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/CET1866017

Application of High Density Electrical Method in Detecting Goaf water in Coal Mines

Mingrui Yang[a*], Peng Dong[a], Yonggang Wang[a], Zhaolong Yang[b]

[a]PowerChina, Guizhou Electric Power Design & Research Institute Corporation Limited, Guiyang 550023, China
[b]Administration of Work Safety of Shuicheng country, Shuicheng 553600, China
138172886@qq.com

High-density electrical method is a rapid, economical and efficient method for detecting goaf water in coal mines. In this paper, firstly, the high-density electrical method was used to perform forward and inverse calculations on the numerical model of the old mine goaf, and the characteristics of geoelectric response were analysed. It can provide scientific basis for on-site detection, analysis, and interpretation of goaf features. Then, the water-accumulated goaf was explored by combining the engineering cases to make accurate description of the location and extent of the goaf area. Finally, the reliability of the geophysical prospecting was further verified through drilling case. This shall provide the effective reference materials for safe mining and water control.

1. Introduction

With the rapid development of China's economy, coal resources have been exploited extensively. However, due to the disorderly exploitation in many areas, the distribution of goafs in old coal mines is unclear, resulting in undesirable social and environmental effects, and causing a great potential safety hazard for the integrated mine safety production (Wu et al., 2013). Therefore, the detection of goaf water in coal mines is a major problem in the current coal mine safety. To identify the location of the goafs and their water supply conditions during the mining of old coal mines has been the basis for assisting mine safety production.
At present, the effective detection method for goaf water in coal mines is mainly the ground geophysical prospecting method. Based on many previous researches and practical examples (Zhang, 2012; Dzimunya et al., 2018; Zhao, 2003; Qian, 2014), it's found that high-density electrical method is a rapid and economical method for detecting goaf water in coal mines because of its high detection accuracy and sensitivity to low-resistance anomalous responses such as goafs. In 2004, Zhang et al., (2004) demonstrated the effectiveness of high-density electrical method in the detection of underground goafs through geoelectric image display. Yuan and Zhang (2006) used high-density electrical method to detect underground goafs; according to geoelectric section images, the detailed location and detailed interval information of the underground and unmined areas were obtained. Qi et al., (2006) combined high-density electrical methods with centimetre-level high-precision GPS measurements and shallow drilling techniques to predict the spatial distribution characteristics of underground goafs. Feng (2009) introduced the qualitative and quantitative data interpretation process using Surfer and RES2DINV maps, pointing out that the reliability and accuracy of the original data is the most important, and the data interpretation process should be combined with the actual geological conditions. Lei et al., (2009) conducted high-density resistivity method for airport karst and soil caves, coal roadway for coal mining, concealed small coal mine goafs and complex geological disaster tunnels; the exploration results were verified by drilling at the accuracy rate of more than 60%. Yang (2012) applied the high-density resistivity method to detect the goal of steeply inclined coal seams and inferred the position of the collapsed goaf and ground fissures. Sun (2012), in a certain area of Inner Mongolia, achieved good results by comprehensively applying high-density resistivity method and shallow seismic to detect goafs in coal fields for different geoelectric conditions in the survey area. Yang et al., (2014) explored the feasibility of using high-density resistivity method to evaluate the effect of grouting treatment in coal goafs with application examples. Xue et al., summarized and analysed the ground geophysical exploration methods in the coal goaf, and then pointed out that the high-

Please cite this article as: Yang M., Dong P., Wang Y., Yang Z., 2018, Application of high density electrical method in detecting goaf water in coal mines, Chemical Engineering Transactions, 66, 97-102 DOI:10.3303/CET1866017

density resistivity method will play a broader role in the prediction and treatment of coal mine geological disasters.

Therefore, in order to accurately detect the location of goaf water within the mine area and the water-accumulated scale, based on previous research, this paper first uses high-density electrical method to perform forward and inversion calculations on the numerical model of the goaf in different types of fill, and analyse the characteristics of geoelectrical response of different geological anomalies, so as to provide scientific basis for site detection, analysis, and interpretation of goaf water features. Then, in combination with examples, the goaf water existing in the mining area was detected, which provides the effective reference for the safe mining and water control in mines.

