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/CET1866209

Goal Mine Detection with Transient Electromagnetic Method and Magnetic Method

Zhengyuan Jia[a], Kui Suo[b], Ziling Song[c], Guibin Zhang[a*]

[a]School of Geophysics and Information Technology, China University of Geosciences, Beijing 100083, China
[b]Institute of Mining Technology, Liaoning Technical University, Fuxin 123000 China
[c]School of Resources and Environment, North China University of Water Resources and Electric Power, Zhengzhou 450000, China
gbzhang@cugb.edu.cn

Coal mine goaf is rather severe safety hazard during the process of coal mining. Besides, it is also difficult to be detected accurately. Based on the electrical, magnetic and physical properties of coal mine goaf, the paper proposes the comprehensive use of magnetic method and transient electromagnetic method to detect coal mine goaf. Within the research region, the magnetic method is used to measure the area, and designate key zones. Then, transient electromagnetic method is adopted to survey the key regions and learn about electrical resistivity underground. Comprehensive analysis is conducted on magnetic susceptibility and electrical resistivity to infer the spatial distribution features, such as the possible scale and depth of goaf. Drilling data prove the reliability of joint detection and explanation method.

1. Introduction

Coal mining industry is one of main energy sources in China. It plays an important role in promoting the development of the national economy. During the process of coal mining, some holes or cavities (goaf) are likely occur, causing safety hazards to urban construction and geological environment（Zhihai et al., 2014）. How to rapidly and effectively defect the scope of underground goaf is an important task of geologic prospecting. Many domestic and foreign science researchers have conducted a lot of research and studies on goaf defection. Primary methods include thermometry, magnetic method, resistivity measurement, gas measurement, transient electromagnetic method, geological radar detection method, remote sensing and radioactive radon detection. Among these methods, transient electromagnetic method and magnetic prospecting method have merits like short prospecting time and favorable resolution capabilities. Hence, they are effective methods to defect fire zone boundaries and water abundance of coal beds (Wang et al., 2014, Weidong et al., 2012 and Zhang et al., 2015). According to the physical features of goaf, the paper utilizes transient electromagnetic method and magnetic method to conduct joint exploration on a certain goaf region in Shanxi, in order to find out the spacial distribution of goal region, eliminate safety hazard, and provide basis for dealing with geological disasters and coal mine safety (LI et al.,2011).

2. Detection Principles

According to the residual magnetism theory, the theoretical model can be formulated (Figure 1.) The magnetic anomaly curves are demonstrated as follows: Normal coal-bearing region has stable magnetic field. Spontaneous combustion area shows apparent magnetic anomalies (Qi et al., 2014, Yan et al., 2014; Jiang et al., 2013). For the whole detection region, magnetism of the burning region shows the following anomalies: It is quite difficult to detect magnetic anomalies in the burning temperature curie point, the evaporation zone of absorbed water and discharging zone of volatile matter. As for the

Please cite this article as: Jia Z., Suo K., Song Z., Zhang G., 2018, Goal mine detection with transient electromagnetic method and magnetic method, Chemical Engineering Transactions, 66, 1249-1254 DOI:10.3303/CET1866209

burning region, the coal bed is oxidized by the air in the tunnels, collapse craters and fissures. Hence, it is feasible to determine the scope of burning regions and goad zones according to magnetic anomalies.

Transient electromagnetic method is the geophysical exploration method based on the law of electromagnetic induction to detect underground information of terrestrial electricity. An impulse is sent through the earthed return line to detect the inducted secondary field caused by vortex due to stimulation of geologic body. Through observing the changing rate of secondary magnetic field over different periods, it is feasible to explain space structures and electrical parameters of geologic bodies at different depths (Song et al., 2011,). When coal beds are mined, gaps may form between the bottom and top rock stratum layers and disrupt the integrity and continuity of rocks. Hence, the electrical resistivity in this region is higher than that of surrounding rocks. When gaps are filled with water in the goaf region, the electrical resistivity indicate low levels of resistivity (Li et al., 2017; Markku et al., 2003; Xu et al., 2009; Liu, 2006; Zhang, 2007; Yang et al., 2008; Zhang et al., 2013; Zhu et al., 2014).

