CHEMICAL ENGINEERING TRANSACTIONS
VOL. 66, 2018
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet
Guest Editors: Songying Zhao, Yougang Sun, Ye Zhou

ISBN 978-88-95608-63-1; **ISSN** 2283-9216
DOI: 10.3303/CET1866099

Application Research of Mathematical Economic Model in Terms of Gas Distribution and Reconstruction of Distribution Field in Coal Mine Stope

Jingguo Du[a,b], Jianxun Jiang[a], Yongqing Wang[a*], Xun Chen[b], Chenjun Wang[b]

[a] College of Oil and Natural Gas Engineering, South Pertroleum University, Suchuan 610500, China
[b] College of Mining Engineering, North China University of Science and Technology, Hebei 063210, China
carlpetrol@yeah.net

Research of the application on Mathematical Economic Model in Terms of Gas Distribution and Reconstruction of Distribution Field in Coal Mine Stope The research is divided into 2 sections, the first section is to analyze the application of mathematical economic model in coal mine stope gas distribution; The second section is to analyze the application of mathematic economic model in reconstruction of coal mine stope gas distribution field. From the perspective of mathematic economy, when there are a lot of data samples participating in distribution field reconstruction, the reconstruction based on neutral network algorithm is slightly superior to space information statistical approach. When there are a few data samples participating in reconstruction, the spatial system statistical approach is obviously superior to neutral network reconstruction approach in terms of reconstruction result. It is essential to choose coal mine stope gas distribution field reconstruction method scientifically so as to reduce occurrence of gas accident.

1. Introduction

Gas accident is a kind of most serious accident form, and it often causes a lot of life and personal injuries and major economic loss. During the explosion accidents of coal mine gas, most of which happens in the recovery and excavation area. Recovery and excavation area roadway is the main gas discharge area, and gas accumulation is easy to occur here. Computer numerical simulation is mainly adopted for the gas distribution in the excavation roadway wind flow, and the gas distribution rule can be recognized and ventilation design can be optimized but it is impossible to judge and predict the gas discharge and accumulated district according to the concentration of field gas and effective analysis can not be also made to the gas distribution in the stope according to gas concentration date of coal mine actual measurement. Utilizing field gas concentration monitoring data to reconstruct gas distribution field can achieve quantification cognition for stope gas distribution to define gas discharge and accumulated areas quickly. In this way, the gas accidents can be further reduced to reduce economic loss and social loss arising from gas accidents.

Therefore, the paper mainly performs theoretic and experimental analysis based on gas distribution law and studies reconstruction technology of gas distribution field. Only based on the distribution rule of stope gas can we further use related experiments to find out the frequent occurrence points of gas accidents, and propose basic requirements for gas monitoring of working face. And then based on the point, reconstruct the distribution field of gas.

2. Literature review

The stope is the general name for a mining area, including the mining face, the heading face, the coal seam, the goaf, the ventilation tunnel and the transportation lane, etc., which are the important components of the mine ventilation system. The ventilation flow field of stope is a composite flow field including coal mining and heading face and goaf. Because the geometric boundary shape of the ventilation flow field of the stope is extremely irregular and the distribution of the flow pattern is very irregular, the gravity action of the stope in the steep seam is equal to the mechanical ventilation pressure P, so the flow field in the stope is a rather

Please cite this article as: Du J., Jiang J., Wang Y., Chen X., Wang C., 2018, Application research of mathematical economic model in terms of gas distribution and reconstruction of distribution field in coal mine stope, Chemical Engineering Transactions, 66, 589-594 DOI:10.3303/CET1866099

complicated flow field. The gas accumulation area is related to the source of gas, and is affected by the shape of the space, causing the joint action of local turbulence and air flow. Therefore, a simple analysis method cannot be used in the study. It is necessary to combine the wind flow and the gas concentration distribution field by combining the field theory analysis method with the test and actual field measurement and combine the gas migration law with the flow of the tunnel and combine the numerical simulation with the calculating machine to realize the quantitative research on mine gas distribution under turbulence state.

