhang et al. The roles of foam ceramics in suppression of gas explosion overpressure and quenching of flame propagation[J], *Journal of Hazardous Materials*, 2011, 192(2):741-747.

[7] XU Shengli, ZHANG Hongjie,YUE Pengtao,etc. Study on properties of pressure waves generated by steady flames in a duct[J].Journal of university of science and technology of China,2000, 30(8):387-392. (In Chinese)

[8] WU Bing, ZHANG Licong, XU Jingde. Numerical Simulation of Shock Wave Induced by Moving Flame for Gas Explosion [J].Journal of China University of Mining and Technology,2005,34(4): 423-426. (In Chinese)

[9] YANG Guogang,DING Weixin. Experimental and simulation of flammable vapor cloud explosion[J]. Journal of China coal society, 2004, 29(5):572-575.(In Chinese)

[10] LIN Baiquan, GUI Xiaohong. Numerical simulation research on flame transmission in gas explosion[J]. Journal of China university of mining and technology, 2002, 31(1): 6-9. (In Chinese)

[11] WANG Zhirong. Limited space and dynamics of gas explosion propagation[D].Nanjing :Nanjing university of technology,2005. (In Chinese)

[12] LI Jiangtao. Numerical simulation of micro-tube structure on the inhibition of flame propagation[D].Dalian : Dalian university of technology,2006. (In Chinese)

[13] Michele Maremonti et al. Numerical simulation of gas explosion in linked vessles. Journal of Loss Prevention in the Process Industries, 1999 ,12 :189-194

[14] E Salzano et al. Numerical simulation of turbulent gas flames in tubes[J]. Journal of Hazardous Materials, 2000,95: 233-247

[15] Bretislav Janovsky. Petr Selesovsky, Jan Horkel and Lukas Vejsa.Vented confined explosions in Stramberk experimental mine and AutoReaGas simulation. Journal of Loss Prevention in the Process Industries, 2006,19(2-3): 280-287

[16] ZHOU Lixing. Combustion theory and chemical fluid mechanics [M]. Beijing: Science Press,1986.

[17] Cheng Wang, Jianguo Ning, Tianbao Ma, Numerical Simulation of Detonation and Multi-Material Interface Tracking, Computers, Materials & Continua, 2011(22):73~96.