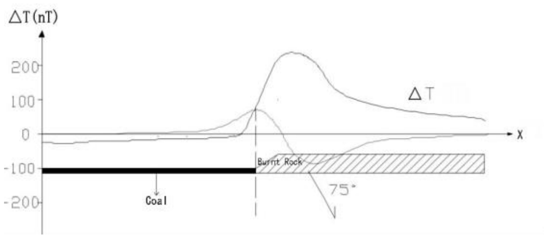

Figure 1: Diagram of incline step model

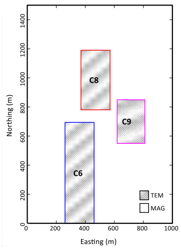

Figure 2: Arrangement diagram

3. Data Collection and Processing

In the mining area, the coal bed is relatively shallow. Besides, due to the low rate of recovery, a lot of coals are left in the goaf zone. The mining zone is transient from chestnut soil to castano-cinnamon soil. Parent material and soil mainly include alluvial deposit, diluvium, and slope wash, as well as some eluvium. In the goaf zone, areas with high resistance should be given extra consideration on electrical property. Firstly, magnetic method is used to measure the area. Then, according to magnetic inversion results, conduct the transient electromagnetic measurement in key regions(Figure 2).

3.1 Magnetic data collection and processing

Magnetic detection range covers the whole area, which is 1010m×1540m(Figure 2). the network is designed as 50m×20 m. accuracy is 2.5 nT. After daily variation change, height change and pole changes, magnetic anomalies are shown in Figure 3.

The goaf is mainly in the zone of superficial layers. The detected data are anomaly overlays by different geologic bodies, which indicate geologic bodies of different depth and sizes. Hence, it is necessary to separate the anomaly overlays, extract superficial information and conduct post processing. Optimized filtering method is used to separate the original observation data and obtain the local anomaly (Figure 4). According to Figure 3 and Figure 4, it can be seen that regions with high values in the southeast part of Figure 3 have deep source. Some regions (northeastern part) didn't indicate anomalies, but obvious anomalies are shown after smoothing, which verify the necessity of extracting superficial information.

To accurately determine the position and depth of field sources, three-dimensional inversion is implemented on the underground model after mesh generation. The number of networks is 54×80×51 (Figure 5)

Compared with traditional two-dimensional section inversion and man-machine interaction inversion, three-dimensional inverse also gives consideration to magnetic anomalies in the whole region, in order to eliminate the influence of side anomalies. After 15 iterations, underground magnetic susceptibility inversion distribution results are shown in Figure 6.

3.2 Transient Electromagnetic Data Acquisition and Processing

Because the induced voltage signal is small, which is susceptible to all kinds of human electromagnetic interference, it is necessary to analyze and filter the noise after drawing the original multi track map. After filtering de-noising, it is also necessary to convert the apparent resistivity parameter to facilitate understanding and post-processing of data. The result of the late phase of TEM is useful for the stratified information of the geoelectric section. Moreover, its stratification ability is strong, its volume effect is small, and the detection depth is large.

The apparent resistivity mentioned above is the basic parameter to be processed further. After inversion calculation, it would be analyzed and explained according to the actual data of the work area.

4. Results and Discussions

4.1 Analysis of Results from Magnetic Method

The studied area is an opencast coal seam, which is buried shallower. Also, the magnetic anomalies caused by the fire area are mainly distributed in the shallow part. Therefore, the shallow magnetic anomalies separated from the original anomalies can more accurately reflect the distribution of the burned areas. Combining the known data and the high magnetic area of the measured magnetic anomalies in the magnetic anomaly, the region likely to exist in the burning area has been circled in the figure. The part circled by the black line is the inferring abnormal area (Figure 7). In Figure 8, it is three-dimensional inversion result diagram, in which the distribution, burial depth and direction of underground high magnetic lift are further shown. It can be seen from the figure that the distribution of fire area in this study area is relatively scattered with a large range of abnormal reflection in the northwest corner. And the corresponding transient electromagnetic workers should be arranged in the key areas of the magnetic research area to provide reference for further confirmation of goaf and production construction.