2. Methods and principles

The high-density electrical method is an array exploration method developed in the late 1970s. It is an economical, non-destructive, fast, and intuitive method for geophysical exploration, with the advantages of high resolution, high efficiency, low cost, and easy interpretation. Its basic principle is based on the difference in electrical conductivity between different rock-soils or ores. An artificial electric field is established underground through the grounding electrode. Four electrodes in the electrode array are selected as A, B power supply electrodes and M, N measurement electrodes each time. The measured potential difference ΔV between supply current I and MN between AB is automatically measured, so as to obtain the apparent resistivity value ρ_s=KΔV/I at point O (MN midpoint), where K is the device coefficient. It is determined by the position of the A, B, M, and N electrodes and the device type. By analysing the distribution and change characteristics of the surface electric field in the presence of different conductors underground, the geological problems such as the distribution and occurrence of the underground geological body can be inferred and interpreted.

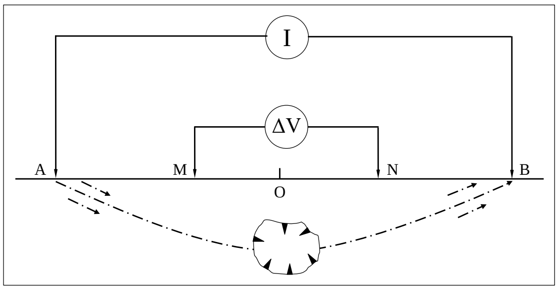
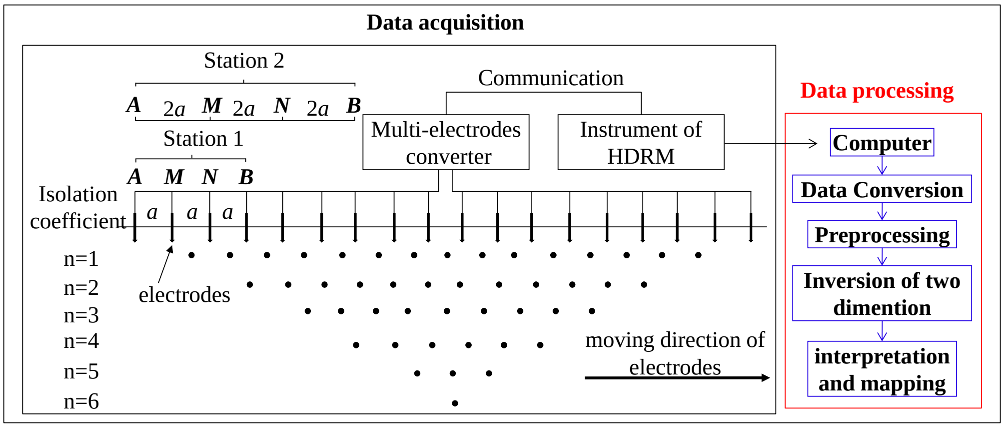


Figure 1: Basic principle of high density resistivity method



(A and B are source electrodes, M and N are measuring electrodes, n is isolation factor, and a is electrode spacing)

Figure 2: Field measurement and data processing flow of high-density electrical method

High-density resistivity imaging has the advantages of both electrical profiling method and electrical sounding method. Unlike the common high-density resistivity method, high-density resistivity imaging is an array exploration method to measure the resistivity difference of a medium by placing a large number of electrodes. In the field measurement, all the electrodes are placed on the measuring point first, and then the data acquisition is performed through a programmable electrode converter and an electrical tester (as shown in Fig.2). Because the electrodes are arranged once and the data acquisition is performed automatically by program control, the work efficiency is high, and the mistakes that are easily caused by manual operations can be avoided. Once the electrodes are arranged at one time, measurement of various electrode devices can be performed to obtain a large amount of resistivity data that reflects detailed information inside the media. After data processing, rich geoelectric section information is available. Compared to the conventional resistivity method, the interpretation results have the advantages of "high accuracy" and "high resolution". It can provide more basis for the geologists' interpretation and inference.

3. Simulation test

In order to verify the feasibility and reliability of high-density electrical method for the detection of goaf water in coal mines, the geoelectric response characteristics of different geological anomalies were summarized and analysed to provide scientific evidence for on-site detection, analysis, and interpretation of goaf-water features. This paper first establishes a numerical model of the goaf, uses software to perform forward and inverse calculations, and then selects a known water sump for field testing to determine the optimal technical parameters for subsequent data collection.

