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Intelligent identification of gas anomalous area by electro-magnetic joint exploration technology

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Abstract: For intelligent and accurate identification of the gas anomalous area, two geophysical exploration methods, namely, the direct current (DC) method and the transient electromagnetic method, were adopted for advance detection of the underground roadway before the joint inversion of the detection data to obtain the fusion image of apparent resistivity. Based on the high-resistivity area in the image, the range of 13–65 m ahead of the driving face is the gas anomalous area. According to the test results of gas prediction indexes q and Δh_2, there is an area with high prediction values in front of the roadway, which is consistent with that determined by geophysical exploration. From the analysis of the thickness of exposed coal, there is an area with large coal thickness ahead of the roadway where there is an increase in gas content. The electrical characteristics of the coal are changed in the area, contributing to the anomalous resistivity, which keeps in consistency with the results of geophysical exploration. Therefore, the electro-magnetic joint exploration technology can realize the intelligent identification of gas anomalous areas, which is of great significance for the efficient and accurate detection of gas anomalous area in the coal seam.

1 Introduction

As the largest coal-producing country and consumer of coal resources in the world, China has abundant reserves of coal resources that take a dominant part in the primary energy consumption, due to the feature of resource endowment which is ‘rich in coal yet poor in oil and gas’ [1]. At present, the coal accounts for over 70% of China's primary energy production and consumption, which is expected to remain over 50% by 2050 [2]. Therefore, China will continue to rely on coal as its major energy resource for a considerably long period.

Underground mining finds the widest application to China's coal mines. With the resources depletion in shallow deposits, mining operations have extended to the deep ones and the depth of many mines has reached 800–1500 m. The deep mining has witnessed the occurrence of disasters caused by gas, water, fire, roof fracture and high temperature, which poses a huge threat to the safety of underground mining. As the mining depth and intensity increase, the complex disasters occur frequently in various configurations, resulting in casualties and great losses. Among the causes of disasters, the gas is known as the ‘first killer’ of safe production [3], because it is likely to exacerbate the consequences [4].

Due to the complexity of underground geological conditions, the gas finds its uneven occurrence in different areas of the same mine and even at the different position of the same area. The gas enrichment areas can increase risks in mining operations and, without timely and accurate identification, the gas concentration will exceed limits, giving rise to a gas explosion and gas outburst disasters. Studies have indicated that the gas-bearing coal, as a geological body combining gas and solid, launches information from its generation in the form of, for instance, pressure transmission and gas migration, producing in this process magnetic field, electric field, thermal field etc. He and Lv [5] considered that gas outburst was the geophysical field of the geological body combining gas and solid in time and space under the effect of ground stress and gas pressure. Wang *et al.* [6] reported that there were multiple physical and mechanical responses in gas dynamic disasters, ranging from the mechanical process, mechanical response, and change in physical parameters to electromagnetic response, which enlarged the research scope of gas detection. Currently, the detection of gas enrichment areas depends greatly on drilling, i.e. the underground borehole, to determine the gas pressure or content of the coal seam on a regular basis [7]. It requires a heavy workload and fails to cover the whole study area due to its ‘point’ test, which tends to cause leak measurement and misjudgement. Therefore, the geophysical exploration is a preferable technology with perfect theory, simple data interpretation, mature technology and equipment and strong resolution of the geological anomalous body, which thereby finds wide application to coal mines [8, 9].

The gas-bearing coal can be regarded as a conductor whose electrical characteristics vary with the change of gas content [10, 11]. Specifically, the greater the gas content, the lower the coal conductivity, and the higher the resistivity. Research studies were conducted on the underground driving faces by adopting the joint exploration of the direct current (DC) method and the transient electromagnetic method. With the imaging analysis of the coal before driving faces, the gas anomalous area was analysed from the perspective of the coal seam and gas occurrence to determine the gas enrichment area. The results were verified according to the conventional gas prediction index during the in-situ tunnelling process in addition to the analysis of geophysical response as well as its mechanism of the gas enrichment area, which is of the vital significance for efficient and accurate detection of the gas anomalous area, providing a new technical means for the detection of gas disasters and reference for the detection and evaluation of disasters.