Ventilation in the working face not only flows in the roadway, but also causes the corresponding gas flow in the adjacent goaf. Stope is not only the main place for mining, tunnelling, transportation and other related production activities, but also the most concentrated area of gas emission in the whole mine. The gas composition of the whole mine is mainly from stope. After the production activities such as coal mining and tunnelling, such as coal wall, roof and floor, goaf, coal and other areas gushed out, the gas in the stope is mixed and dispersed in the flowing stope air, accompanied by corresponding flow and diffusion. The movement of gas in ventilation and airflow of stope follows the law of dispersion of fluid dynamics (Pinetown, 2014). Since 1980s, a great number of theoretical, experimental and computer simulated numerical research and analysis have been carried out on the research of mine gas distribution in the domestic research institutes, and a great number of valuable research results have been obtained, and the distribution and migration laws of gas under different conditions of the mine have been basically mastered. Especially with the progress of fluid dynamics and numerical calculation methods, the analysis and understanding of gas flow and gas distribution in stope have also been greatly improved. In recent years, Computational Fluid Dynamics (CFD) has been developed rapidly and widely used (Tanguturi and Balusu, 2014), At the same time, it also promoted the research and in-depth study of the air flow and gas distribution in the stope area.

Wang and others pointed out that the domestic scholars first put forward the research method of applying seepage theory to the analysis of the air flow in the working face and goaf (Wang et al., 2014), a unified seepage mathematical model based on mass conservation principle is established. In addition, using the observation data obtained from the observation point in the stope and using the finite element method to calculate the reverse osmosis coefficient, the mathematical model is closer to the reality, and the finite element method is used to obtain the results. The quantitative analysis of the air flow status of the stope is a step further than the ideal fluid hypothesis. The mathematical model of three-dimensional steady seepage and gas distribution in stope and its Galerkin finite element method are further improved to further improve the numerical model of gas distribution in stope. Frippiat and others using the Fortran language to write a stope ventilation simulation system software (Simulation System for the Ventilation of Fields, referred to as SSVF), which can be used to simulate the natural fire sources of different positions and the diffuse state of the fire gas. According to the simulation results, the prevention and control schemes and measures of the phase can be formulated (Frippiat et al., 2015). In the study, Wang and others said that Professor Ding Guangxiang of China University of Mining and Technology, in view of the irregular geometric boundary and the complex distribution of the stope, has complicated flow field in the mining field with the complex distribution of gravity and mechanical pressure. The basic principle of similar theory is proposed to solve the problem of fluid dynamics in the field flow field. The composite Euler criterion is proposed and the characteristics of turbulence independence are demonstrated (Wang et al., 2015).

Field reconstruction technology, and data visualization technology, field reconstruction technology and computer imaging technology belong to a category. Because the technology needs a lot of data processing and analysis, the technology is basically a new field of research with the development of computer technology, which is the computer technology, graphics and images. A variety of theories, methods, and techniques that can be converted into a figure or image based on a certain amount of data, which can be converted to a figure or image by a variety of display devices (Nazarova et al., 2014). Computed Tomography (CT) is the most representative of various field reconstruction techniques, and CT technology is produced in 1970s. It has been applied in many fields of science, such as medical diagnosis and pathology, industrial detection and non-destructive detection. CT technology is based on projection image reconstruction technology, that is, by projecting multiple axes of an object and reconstructing the target image with projection. Different types of CT imaging techniques, such as transmission fault imaging, emission tomography, magnetic resonance imaging, ultrasonic tomography, reflection tomography, etc., are developed according to the different projection reconstruction methods (Huang et al., 2015). Hua and others use the transformation method and iterative reconstruction method, which are based on Radon transform, and develop a variety of transform algorithms, such as filter back projection algorithm and convolution back projection algorithm and form new algorithms based on two methods to be used in different industrial fields (Hua et al., 2015). The feature information contained in the sampled data should be made full use of the feature information contained in the sampled data in the interpolation calculation and estimation of the region valuation, so that the unknown spatial estimation of the output can fully reflect the role of these characteristics, and the estimation model which is as consistent as the real model is constructed.

3. Method

3.1 Gas distribution of coal mine stope

In order to ensure safe production of coal mines, basic requirement for gas motoring of working face in terms of coal mine safe procedure, mine safe monitoring system and detecting instrument use management rules is proposed. U-type ventilation way is generally used for long wall coal face, and the gas monitoring sensor should be set according to figure 1 and it is required to set gas monitoring instrument on the three positions including upper corner, working face and working face air return way (T0, T1 and T2 in the figure). In order to whole non-intrinsically safe electrical equipment which can not control inlet air way of the whole coal mining working face for coal and gas outburst mine and gas sensor T1, one set of gas monitor should be newly-added in the inlet air way. For the low gas and high gas mines which are applied tandem ventilation way in the working face, one set of gas monitor can be newly-added in the inlet air way of working face (see T4 in the figure). The setting of gas monitor in the working face under the ventilation way of H, Y, Z and W-type is basically the same.