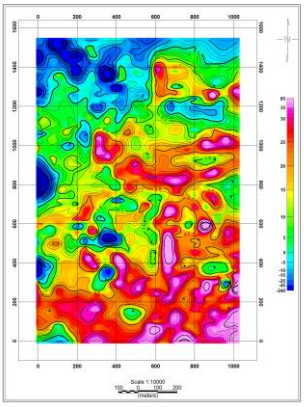

Figure 3: Original ΔT magnetic anomaly in research area

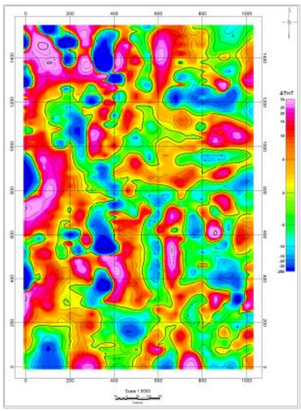

Figure 4: Local ΔT magnetic anomalies in research region

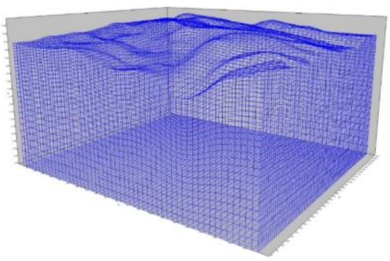

Figure 5: Mesh generation in research region

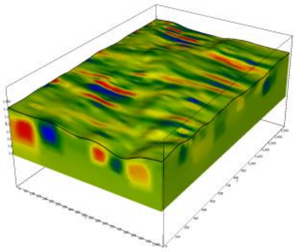

Figure 6: ΔT Underground magnetic susceptibility inversion distribution results

4.2 Analysis of the Transient Electromagnetic Results

(1) Analysis of the Results in C6 Area

Figure 9 is a three-dimensional diagram from the transient electromagnetic method to infer the abnormal results of goaf in the C6 area. The envelope of a graph is an equivalent surface of apparent resistivity. And the shadow part of the delineation is the deduced high resistivity anomaly area, that is, the goaf area. On the whole, the goaf is north-south, which is consistent with the trend of high magnetic anomaly in C6 area. It means that the construction mode of coal mining is in the direction of North and South with the 1200m in depth. In order to analyze the location of goaf in the whole survey area more finely, it is projected to the the surface, as shown in Figure 10. It can be seen from the diagram that the goaf in this area is mainly distributed in the North (400-500 m). and the region with a resistivity higher than 780 Ω·m is circled by a red line, which is in high credibility. Therefore, relevant treatment and prevention work is necessary before construction here. The outward blue lines and green lines refers to 700 Ω·m, 550 Ω·m respectively, whose reliability is slightly lower. Attention should be paid here to exclude risk factors before construction

(2) Analysis of the Results in C8 Area

In Figure 11, it is the spatial location diagram of goaf in C8 area through transient electromagnetic method. It can be seen from the diagram that the high resistivity area is mainly located in the north-south direction of the survey area in the west of 1000-1100m. In order to observe the more precise location of goaf in the whole survey area, it is projected on the surface, as in Figure 12. It can be seen from the diagram that the goaf in the survey area is mainly distributed in the central and western areas. The area with resistivity higher than 700 Ω·m is circled by the red line, which is high credibility. It needs to be harnessing and warning before the construction. Outward, areas circled by blue and green lines are 600Ω·m, 470Ω·m respectively, which is in low credibility. It is needed to pay attention to and eliminate hidden dangers before construction.

