A Study on Detection of Goaf Water of Tianli-Tianxin Coal Mine Based on Transient Electromagnetic Method

Xiaoli Cui*
Department of Civil Engineering, Sichuan Staff University of Science and Technology, Chengdu, China

*Corresponding author e-mail: cxlzxfi@126.com

Abstract: Goaf water is a major hidden danger affecting the production safety of coal mines. This paper describes a study on the application of transient electromagnetic technology for detection of goaf water in Tianli-Tianxin Coal Mine, which may play a reference role for the detection of goaf water in similar mined areas.

1. Geological Overview
Tianli-Tianxin Coal Mine is located in the western section of the frontal depression of the Urumqi Mountain, and the southern margin of the Junggar Basin. The outcrops in the exploration area include the following from the earliest to the latest: Sangonghe Formation (J1s), Xishanyao Formation (J2x), Toutunhe Formation (J2t) and Quaternary (Q4) sediments.

Among them, the Jurassic Zhongtong Xishanyao Formation (J2x) is the main coal-bearing stratum in the area. This formation is a river-lake-peat swamp facies deposit with lithology of medium-grain sandstone, fine sandstone, siltstone, shale, mudstone, coal seams, etc. According to the lithological combination, lithofacies and coal bearing characteristics, it is divided into four lithologic sections: lower glutenite section (J2x1), lower coal-bearing section (J2x2), upper coal-bearing section (J2x3) and upper sand-mudstone section (J2x4). This formation contains 17 minable seams, mainly including B12+13 and B14 coal seams, with the average coal seam thickness of 16.1m and average outcrop thickness of 462m.

2. Geophysical Characteristics
The terrain in the minefield is high in the south and low in the north, and the south-north valleys are developed, steep and severe in dissection. According to the ground survey data, there are civil buildings, high-voltage lines and lakes in the middle and southeast of the survey area, some sections bring difficulties to the transient electromagnetic fixed-point measurement. The shallow and surface terrestrial electricity conditions of this area is at the general level.

According to the transient electromagnetic detection data of this area, the upper strata of the Xishanyao Formation are dominated by sand-mudstone and siltstone, and the resistivity is low; the upper coal-bearing section of the Xishanyao Formation is mainly composed of sandstone and mudstone interbed, and the resistivity is medium and low; the lower coal-bearing section of the Xishanyao Formation is dominated by sand-shale, carbonaceous mudstone and coal seam, and the resistivity is medium-high; the glutenite formation in the lower part of the Xishanyao Formation is the highest. Combined with logging data, the transient electromagnetic conversion depth (resistivity curve) in this area corresponds to the electrical changes of the formation in the longitudinal direction.
In the vertical coal seam direction, the apparent resistivity of terrestrial electricity profile in the area increases first and then decreases, indicating the electrical change trend in the area is basically consistent with the stratum change law [1]. Therefore, the medium and deep terrestrial electricity conditions in this area are better, and the area has the geophysical premise of electric law exploration.

3. Experimental Research

The tests mainly include: instrument performance test (instrument stability, probe consistency), background noise investigation, and acquisition parameter test [2]. The finalized construction parameters are as follows:

1) Instrument factors: The instrument performance is stable, the consistency between the instrument and the probe is good, the data acquisition mode is correct and reliable, meeting the accuracy requirements.

2) Construction parameters: emission line frame: 320m × 320m; transmission frequency: 16Hz; emission current: 12A; sampling delay: 340μs; and number of superimposition times 128.

3) The transient electromagnetic change characteristics are consistent with the stratigraphic change characteristics.

4. Layout of Survey Network

The transient electromagnetic detection is arranged in a two-dimensional survey network and the transient electromagnetic detection network is 40m×40m (i.e. line spacing 40m and dot pitch 40m), evenly covering the whole area, and encrypted as 20m×20m near the middle wellhead of the survey area (D172-D220 lines). The DC depth detection adopts degree of freedom network, with a dot pitch of 50 m [3].