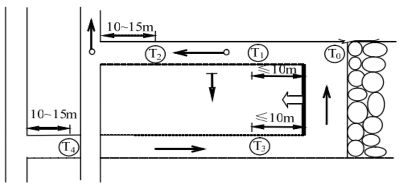

Figure 1: Settings of Gas Sensor Under U-shaped Ventilation Mode

The setting position of gas monitor in the excavating working face is shown in figure 2. There are 3 setting positions: 1. Working face mixed wind flow location (T1); 2. Working face return wind flow location (T2); 3. In front of local fan in the excavating working face of tandem ventilation (T3). When dual-way excavation is adopted and the mine is high gas, coal and gas outburst mine, then gas monitor should be set according to figure 3. There are 3 setting positions: 1. Mining working face(T1) 2. Air return lane (T2) 3. Working face mixed return wind flow location (T3); In the coal mine safety regulations, coal mine safety monitoring systems and testing instrument use management specifications, not only detailed provisions have been made for the setting positions and number of gas monitors, but also the suspension height, suspension method, alarm, and power-off concentration, re-test period for gas monitors are required as well. For example, it is required to suspend the gas monitors on the position with stable wind flow in the upper of roadway vertically, and the distance cannot be larger than 300mm from roof (top beam), also not be lower than 200mm from side wall of roadway, and it should be convenient for installment and maintenance and the pedestrians and travelling cranes cannot be influenced. It is stipulated that an alarm will be given when the gas concentration in the working face is generally equal or larger than 1%, and it will be powered-off when the gas concentration is equal or larger than 1.5% and then it will restore when the gas concentration is less than 1.5%. In some special locations, the alarming and power-off concentration is slightly different.

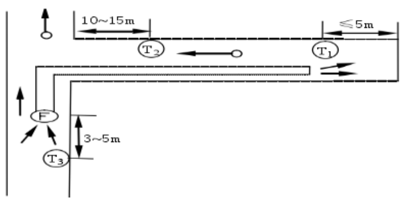

Figure 2: Gas Sensor Setting in Heading Face

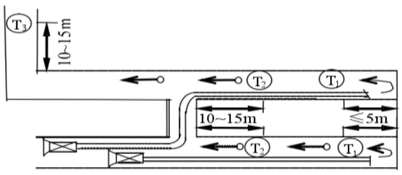

Figure 3: Settings of Gas Sensor Under Double Tunneling Face

A certain amount of gas concentration monitoring data is needed to achieve construction of gas distribution field in the working face. And a certain amount of gas monitoring points need to be increased, the existing wide-used wired data transmission way is hard to meet the requirements, and it is more convenient to adopt wireless data transmission gas sensor in terms of wiring, installing and monitoring substation coordination compared to tradition wired way. Currently there are a lot of wireless communication methods which are used maturely, such as Zig Bee, Bluetooth, GPRS, RFID and so on. Among them, what is proper for being used for monitoring in the environment under the coal well are mainly Zig Bee and RFID. RFID is currently applied in personnel location system and equipment management under the well, and Zig Bee is a more proper wireless transmission method. Zig Bee wireless network technology is a kind of new wireless connection technology, and the wireless connection technology mainly resolves the equipment networking application with low cost, low power consumption, low complexity, low transmission rate and near distance. Zig Bee standard was established based on 802.15.4 protocol stack and it is equipped with powerful equipment networking function and supports three major self-organizing wireless network types, that is, star configuration, net structure and cluster tree, especially the mesh structure, which is applied multiple-jumping route communication with big network capacity, which can span big physical space and it is proper for structure with a long distance and rather scattered. Mesh network topology owns powerful functions, and all of entities in the network can communicate with each other only if they are within the scope of communication. If there is no direct path, the communication can also be performed through the way of “multiple-class jumping” and the topological structure can also constitute network which is rather complex. In addition, the network is also equipped with self-organizing and self-healing functions. It owns powerful network robustness and system reliability. There are 2 types which constitute the network equipment of Zig Bee: Fully function equipment(FFD)and simplified function equipment(RFD). FFD is taken as the router or application equipment in the whole network, while RFD is taken as the application equipment in the network and can communicate with FFD and owns the function of taking over route. The distance between two Zig Bee nodes is generally 150 to 200m, utilizing its function of taking over route can achieve data transmission for a longer distance by adopting relaying communication method. Stope gas monitoring system topological graph is shown in figure 4. The stope gas monitoring network based on Zig Bee technology includes distributed self-powered Zig Bee gas sensor monitoring node and Zig Bee central node. Mesh network structure is adopted so as to ensure reliability of data transmission fully. The gas monitoring system firstly obtains the gas concentration of the unit through a Zig Bee gas monitoring node set up on the working face, and then transmits the monitoring data to the Zig Bee central node. Finally, transmitting to the ground monitoring data management center by the coal mine safety supervision and communication system to be displayed and saved. Because each gas monitoring nodes are connected by adopting wireless network, the quantity of gas sensor can be established flexibly according to the length of working face and actual situation.