2 Methods

2.1 Introduction to the working face

Xinyi mine is a new member of Yima Coal Industry Group. With the design production capacity of 1.2 Mt/a, it is in Xin'an coalfield of the west Henan coalfield. Due to the regional geological structure, the 2-1 coal seam in Xinyi mine which finds the development of tectonic soft coal has low permeability and great variation in thickness. This study was conducted on the No. 12011

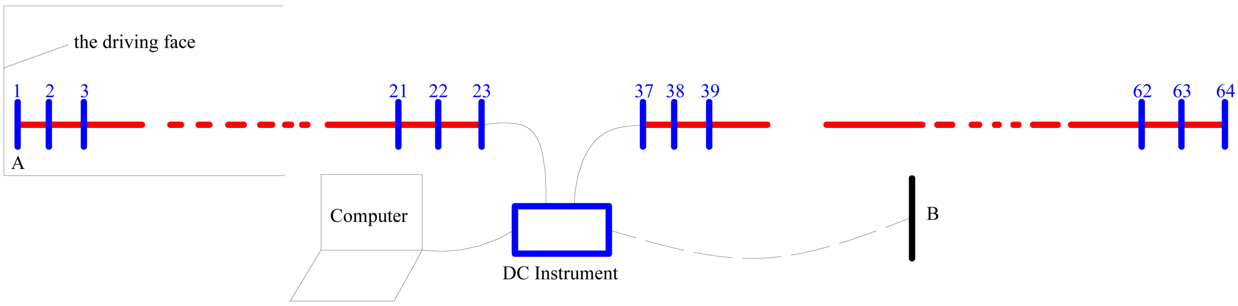

Fig. 1 *Schematic diagram of site stations arrangement of the DC method*

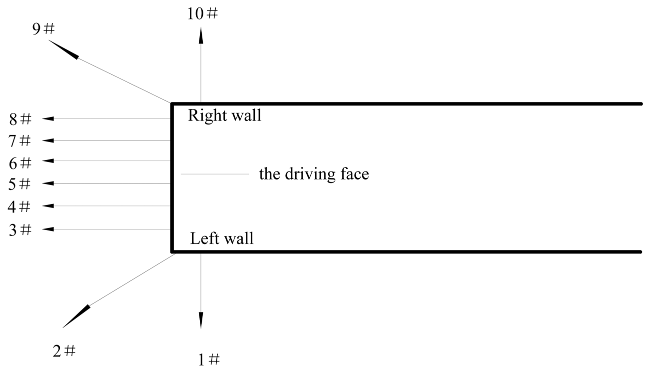

Fig. 2 *Schematic diagram of the site measuring points of the transient electromagnetic method*

working face, the first coal face of No. 12 mining area in Xinyi mine, with the ground elevation of 367–402 and underground elevation of −214.49 to −310.30. The length of the strike is 140 m, and those of haulage way and return airway are 910 and 859 m, respectively. The coal seam is simple in structure, with the pitch of 7–14° and the thickness of 3.47–7.25 m with an average of 5.36 m, thickening from the southwest to the northeast. With the gas content of 2.21–9.80 m/t and the gas pressure of 0.3–1.2 MPa, the 2-1 coal seam has the risk to outburst.

The 2-1 gas outburst seam has witnessed the unusual gas emission for several times, suggesting the existence of the gas enrichment area in the coal seam. Therefore, it is of great importance to detect in advance the gas enrichment area before driving faces for formulating gas-prevention measures. The DC and transient electromagnetic technology were applied to detect the area within 100 m along the tunnel direction to determine the gas anomalous area and verify the results.

2.2 DC method

The DC electrical apparatus used in this study is the network parallel electrical apparatus that not only boasts high data acquisition speed but also can be controlled remotely and monitored online. Parallel, massive and efficient data acquisition and processing is the core of the technology. Parallel computing, which refers to the process of using a variety of computing resources to solve computing problems simultaneously, is an effective means to improve the computing speed and processing ability of the computer system. Its basic idea is to solve a problem with a number of processors, i.e. the problem is decomposed into several parts, and each part is computed by an independent processor in parallel. Besides, during its implementation, multiple electrodes can realise simultaneous measurement with the power supplied by one electrode. Since parallel computing overcomes the shortcoming of low efficiency existing in the traditional serial acquisition, it boasts high data acquisition speed, thus greatly shortening the data acquisition time.