5. Data Processing and Interpretation

5.1. Data Processing

The data collected in the field during TEM exploration is the induced electromotive force, as shown in Figure 1. The abscissa is a logarithmic coordinate indicating the time at which the secondary field is observed; the ordinate is a logarithmic coordinate, indicating the normalized induced electromotive force. The induced electromotive force shall be converted to apparent resistivity, and the conversion formula is as follows:
\[
\rho = \frac{\mu_0}{4\pi t} \left( \frac{2\mu_0 S_T S_R}{5t(V(t)/I)} \right)^{2/3}
\]

Where, \(\mu_0 = 4\pi \times 10^7 \text{H/m}\), ST is the transmission return line area, SR is the receiving coil area, t is the tracking time, and \(V(t)/I\) is the normalized induced electromotive force transient value.

5.2. Data Analysis and Interpretation

From the apparent resistivity section of each line in this area, it can be seen that when the coal seam is not mined, the resistivity profile is basically horizontal, and the resistivity contour lines are gentle and smooth; when the coal seam is mined out, the section is reflected as abnormal high resistance; when there is water accumulation, the contour lines are distorted, deformed or densely striped, which is reflected as abnormal low resistance.

In the vertical direction, the apparent resistivity of the stratum in the survey area is characterized as low resistance to high resistance from shallow to deep. This characteristic is clearly reflected in each line in the area. According to the geological data of the survey area, combined with the interpretation of this data, the apparent resistivity sections of each survey line can be divided into four groups of electrical layers from top to bottom:

- The first group of electrical layers is the upper sand-mudstone section of the Xishanyao Formation, and the apparent resistivity is \((40 ~ 70) \Omega\cdot\text{m}\);
- The second group of electrical layers is the coal-bearing section of the Xishanyao Formation, and the apparent resistivity is about \((50 ~ 90) \Omega\cdot\text{m}\);
- The third group of electrical layers is the lower coal-bearing section of the Xishanyao Formation, and the apparent resistivity is about \((60 ~ 120) \Omega\cdot\text{m}\);
- The fourth group of electrical layers is the lower glutenite section of the Xishanyao Formation and the apparent resistivity is approximately \((70 ~ 140) \Omega\cdot\text{m}\).

According to the calibration results of the geomagnetic horizon in the borehole histogram, combined with the analysis of the transient electromagnetic single point curve and the geophysical characteristics of the strata in the working area, the typical apparent resistivity profile is analyzed by taking the D140 line profile analysis as an example. The results are as follows:

**Figure 2** Schematic Diagram for Interpretation of D140 Line Profile

The D140 line profile is located near No. 6 exploration line in the northwest of the survey area. According to the geological data of the survey area, combined with the interpretation of transient electromagnetic data, the upper sand-mudstone section of the Xishanyao Formation in this area is outcropped at the upper part of 215-230 points, with the lithology of sandstone, siltstone, mudstone and carbonaceous mudstone, the layer thickness of about 50m, and apparent resistivity of generally less than 50\(\Omega\cdot\text{m}\); the upper coal-bearing section has the lithology of sandstone, mudstone, carbonaceous mudstone, coal seam, with the layer thickness of about 65m and the apparent resistivity
of 50–65 Ω·m, which values are medium-low; the lower coal-bearing section has a lithology of sandstone, siltstone, mudstone, carbonaceous mudstone and coal seam, with the apparent resistivity between 65-75 Ω·m, and layer thickness of about 75 m, which values are medium-high; and the lower glutenite section consists of glutenite, sandstone and thin-layer mudstone, with high apparent resistivity value, which is generally greater than 75 Ω·m.

The D140 line apparent resistivity profile reflects the distribution characteristics of each electrical layer. From the apparent resistivity profile (Figure 2), the apparent resistivity contour lines have obvious bending and deformation at the B12+13 and B14 coal seam horizons between 176 point and 204. Combined with the geological data, it is deduced that coal seam goaf exists in this area, and the goaf range is about 280m.

5.3. Analysis of Goaf and Water Accumulation Area in B14 Coal Seam

The B14 coal seam is located in the upper coal-bearing section of the Xishanyao Formation. The roof is mainly mudstone, the bottom is mainly fine sandstone, and the coal thickness is about 2.47m.