3.1 Forward modelling

First, the Res2dmod forward software was used to perform the forward calculation of the goaf area model as shown in Fig. 3(a), and then the inversion processing based on the apparent resistivity data (as shown in Fig. 3(b)) obtained from forward modelling was made, to obtain the apparent resistivity pseudo-section diagram (Fig.3(c)). Compared with the resistivity model of goaf, it can be clearly seen that the high-density resistivity imaging can clearly reflect the characteristics of the goaf: normal apparent resistivity of the coal seam has no significant anomaly, showing high resistance characteristics without water in goaf, and low resistance characteristics with water; it's required of high detection accuracy for the water-contained goaf.

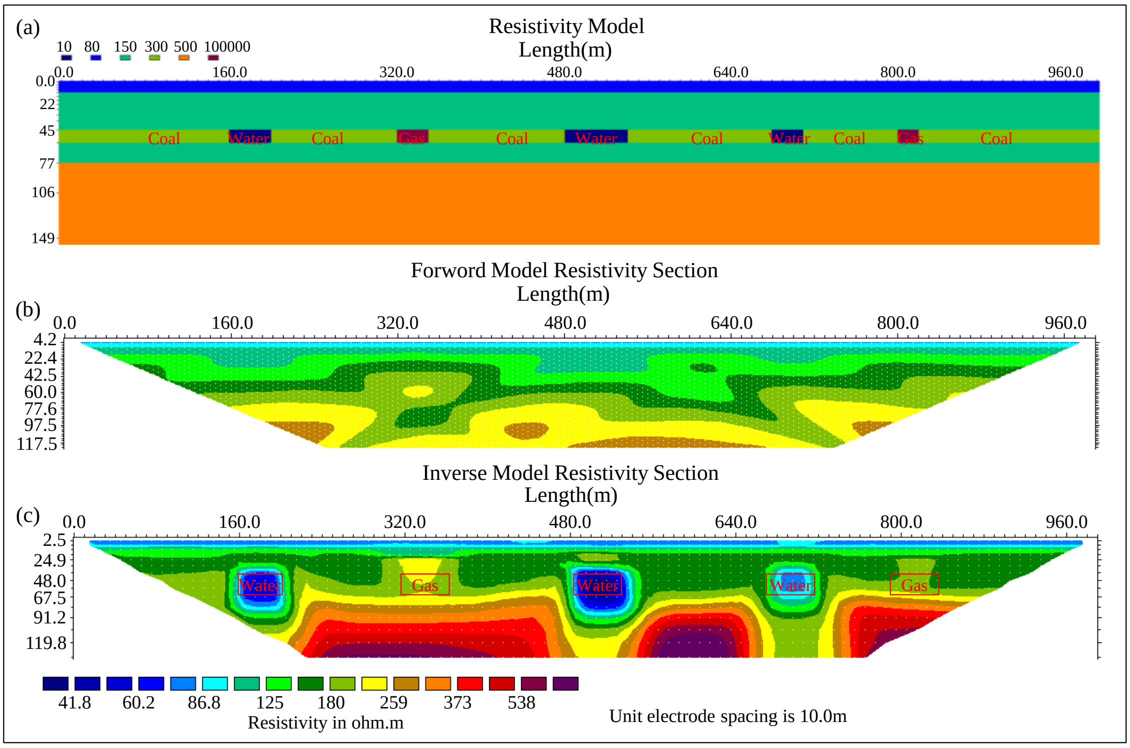


Figure 3: Resistivity Model of Coal Goaf (a), Forward Model Resistivity Section(b), and Inverse Model Resistivity Section(c)

3.2 Water sump test

In order to verify the rationality and effectiveness of the design method, reasonable technical parameters were determined for the subsequent data collection, and the known underground water sump provided by the mine was tested. According to the data provided by the mine, the water sump was about 1,450m deep.