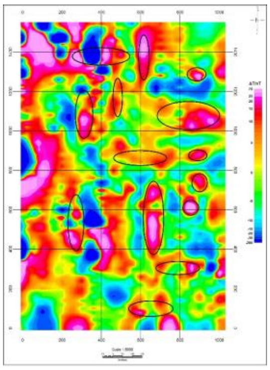

Figure 7: Inferential Diagram of the Goaf in the Magnetic Anomaly

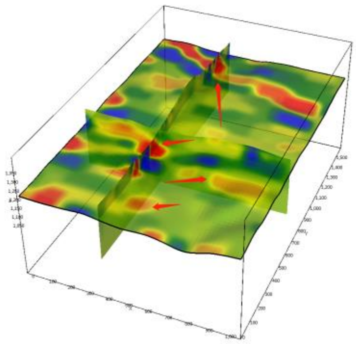

Figure 8: Three-Dimensional Inversion Slice of Magnetic Anomaly Susceptibility

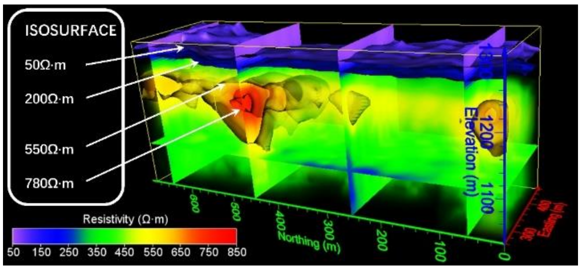

Figure 9: 3D Diagram of Electrical Inversion in C6 Area

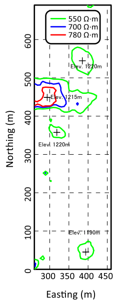

Figure 10: The Surface Projection of the Goaf in C6 Area

(3) Analysis of the Results in C9 Area

Figure 13 is a three-dimensional diagram of the goaf in the C9 area deduced by transient electromagnetic method. And its surface projection is as shown in Figure 14. It can be seen from the diagram that the high resistance area in this is mainly distributed in the South and North side, who is also heading for North and South. Its top buried depth is 1250 m, which is larger than that of C6 and C8. The area circled by red lines is a region with a resistivity higher than 450 Ω·m located in southwest corner of the survey area, with high credibility in scale concentration. But here, the red circles ares overlap with the blue and green ones highly, which may indicate the sudden occurrence of electrical properties.

4.3 Result Verification

After analyzing the data of magnetic method and transient electromagnetic method, drilling validation was carried out in the C6 area (300,450), C8 area (400,1000) and C9 area (670,680). As a result, all 3 boreholes were hit in the goaf, which verifies the accuracy of the combined interpretation of magnetoelectric results. Therefore, other areas of goaf / burning zone that may be identified by magnetic method and transient electromagnetic method should be mainly focused on for safety production.

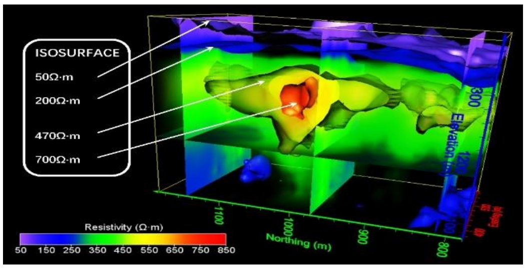

Figure 11: 3D Diagram of Electrical Inversion in C8 Area

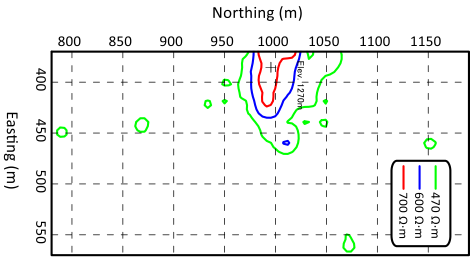

Figure 12: The Surface Projection of the Goaf in the C8 Area

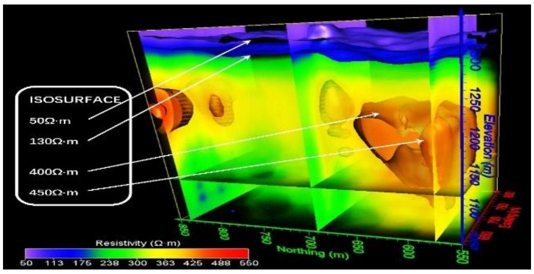

Figure 13: the 3D Diagram about Electrical Inversion in C9 Region

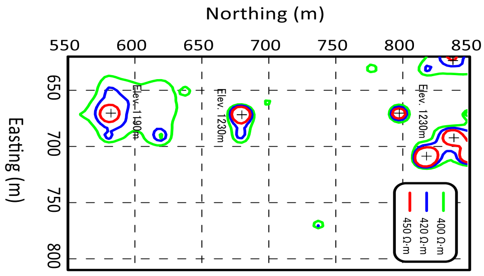

Figure 14: The Surface Projection of the Goaf in the C9 Area

5. Conclusion

The results of comprehensive utilization of magnetic and transient electromagnetic methods show that it is feasible and effective to use two methods in synthetically detecting the goaf in coalfield. Before working, the magnetic and electrical characteristics of the target area should be determined according to the actual situation. The range of the burned area can be effectively delineated by using high magnetic anomalies. And the specific shape of the target body can be determined by using high resistivity or low resistivity anomalies. The two methods should be complementary to each other, which is an effective way to accurately detect the goaf in the coal field.