The network parallels electrical technology adopts smart electrodes which enable it to contact with the host computer in real time through network protocols and to send measurement data back to the host in real time through the communication line. Another feature of the system is the realisation of remote data collection. Remote monitoring and collection of electrical data can be realised through the connection of a specific software system, a data modem and telephone lines.

During the site arrangement, the haulage way was tunnelled to the position 128 m in front of the stop line. A measuring line was arranged in the haulage way of No. 12011 working face, which is about 1.5 m from the left wall. The 1# electrode was clung to the driving face and a total of 64 electrodes were arranged at intervals of 2.5 m on the 157.5-m-long line with an acquisition station in the middle. The current electrode A powered electrodes in turn from 1# to 64# for 2 s each time with the sampling interval of 50 ms. The infinite electrode B is placed at the position 450 m behind the haulage way. Based on the whole space theory, the apparent resistivity within 100 m ahead of the driving face was calculated and presented in the graph. The schematic diagram of site arrangement is given in Fig. 1. The back and ahead of the haulage way were set to be negative and positive, respectively, so as to obtain the relative coordinate of each electrode.

2.3 Transient electromagnetic method

The transient electromagnetic instrument was arranged on the driving face +128 m from the stop line of No. 12011 working face. To expand the coverage range, the detection was conducted in three directions. From the schematic diagram in Fig. 2, 10 measuring points (1#–10#) were placed on the driving face of each roadway at intervals of about 0.5 m, with a total of $10 \times 3 \times 2 = 60$ points arranged. The multi-turn tesseral wire-frame and small-loop measurement were applied to detect the water content along the tunnelling direction and the roof and floor strata of the roadway.

3 Results

3.1 Detection results

From the apparent resistivity ahead of the driving face obtained by DC method in Fig. 3, it can be observed that the apparent resistivity follows a certain layered distribution pattern. From 10–52 m before the driving face of the roadway, it is the relatively high resistance area with the apparent resistivity value over 75 Ω m; from 26 to 33 m, it is the absolute high-resistance area with that exceeding 100 Ω m; and from 64 to 75 m, it is the low resistance area with that below 60 Ω m.

The apparent resistivity obtained by the transient electromagnetic method is shown in Fig. 4. Due to the frequent

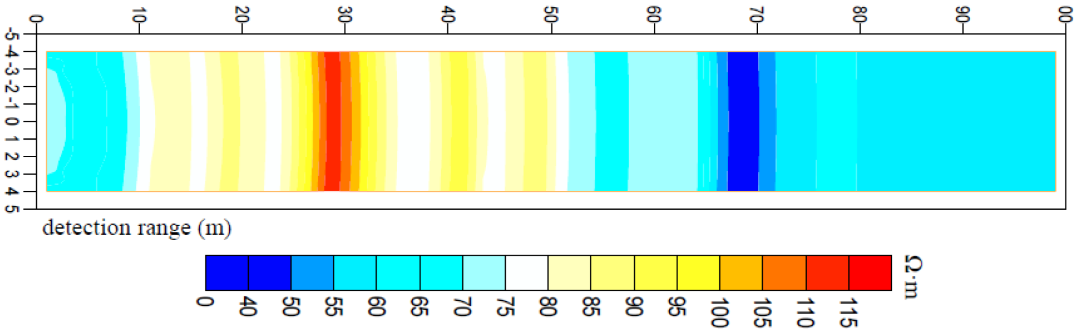

Fig. 3 *Profile map of apparent resistivity obtained by DC method*

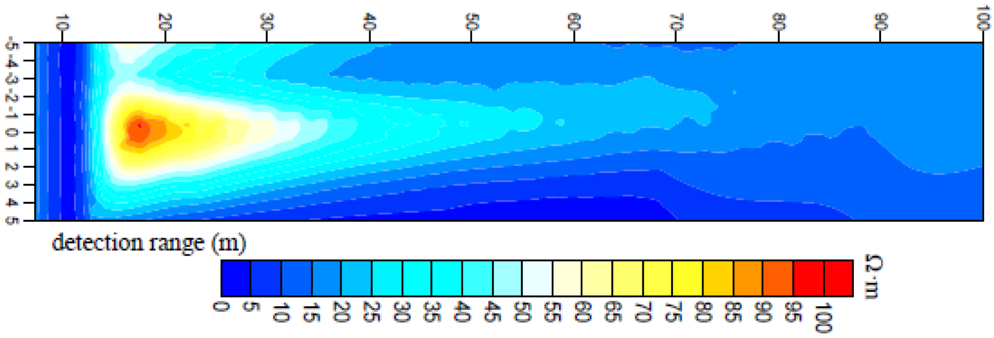

Fig. 4 *Profile map of apparent resistivity obtained by the transient electromagnetic method*