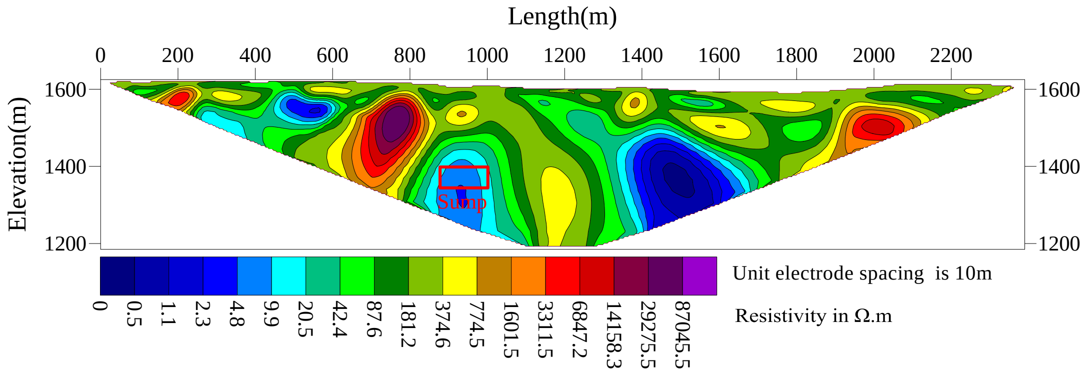


Figure 4: Inverse model resistivity pseudo-section of water sump test line

After data acquisition and inversion processing, the apparent resistivity pseudo-section is shown in Fig. 4. It can be clearly seen from the figure that the position of the water sump is obviously low-resistance, which is consistent with the position of that provided by the mine. Therefore, the high-density electrical method has obvious detection effect on the location, scale, and fill type of the goaf.

4. Application example

4.1 Geological overview and physical property conditions

The exploration area is located in Liupanshui City, Guizhou Province, which belongs to the erosional landform, with the greatly varying topography. The exploration coal mine is formed by integration of many old mines. The mine adopts an inclined shaft development method and the long-wall flexible shield support coal mining method at the mining elevation of +1660m to +1280m. Due to the serious absence of goaf data before integration and the unclear distribution of boundary areas, the old mine water directly threatens the mining work in the adjacent area of the mine. According to the previous field investigations by the mines, the distribution range of coal goafs was tentatively delineated, but there were large deviations in the specific distribution scope and boundaries of the goafs, and the situation of the accumulated water in the goafs was even more unclear; besides, the aquifer near the main coal seam also poses a certain threat to the production of the coal mine. Therefore, the location of the goaf water, the condition of water accumulation, and the distribution of the water-producing zones of major aquifers need to be thoroughly explored to provide effective reference for the safe mining and prevention of water in the mine.

After the coal seam is mined out, certain gaps are formed in the upper and lower rock layers of the coal seam, destroying the integrity and continuity of the rock, and the resistivity of the rock layers will change accordingly. Compared with the intact stratum, the gob caving zone of coal seam has loose lithology and low density. The apparent resistivity of the internal filled loose material is obviously higher than that of the surrounding medium, showing high resistance anomaly in the electrical property. For the fissure zone of goaf, compared with the intact strata, its lithology does not change significantly. However, due to the development of rock fractures in the fissure zone, the filled air causes the conductivity in the fissure to decrease, also showing high resistance anomaly in electrical property. If water is injected into the caving zone and the fissure zone, the loose fissure area will be filled with moisture and then reach saturation, causing the electrical conductivity of this area to increase rapidly and behave as the low-resistance anomaly. This electrical difference provides good precondition of physical property for the application of high-density electrical method.

4.2 Test line layout

In order to reasonably and effectively identify the distribution of goaf water in the exploration area, six high-density electrical test lines were arranged according to topographic and geomorphological conditions. Fig.5 shows the line layout, in which the horizontal line G02 and the vertical lines G05 and G06 are perpendicular to the old mine position roughly defined by the mine side.