Acknowledgments

This work is supported by China Geology Survey under grant No. 12120114067701 and grant No. DD20160125

References

Jiang L., 2013, Application of Magnetic Method in Detecting Coal Fire Area in Talad Sayi Coal Mine, Energy and Environment, 2, 57-58, DOI: 10.3969/j.issn.1672-9064.2013.02.025.

Jiang Z.H., Guang Y., 2014, Research and application of TEM detection technology for small mine gob area in shallow buried and extremely thick seam, Journal of Mining & Safety Engineering, 31(5), 769-774.

Li J.C., 2017, Application of high density resistivity method in coal mine goaf exploration. Equipment for Geotechnical Engineering, 1, 29-31, DOI: 10.3969/j.issn.1009-282X.2017.01.008.

Li Y.H., Yang J., Li S.F., 2011, The Application of TEM AND Resistivity Sounding to The Investigation of Gob Areas Near Shawu Railwa, Geophysical and Geochemical Exploration, 2, 274-279.

Liu H.S., 2006, The Appliance Research of High Density Resistivity Method on Detecting Colliery Underground Gob, Master, Taiyuan University of Technology, Taiyuan, China, DOI: 10.7666/d. y979699.

Markku P., 2003, Numerical Modeling and Inversion of Geophysical Electromagnetic Measurements Using a Thin Plate Model.

Qi C.Y., 2014, An Ja Ling Open-Pit Mine Goaf Fire Detection and Fire Prevention Technology, PhD Thesis, Liaoning Technical University, Liaoning, China

Song Y.H., Liu H.F., 2011, Application of integrated geophysical exploration in mined-out areas. Shanxi Coal, 5, 73-75. DOI: 10.3969/j.issn.1672-5050.2011.05.020.

Tian W.D., Chongguang G., 2012, Application of Integrated Geophysical Prospecting in Inner Mongolia Spontaneous Combustion Zone, Coal Geology of China, 4, 62-67, DOI: 10.3969/j.issn.1674-1803.2012.04.15.

Wang Z., Lin J., Liu L., Shao P., 2014, Application of small-loop transient electromagnetic method in detecting undergroud fire area. Jiangxi Coal Science & Technology, 49(91), 57-58, DOI: 10.3969/j.issn.1006-2572.2014.03.021.

Xu Y.Z., 2009, Application of transient electromagnetic pilot exploration technology to mine heading in Gequan mine, Coal Science and Technology, 7, 033. DOI: 10.13199/j.cst.2009.07.113.xuyz.008.

Yan J.B., Zhou W., University L., 2014, Application of Curvature Gradient Tensor Matrix in Magnetic Anomaly of Burnt Coal Area. Science and Technology Review, 31, 75-79. DOI: 10.3981/j.issn.1000-7857.2014.31.011.

Yang J.J., Shen Y., Liu H.F., 2008, The Application of Radon Measurement and Transient Electromagnetic Methods in Detection of Coal Mine Goaf. Geophysical & Geochemical Exploration, 6, 661-664.

Zhang G.Y., Amp C.M., Amp, T.S., Co T., 2015, Charged burned area exploration of coal mines with magnetics and transient electromagnetic method. Coal Mining Technology, 4, 23-24, DOI: 10.13532/j.cnki.cn11-3677/td.2015.04.006.

Zhang H.W., Liu H.F., Bao N.L., School M.E., 2013, Application of Nanometer Transient Electromagnetic Method in Exploring Shallow Gob of Coal Mine, Coal Mining Technology, 5, 21-23, DOI: 10.3969/j.issn.1006-6225.2013.05.006.

Zhang X.F., 2007, The Applied Researsh of TEM in Detecting Coalfield Goaf, Master, Chang'an University, Xi’an, China.

Zhu H.Q., Yang T.C., Qin X.F., He C.N., 2014, Integrated coal mine fire district detecting method based on transient electromagnetic method, Science and Technology Review, 25, 15-19, DOI: 10.3981/j.issn.1000-7857.2014.25.001.