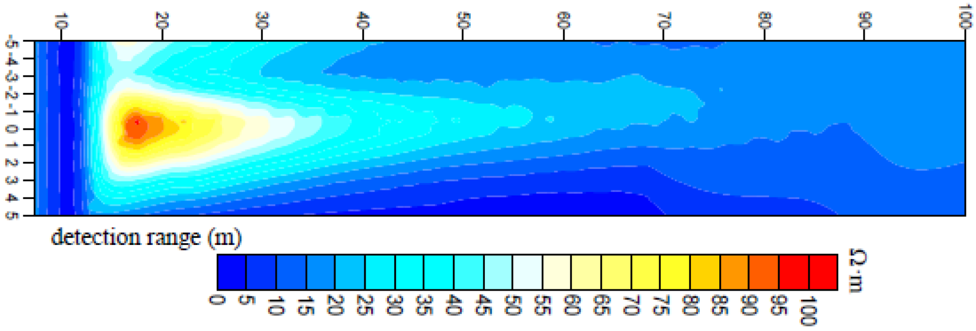

Fig. 5 *Fusion image of DC method and transient electromagnetic method*

distortion of early transient electromagnetic signals, there is a blind area of detection 0–8 m ahead of the driving face. The apparent resistivity value is higher than 40 Ω m in the range of 12–70 m where there may be an anomalous body with high resistivity based on the forward modelling and exploration of transient electromagnetic advance detection.

The data obtained by the DC method and transient electromagnetic method was processed [12] with sieving as the first step. Due to the blind area of detection induced by the distortion of early transient electromagnetic signals, the data obtained by the transient electromagnetic method in the range of 0–8 m ahead of the driving face was rejected. The interpolation processing was performed before wavelet decomposition, following the principle of maximum absolute value for tackling details and conducting averagely weighted calculation for approximate parts to implement data fusion. From the image by a surfer in Fig. 5, there is a high-resistivity anomalous body within a range of 13–65 m ahead of the driving face of the roadway.

To sum up, there are no major faults developed in No. 12011 working face from the perspective of regional geological conditions, and no small faults on the grounds of the tunnelling of the haulage way. Hence, this area is simple in structure and the impact of the fault is negligible on detection results. Based on the distribution of apparent resistivity, there is a changing anomalous body in the detection object due to the large area of anomalous apparent resistivity and the co-existence of high- and low-resistance areas with a certain range of transition areas. In the light of the foregoing discussion, the larger the gas content of the coal mass, the lower the electrical conductivity, and the higher the resistivity. Therefore, the range of 13–65 m before the driving face is the gas anomalous area, i.e. the gas enrichment region.

3.2 Verification analysis

After the determination of the gas anomalous area by geophysical exploration, the roadway excavation was carried out with certain safety precautions when the gas prediction index was tested by periodically drilling holes. The current prediction indexes for Xinyi mine is borehole gas emission initial speed q and drilling cuttings gas desorption index Δh_2, both of which indicates the velocity and capability of gas emission. The two indexes can be applied to verify the results of geophysical exploration because the larger the gas content, the greater the index value. Take the point 128 m ahead of the stop line as the zero point in accordance with that in the geophysical image to obtain the relationship between prediction indexes and the detection range, as shown in Figs. 6 and 7. Δh_2 and q maintain good consistency as the value of Δh_2 is high in the range of 15–60 m with the maximum of 220 Pa, and that of q maintains a high level in 20–75 m with the maximum of 4.7 l/min.

The range with high Δh_2 and q, which is the index-rising and index-anomaly region, is covered in the anomalous area of the image obtained by the electrical method, proving the reliability of the regional division in the previous paper.