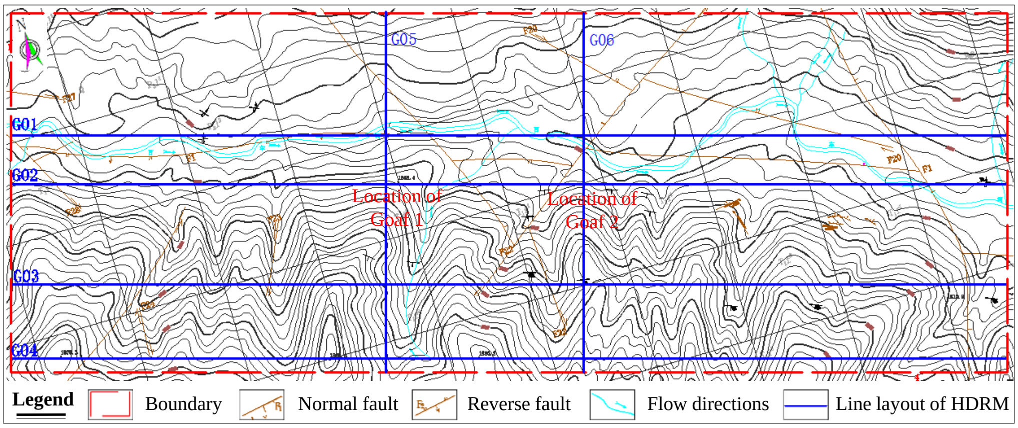
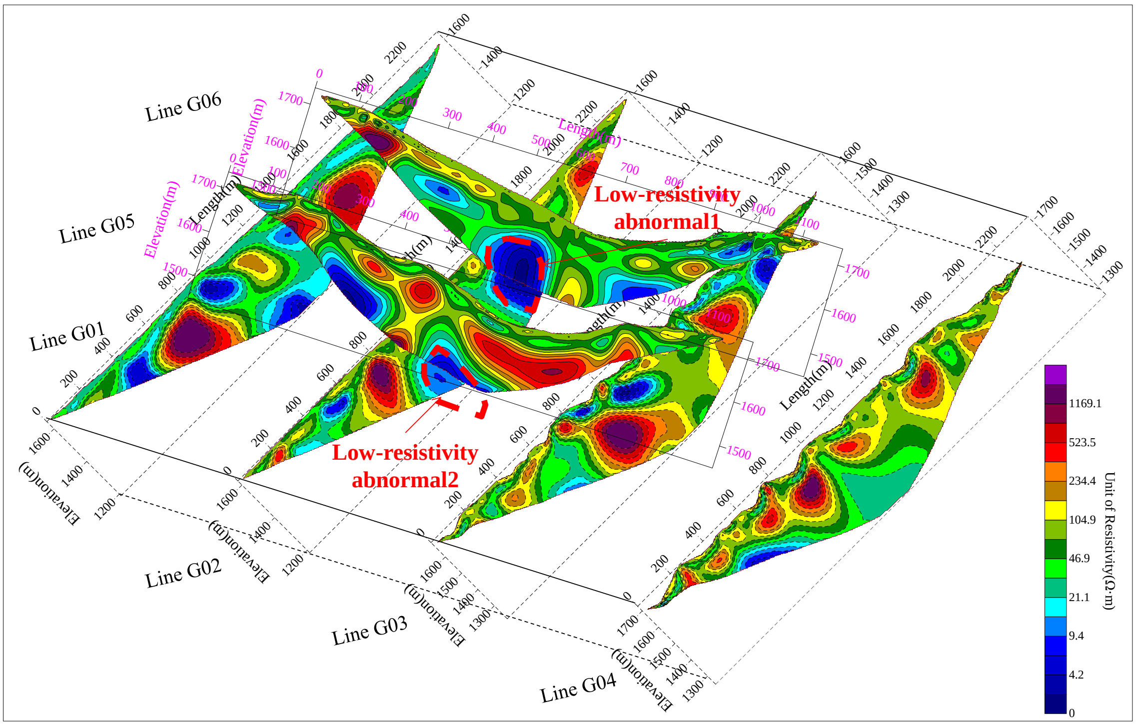


Figure 5: Line layout of High Density Resistivity Method

4.3 Data processing and geological interpretation

Firstly, the field-measured high-density apparent resistivity data were subjected to pre-processing such as distortion point elimination and terrain correction. Secondly, inversion imaging was performed to obtain the apparent resistivity inversion profile of the medium underground. Finally, according to the characteristics of the apparent resistivity of different physical properties, combined with known geological, hydrological, and mining data, the high-density apparent resistivity inversion section data in the mining area was comprehensively inferred and interpreted on the basis of the principle “from known to unknown and from simple to complex”.



(Red dotted line denotes the predicted water-accumulated goaf)

Figure 6: Inversion pseudo-section map of high density resistivity

(1) Inferential interpretation: Fig.6 shows the cross-sectional view of the high-density apparent resistivity of the test line. Combined with the preliminary delineation of the mine for the distribution range of the old coal mine goaf, it can be seen from the high-density resistivity inversion pseudo-section map that there are two low-resistance abnormal traps on the G02 line, respectively located at the line length of 900-950m and the line

length of 1450-1550m, and for the depth elevations at the positions of 1,400-1,480m and 1450-1500m, respectively, which is basically consistent with the initial delineation by the mine. Then it's inferred as the the well-watered old mine goaf area. Besides, according to the inversion of the high-density resistivity pseudo-sections map of the longitudinal lines G05 and G06, it can be clearly seen that the two low-resistance abnormal traps shown on the G02 line, and low-resistance abnormal traps are also shown in the corresponding positions of the line G05 and G06, respectively. Therefore, combined with known geology, hydrology, and excavation data, it's comprehensively inferred and interpreted that the two low-resistance anomaly traps were caused by the accumulated water in the old mine, and the water accumulation ranges are delineated by dotted lines as shown in the figure, with about 100-130m depth from the top off the ground.