Figure 3 is a slice view of the apparent resistivity for the coal bedding of B14 coal seam. Through comparison with the known goaf of B14 coal seam, combined with the analysis of apparent resistivity profile of the area near the goaf, 2 coal seam goaf abnormalities were defined on the profile, with the resistivity of 44-56 Ω·m, dense contours, and quick gradient change as the standard; and 1 coal seam water accumulation abnormality was defined, with the resistivity threshold of less than 50 Ω·m as the standard.

Among them, No.1 goaf abnormality area and No.2 goaf area are distributed in the west and middle of the survey area respectively, and the apparent resistivity contour lines are densely distributed, the gradient changes greatly, and the anomalous area is large. The analysis concluded that the B14 coal has been mined out in the two sections.

No. 1 goaf water abnormality area is located in the east part of No. 1 goaf abnormality area. The apparent resistivity contours show a low-resistance bulge, the amplitude is relatively low, and the anomalous area is large. On the basis of analysis, it is considered that this section is a goaf area with local water accumulation.

5.4. Analysis of Goaf and Water Accumulation Areas of B12+13 Coal Seam

The B12+13 coal seam is located in the upper coal-bearing section of the Xishanyao Formation and consists of sandstone, siltstone, mudstone, carbonaceous mudstone and coal seam.

Figure 4 is a slice view of the apparent resistivity of the B12+13 coal seam. Combined with the known goaf and geological data, according to the characteristics like resistivity threshold of 42 ~ 52 Ω·m, relatively dense contour lines, quick change of gradient, and so on, two blocks of coal seam abnormality area are defined on the profile.
Among them, Area 1 and Area 2 are distributed in the west and middle of the survey area respectively. The apparent resistivity contour lines are distributed densely and the gradient changes greatly. The abnormality area is large in area. According to the analysis, it is considered that these two sections are the goaf abnormality area of the B12+13 coal seam.

From the plan analysis, the B12+13 coal goaf overlaps with the B14 coal goaf by a small part. The spacing of the three coal layers is about 70m, and the coal seam is thick. After the goaf collapses, the caving zone and fissure zone of each coal seam overlap, increasing the size of the caving zone and the fissure zone, and the fissure zone connected the water-bearing stratum to form a goaf water zone. It is not excluded that the previous goaf water zone of B12+13 and B14 coal seams are connected in some sections, forming a water inrush disaster. Therefore, previous B12+13 coal and B14 goaf water area should be merged and taken with prevention and control measures.

6. Conclusion

From the study on the goaf water-bearing abnormality detection of B12+13 and B14 coal seams, 2 goaf abnormalities and 1 goaf water abnormality were defined in the B14 coal seam; 2 goaf abnormalities and 1 goaf water abnormality were defined in the B12+13 coal seam. According to the empirical calculation formula of the goaf water of Laoyao: \( Q = KMF/\cos\alpha \), the goaf water volumes were calculated respectively. In the formula, \( K \) is the water filling coefficient, and for the goaf water zone defined with the transient electromagnetic method, \( K=0.5 \). The water-bearing abnormality data of the goaf zone is shown in Table 1.

| Abnormality number | Area (m²) | Abnormality reliability | Water Volume (m³) | Remarks |
|--------------------|-----------|-------------------------|-------------------|---------|
| C14-1              | 101980    | Reliable                |                   | No accumulated water or a small amount of accumulated water |
| C14-2              | 67200     | Reliable                |                   | No accumulated water or a small amount of accumulated water |
| F14-1              | 25126     | Reliable                | 23489             | Water accumulated |
| C12+13-1           | 22358     | Reliable                |                   | No accumulated water or a small amount of accumulated water |
| C12+13-2           | 22902     | Reliable                |                   | No accumulated water or a small amount of accumulated water |
References

[1] Lu Cuixia, Application of Transient Electromagnetic Method in Detection of Goaf Water of Coal Mine, Shanxi Architecture, December 2015

[2] Liu Xia, Wei Rongfu, Han Yulei, Application of Transient Electromagnetic Method in Detecting Coal Mine Goaf and Its Water Accumulation Area, Journal of Engineering Geophysics, March 2014.

[3] Zhang Guannan, Ma Ke and Shi Hai, Detection of Coal Mine Water Goaf Based on Transient Electromagnetic Method, Mining Engineering, 2015, No. 10.