Based on the profile of the exposed coal in the roadway (Fig. 8), the thickness of the coal seam varies greatly in the advanced detection area. From the detection range of 10 m, it

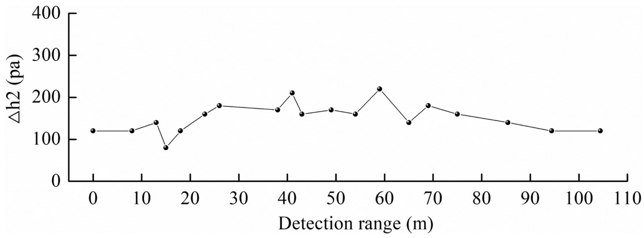

Fig. 6 *Change of drilling cutting gas desorption index Δh_2 with the detection range*

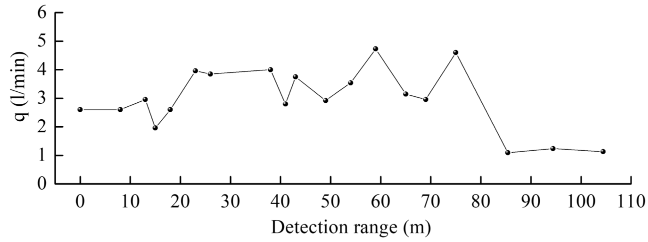

Fig. 7 *Change of borehole gas emission initial speed q with the detection range*

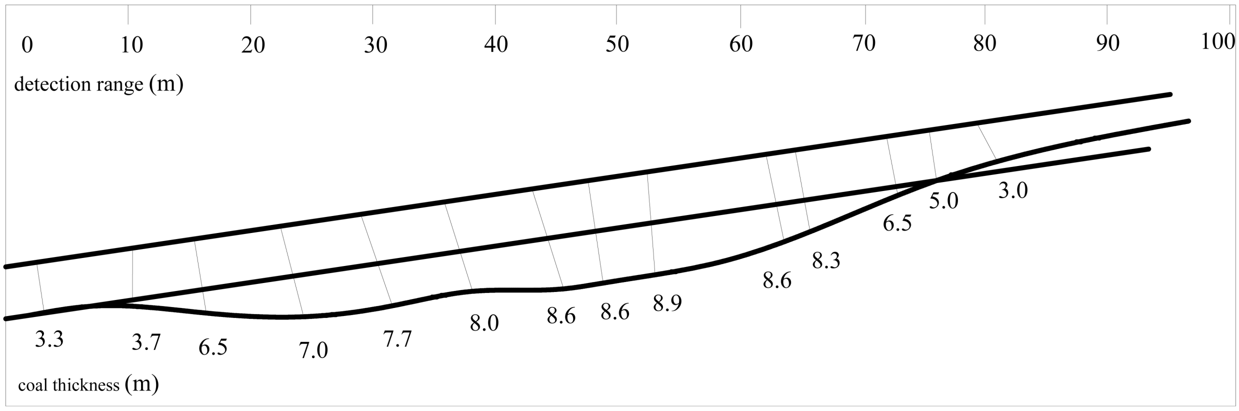

Fig. 8 *Profile of measured coal thickness*

gradually rises to the maximum value of 8.9 m at 50 m before falls to 3 m at 74 m, which indicates the anomalous zone of coal seam thickness lies in the range of 10–74 m where the thickness is greater than the average. The gas anomalous area, ranging from 10 to 65 m in Section 3.1, is basically consistent with that of the exposed coal thickness.

The greater the coal seam thickness, the larger the gas content, and thereby the two have a positive correlation [13]. Under favourable gas storage conditions, the thick coal zone is generally the gas enrichment area. The coal seams with large variations in thickness contribute greatly to the uneven distribution of gas because the changing coal thickness disturbs the equilibrium state of gas in the coal seam, thus promoting the migration and transformation of gas [14]. With the continuous rise of the gas content, the coal seam becomes a typical gas anomalous area, i.e. a gas enrichment area. Therefore, it finds an increase in the prediction indexes Δh_2 and q. Under this condition, gas disasters are easily produced during roadway excavation, which requires advanced gas control measures.

On the basis of the above analysis, the high resistance area determined by the joint exploration of the DC and transient electromagnetic method is the gas anomalous area. Hence, the geophysical exploration method can be applied to detect the gas anomalous area to realise the intelligent identification of the gas anomalous area and improve the accuracy and efficiency of gas prediction.