(2) Drilling verification: In order to further verify the correctness of the interfered interpretation, according to the results of the high-density electrical survey, the mine implemented one drilling verification project for the anomaly 1 target area with a large range of low resistance anomalies. The drilled results show that water is found at a drilling depth of 105m; the main mining seam at this drilled location has been mined out and has accumulated water, which is basically consistent with the interpretation of geophysical prospecting.

5. Conclusions

This paper uses the high-density electrical method to carry out forward and inversion calculations of the numerical model on the old mine golf, and then applies the engineering case to detect the goaf water in old mine. The following conclusions are made:

(1) Through the forward and inverse calculation of the goaf numerical model with different filling types, the geoelectric response characteristics of different geological anomalies are summarized and analysed, which provides a scientific basis for on-site detection, analysis and interpretation of the features of the goaf.

(2) By applying examples, the detection was made for old coal mine goafs caused by the disordered mining before integration, achieving good geological effects. Then, the location and scope of the goafs were accurately described. Finally, drilling was made to further verify the reliability of geophysical prospecting. This shall provide effective reference for the safe mining and water control in mines.

References

Dzimunya N., Radhe K., William C.M. (2018). Design and dimensioning of sublevel stoping for extraction of thin ore (<12 m) at very deep level: a case study of konkola copper mines (kcm), Zambia, Mathematical Modelling of Engineering Problems, Vol. 5, No. 1, pp. 27-32. DOI: 10.18280/mmep.050104

Feng Y.D., 2009, Application of High Density Resistivity Method to Mined -out area Exploration in Coalfield, Chinese Journal of Engineering Geophysics, 6(5), 624-626.

Lei X.Y., Li Z.W., Zhe J.P., 2009, Applications and research of the high resolution resistivity method in explovation of caves, mined regions and Karst region, Progress in Geophysics, 2009, 24(1), 340-347.

Qi M., Zhang B.L., Liang G.H., Chen Y.M., Guan G., 2006, High-resolution prediction of space distribution characteristics of complicated underground cavities--Preliminary application of high-density electrical technique in an area of Yangquan, Shanxi, Progress in Geophysics, 2006, 21(1), 256-262.

Qian Z.F., 2014, Application and development of electrical prospecting technology in metal mines, Architectural Engineering Technology and Besign, 28, 1, DOI: 10.3969/j.issn.2095-6630.2014.28.1029

Sun L., 2012, The application of high density resistivity method and shallow seismic technique to detecting goaf in the coal mine, Geophysical & Geochemical Exploration, 2012, 36(S1), 88-91.

Wu Q., Cui F.P., Zhao S.Q., Liu S.J., Ceng Y.F., 2013, Type classification and main characteristics of mine water disasters, Journal of China Coal Society, 38(4), 561-565.

Yang J.M., 2012, The application of high density method to the exploration of coalfield goaf, Geophysical & Geochemical Exploration, 2012, 36(s1), 12-15.

Yang J.M., Wei Z.Z., Gao X.W., 2014, The application of the methods of high density resistivity method and transient electromagnetic to detecting coal mining goaf and to inspect grouting effect, Progress in Geophysics, 29(1), 362-369.

Yuan S.S., Zhang Z.J., 2006, Application of high definition electricity method in coal mine empty area, Mineral Resources and Geology, 2006, 20(3), 273-278.

Zhang J.G., Xu X.X., 2004, The Application of High Definition Electricity Method in Coal Mine Empty Area, West-china Exploration Engineering, 16(8), 65-66.

Zhang S.T., 2012, The Application of Geophysical Exploration Technology to the Detection of Coal Mine Goaf, Geophysical & Geochemical Exploration, 2012, 36(s1), 83-87.

Zhao Y.T., 2003, Development and Practice of Coalfield Electric Prospecting Technology in China, Coal Geology of China, 15(6), 59-64, DOI: 10.3969/j.issn.1674-1803.2003.06.018