PASSIVE ULTRA-LOW FREQUENCY ELECTROMAGNETIC DETECTION TECHNOLOGY FOR COAL BED METHANE AND ITS APPLICATION

Qin Qiming, Li Baishou, Li Peijun, Zhang Zexun, Ye Xia, Cui Rongbo

School of Earth and Space Sciences, Peking University, Beijing, 100871
qmqin@pku.edu.cn

KEYWORDS: Ultra-Low Frequency Electromagnetic Wave, CBM Exploration, Geophysical Method

ABSTRACT:

Based on analysis of the significance of the coal bed methane exploration and development and the deficiency of the conventional coal bed methane exploration methods, the paper proposes a new technology of coal bed methane exploration with natural-source (passive) ultra-low frequency electromagnetic waves. The principles of passive ultra-low frequency electromagnetic detection and the mechanism of coal bed methane exploration are first introduced. The paper then shows the coal bed methane explorationexperiments and the latest research results in the Qinshui Basin of Shanxi using BD-6-ultra-low frequency electromagnetic detector developed by Peking University. Finally, the further application of the technology in the exploration of coal bed methane is discussed.

1. INTRODUCTION

Commonly known as gas, coal bed methane (CBM) is a unconventional natural gas. It consists mostly of methane (CH_4) but may also contain trace amounts of carbon dioxide and/or nitrogen. As the CBM is flammable and explosive, it has become a main bottlenecks of the safety production. In the mining process, the CBM is extracted and discharged into the atmosphere. The CBM is a potent greenhouse gas, with 21 times the global warming potential of carbon dioxide. Thus, its emission is an important factor of impact on change of ecological environment. On the other hand, it also is a kind of clean, efficient energy. Exploration and utilization of the rich methane resources in China, can not only alleviate resource shortage and meet the production and life energy demand, but also improve safety in coal mining and protect the ecological environment.

The key of exploitation and utilization of coal bed methane is to determine underground status of coal bed methane. Therefore, exploration is one of the most important steps in the development of coal bed methane. The current geophysical exploration methods include seismic exploration**,** geophysical logging method, and recent use of the electromagnetic detection for obtaining information of CBM.

With the support of the national "Eleventh Five-year Plan" and "863" program, using the ultra-low-frequency electromagnetic detector, Peking University has conducted CBM exploration and application experiments in the mining areas, such as Jining in Shandong, Jiaozuo in Henan, Xuzhou in Jiangsu and Qinshui Basin in Shanxi. The experimnents show that: the ultra-low frequency electromagnetic detector responses sensitively to the enrichment degree of the coal bed methane: ultra-low-frequency electromagnetic spectrum signals reflect the enrichment degree of underground coal bed methane and the electromagnetic difference among source-reservoir-cap rock of the coal bed methane. Based on prior knowledge, through signal parameters inversion and quantitative analysis of the electromagnetic spectrum, we can quickly and efficiently obtain information of the spatial distribution, storage conditions and enrichment degree of coal bed methane, then narrowing detecting target [1] to reduce drilling costs and improve the efficiency of drilling, to provide a new technical way for coal bed methane development and exploration in China.

2. PASSIVE ULTRA-LOW FREQUENCY ELECTROMAGNETIC DETECTION MECHANISM OF CBM

The equipment used by group is the passive ultra-low frequency electromagnetic remote sensing detector. According to definition of the international telecommunication union (ITU), frequency range 30-300 Hz is called as ultra-low frequency. In the electromagnetic spectrum, that band of electromagnetic waves can go through different solid, liquid and gas substance, and weakly effected by the terrain and attitude of stratum (Wait, 1982; Galleys, 1972). Therefore, if we can receive ultra-low frequency electromagnetic signals ranging from dozens to hundreds of Hertz from ionosphere and natural field source under the crust with the detector, we can extract varying information of electromagnetic fields and apparent resistivity in the different layers, to identify and extract underground targets of the different depths.

The Experiments and researches show that, gas in the coal can increases electromagnetic radiation, and its main mechanism can be summarized as follows.