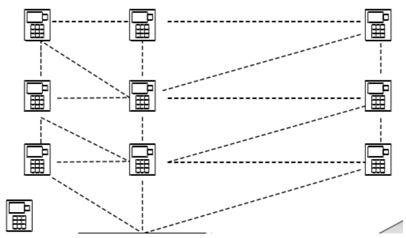

Figure 4: Topology of Gas Monitoring System in Stope

3.2 Reconstruction of coal mine stope distribution field

The length of the working face for reconstructing gas distribution field is approx. 110m, and the goaf area is about 5m away from the front of the coal wall. The gas concentration should be measured according to mensuration of improved unit, and 1 measuring unit should be set every other 10m from the beginning of air inlet side, and 11 measuring units are set in total. A group of actual gas concentration measurement data is list in Table 1.

Table1: Measured Data of Gas Concentrations in Coal Face

	X=										
	10	20	30	40	50	60	70	80	90	100	110
Y=1	0.01	0.06	0.08	0.1	0.14	0.35	0.58	0.72	0.85	0.98	1.12
Y=2	0.01	0.06	0.06	0.11	0.16	0.33	0.49	0.52	0.65	0.78	0.98
Y=3	0.01	0.05	0.07	0.32	0.38	0.51	0.6	0.75	0.89	0.85	0.91
Y=4	0.01	0.08	0.11	0.42	0.48	0.66	0.82	0.91	1.14	1.02	1.05

Firstly, utilizing MATLAB software to draw gas concentration distribution drawing of the working face, as shown in figure 5 (X-direction refers to the working face direction from air inlet side to air return side, Y-direction refers to the direction from goaf area to coal wall surface, the same below)

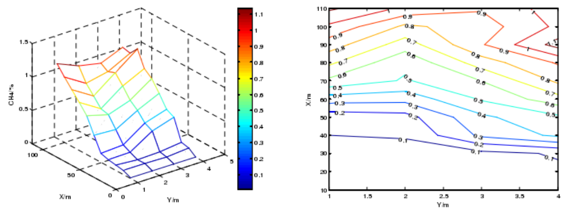

Figure 5: Gas Density Distribution Figure Based on Measured Data

It can be seen from the gas concentration distribution drawing of the group of measurement data and its contour map, the features of gas concentration in the coal mining working face are as follows: (1) The gas concentration gradually rises up from air inlet side to air return side, this is because the wind flow is mixed with gas of high concentration constantly leaked from the coal wall, top baseboard and goaf area; (2) The gas concentration in the goaf area side (left side) is lower than the gas concentration of coal wall side (right side) in the same measurement unit, and this is mainly as a result of influences of gas concentration newly discharged from the coal wall side; (3) The gas concentration at the position 9 (X=90, Y=4 location) of the measurement unit for upper corner and coal wall side is obviously higher than the other positions. In practice, Figure 6 can be used to make the coal mine staff have a preliminary understanding of the gas distribution in the coal mine working face, but it is relatively rough and not accurate, especially in the case that it is impossible to set so many measurement points and data are missing, it is very difficult to accurately grasp the gas distribution in the working face. Utilizing the limited data obtained from field actual measurement, the research on achieving reconstruction technology of gas distribution field based on neural network algorithm will make the research on the gas distribution of stope more perfect and accurate.