4 Conclusions

(i) Advance detection is conducted on the underground excavation roadway by two geophysical exploration methods, namely, the DC method and the transient electromagnetic method. Based on the fusion image of apparent resistivity obtained by the joint inversion of detected data, the high-resistivity anomalous area is observed and the gas anomalous area is determined to be in the range of 13–65 m ahead of the driving face.

(ii) There is a reasonable consistency between drilling cutting gas desorption index Δh_2 and borehole gas emission initial speed q as the value of Δh_2 and q is high in the range of 15–60 m and 20–75 m, respectively. According to the thickness of exposed coal during the tunnelling, the anomalous area of coal thickness is in the 10–74 m range where the coal thickness is larger than the average, causing an increase in the gas content. Therefore, the electrical characteristics of the coal are changed in the area, contributing to the anomalous resistivity, which is highly consistent with the results of geophysical exploration.

(iii) In consideration of gas and geology, the mature electronic and magnetic exploration can implement intelligent identification of the gas anomalous area, which is of great significance for the efficient and accurate detection of the gas anomalous area in the coal seam and for promoting the application and development of geophysical exploration technology in the coalfield. Furthermore, it also provides a reference to the regional exploration and evaluation of other coal and rock dynamic disasters.

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6 References

[1] Wu, S.Y., Wang, M.L.: 'The status of coal in China's energy', *Coal Process. Compr. Util.*, 2006, **5**, (5), pp. 2–8, 58–63

[2] Cheng, Y.P., Fu, J.H., Yu, Q.X.: 'Development of gas extraction technology in coal mines of China', *J. China Coal Soc.*, 2009, **26**, (2), pp. 127–139

[3] Zhao, T.C.: 'Implement conscientiously the coal mine gas control working principle to further intensify coal mine gas control', *China Coal*, 2008, **34**, (7), pp. 11–14

[4] Pan, Y.S.: 'Integrated study on compound dynamic disaster of coal-gas outburst and rock burst', *J. China Coal Soc.*, 2016, **41**, (1), pp. 105–112

[5] Lv, S.L., He, J.S.: 'Ultrasonic characteristics of the disturbed coal mass', *J. Central South Univ. Technol.*, 1997, **4**, (1), pp. 42–45

[6] Wang, E.Y., He, X.Q., Liu, Z.T.*, et al.*: 'Electromagnetic radiation detector of coal or rock dynamic disasters and its application', *J. China Coal Soc.*, 2003, **28**, (4), pp. 366–369

[7] State Administration of Work Safety, State Administration of Coal Mine Safety: '*Prevention and control of coal and gas outburst*' (China Coal Industry Publishing House, Beijing, 2009)

[8] Liu, S.D., Zhang, P.S., Cao, Y.*, et al.*: 'Characteristic analysis on geological abnormity by multi-information of geophysics in the deep laneway', *Procedia Earth Planet. Sci.*, 2009, **1**, (1), pp. 936–942

[9] Liu, S.D., Liu, J., Yue, J.H.: 'Development status and key problems of Chinese mining geophysical technology', *J. China Coal Soc.*, 2014, **39**, (1), pp. 19–25

[10] Chen, P., Wang, E.Y.: 'Variation regularities and mechanism of coal resistivity in gas adsorption/desorption process', *Disaster Adv.*, 2013, **6**, (S3), pp. 257–271

[11] Qiu, L.M., Shen, R.X., Song, D.Z.*, et al.*: 'Non-destructive testing principle and accurate evaluation of hydraulic measures impact range by the DC method', *J. Geophys. Eng.*, 2017, **14**, (6), pp. 1521–1534

[12] Sharma, S.P.: 'Appraisal of equivalence and suppression problems in 1D EM and DC measurements using global optimization and joint inversion', *Geophys. Prospect.*, 1999, **47**, (2), pp. 219–249

[13] Liu, X.R., Xian, X.F.: 'Test on relationship between seam gas, seam thickness and variation', *Coal Sci. Technol.*, 2004, **32**, (8), pp. 69–70, 74

[14] Niu, S.Y.: 'Western coal thick change control mechanism analysis of coal and gas outburst', *Saf. Coal Mine*, 2011, **42**, (7), pp. 127–128