4. Result and discussion

In order to verify and evaluate the reconstruction method of the gas distribution field in the previous paper, the study performs gas distribution field reconstruction for a group of field actual measurement data based on adopting neutral network algorithm and space information statistical approach method respectively. In order to verify the data adaptability of the two methods, 30, 20, and 10 data were randomly selected from 56 measured data respectively. The reconstructing and comparative analysis of the gas distribution field was performed by adopting these two methods. It is shown in the error of the reconstruction results that when there are a lot of data samples participating in distribution field reconstruction, the reconstruction based on neutral network algorithm is slightly superior to space information statistical approach. When there are a few data samples participating in reconstruction, the spatial system statistical approach is obviously superior to neutral network reconstruction approach in terms of reconstruction result.
The reconstruction technology based on space information statistics technology (geostatistics) in the stope gas distribution field proposed in this paper has the features of high reconstruction accuracy and strong data adaptability, and can be used to solve the problem of coal mine gas distribution field reconstruction. On the basis of just adding a small number of gas monitoring devices, this technology can be used to achieve a gas distribution field reconstruction with satisfactory accuracy. Via setting an alarm threshold for the reconstructed field data, it is possible to alarm the area that exceeds the hazardous gas concentration, and display transfinite gas and accumulation area.

5. Conclusion

During coal mine production, one of the most serious accidents is the gas accident. The gas accident will cause extremely major economic loss and life and personnel injuries, which influences the normal production of coal mines and corporate image seriously. According to practice, most of the mine coal gas explosions occur in the roadway of the recovery and excavation area, because this is the area where gas is discharged. Therefore, the study applies mathematical economic model, via field gas monitoring system, obtaining field gas concentration of coal mine and performing reconstruction research for stope gas distribution field. The paper performs analysis for achieving gas testing network in the stope and gas concentration in the stope is measured, also, performing mathematic interpolation analysis for the data obtained from measurement. The research achievement supplies theoretic basis for reconstruction of coal mine gas distribution field, and is beneficial to reducing gas accident during the production process of coal mine and reducing economic loss and life and personnel injuries resulting from gas accident so as to ensure normal production of coal mine and establish good corporate image of coal mine enterprises.

Acknowledgement

(1) Chinese national major science and technology special project (2016ZX05042004-003)—Research on improving the production technology of single well production of coal bed gas;
(2) Hebei science and technology project project (15273616) - Research on magnetization and anti scaling technology of injection water in Gaoshangpu;
(3) Innovation Fund of North China University of Science and Technology (X2013008) - Laboratory study on stress sensitivity of coalbed gas reservoir

Reference

Frippiat C., Veschkens M., Massenhove J.H.V., Pacyna D., 2015, A risk-based method for the design of monitoring networks for surface gas emanations from abandoned underground coal mines, Environmental Earth Sciences, 73(5), 2061-2078, DOI: 10.1007/s12665-014-3557-2.

Hua F.U., Liu Y., Haixia L.I., Yaosong X.U., Wang Y., 2015, Short term forecasting model of gas concentration in coal mine using the capso-enn, Chinese Journal of Sensors & Actuators, 28(5), 717-722, DOI: 10.2991/icmeit-16.2016.7.

Huang Y., Tian F., Wang Y., Wang M., Hu Z., 2015, Effect of coal mining on vegetation disturbance and associated carbon loss, Environmental Earth Sciences, 73(5), 2329-2342, DOI: 10.1007/s12665-014-3584-z.

Nazarova L.A., Nazarov L.A., Karchevsky A.L., Vandamme M., 2014, Estimating diffusion-capacity parameters of a coal bed using the gas pressure measured in a hole and the solution of an inverse problem, Journal of Applied & Industrial Mathematics, 8(2), 267-273, DOI: 10.1134/s1990478914020136.

Pinetown K.L., 2014, Regional coal seam gas distribution and burial history of the hunter coalfield, sydney basin, Journal of the Geological Society of Australia, 61(3), 409-426, DOI: 10.1080/08120099.2014.893539.

Tanguturi K., Balusu R., 2014, Cfd modeling of methane gas distribution and control strategies in a gassy coal mine, Journal of Computational Multiphase Flows, 6(1), 65-78, DOI: 10.1260/1757-482x.6.1.65.

Wang J., Zhang M., Bai Z., Guo L., 2015, Multi-fractal characteristics of the particle distribution of reconstructed soils and the relationship between soil properties and multi-fractal parameters in an opencast coal-mine dump in a loess area, Environmental Earth Sciences, 73(8), 4749-4762, DOI: 10.1007/s12665-014-3761-0.

Wang L., Cheng Y.P., An F.H., Zhou H.X., Kong S.L., Wang W., 2014, Characteristics of gas disaster in the huaibei coalfield and its control and development technologies, Natural Hazards, 71(1), 85-107, DOI: 10.1007/s11069-013-0901-x.