(1) The gas occurring in pores and fissures of coal rock, engenders additional stress in the tip of rock coal crack, and reduces the coal rock surface energy, decreases friction coefficient between the coal rock surface, makes deformation and fracture process of coal rock more intense, and makes

This work was supported by the HI-TECH RESEARCH AND DEVELOPMENT PROGRAM OF CHINA under grant **(2006AA06Z233)** and **(2007AA12Z163)**

intensity of coal rock dropping, finally generates the electromagnetic radiation [2]. Absorption of the gas has a very clear impact on electromagnetic radiation. Below the critical gas pressure, the more absorption capacity is, the weaker electromagnetic radiation is. Above critical gas pressure, the more the absorption is, the stronger electromagnetic radiation is [3].

(2) When the gas flows and is desorbed in rock coal, the flow and impact of the gas generates electric effect, and then generates electromagnetic radiation. So electromagnetic radiation increases with the pressure rising [4-5].

(3) Accelerated development of coal rock deformation and destruction, the formation of new fissures and expansion of the old fissures are at a high rate .Those are the process of rapid energy dissipation. In the process, a part of energy dissipates in the form of radiation, and generates strong electromagnetic radiation [6].

To sum up, main reasons that the gas in the coal produces electromagnetic radiation include damaging effect and electrokinetic effect caused by gas flow, energy dissipation effect caused by coal bed fissures surface oscillation caused by gas flow. Electromagnetic radiation caused by gas flow is in the lower-frequency band (under the present experiment conditions the general frequency is less than 250 kHz). With the pressure gradient rising, the frequency of electromagnetic radiation increases when the gas flows. The greater the pressure gradient is, the higher the rate of gas flow is, the stronger the coal destruction is, the more obvious electrokinetic effect is, the higher frequencies of fractures oscillation is, resulting in stronger electromagnetic radiation and higher frequency [7].

Electromagnetic radiation transmission properties of the being loaded coal rock and gas are as follows [8]:

(1) radiation frequency signal is the low-frequency signals ($\leq$ 1 MHz);

(2) The frequency of the maximum power point of received signal varies with distance changing. The closer distance, the higher the frequency, scilicet the maximum power point of the electromagnetic radiation signal shifts to high-frequency. The farther distance, the lower the frequency, scilicet the maximum power point of electromagnetic radiation signal shifts to the low-frequency;

Based on the above theories, the authors think, in the case of disturbance gas-filled coal seam can produce ultra-low frequency electromagnetic radiation that can transmit up through underground several hundred meter-deep coal seam and strata. In the process of transmission, due to low frequency, the energy attenuation of electromagnetic wave is also low, which can be detected and the received by the passive ultra-low frequency electromagnetic microvolt high-sensitivity sensor on the ground.

In addition, in the "smoke ring" effect theory based on the diffusion of eddy current field, the active electromagnetic detector on the ground emits low-frequency detection signal, and secondary eddy current field will be excitated. The second field is pyramidal shape, with clear direction. The axial line of cone is vertical to emit-back plane [9]. Based on the analysis of interaction between electromagnetic waves and underground materials, because of clear sedimentary sequence of coal-measures seam, in the original state of formation, the characteristics of conductive show change regulation that the vertical changes are fixed, and the horizontal changes are relatively homogeneous. When the coal seam is fully filled with gas, its electrical conductivity is less, and apparent resistivity increases; if gas content is very low even noting, comparatively, its electrical conductivity is high , and apparent resistivity decrease. The regulation provides basis for ultra-low frequency electromagnetic detection with the conductivity difference of rock as physical foundation [10].

The passive ultra-low-frequency electromagnetic remote sensing detector developed by Peking University can detect 3-3000 Hz electromagnetic waves from natural source, which are wider than ultra-low-frequency band, but main band belongs to ultra-low-frequency. At present, it has been confirmed that the ultra-low frequency electromagnetic detector can detect rock interface, fault structure, cave, groundwater, oil and gas [11], coal bed methane [10] and geothermal resources [12].

Peking University research team of coal bed methane exploration conducted exploration experiments of the coal bed methane with the detector, in 28 obvervation sites, in the Qinshui Basin area, from September 22 to 25, 2007. Through the interpretation of the exploration, comparison with borehole data and gas testing data, we can verify and evaluate ultra-low frequency electromagnetic detector application result in the coal bed methane resources exploration.

3. COAL BED METHANE EXPLORATION IN QINSHUI BASIN TEST AREA

3.1. Brief introduction to test area

Qinshui Basin is located in the central south of Shanxi Province, and is a relative large coal-bearing basin in China. The basin is the only whole mount coal bed methane field that has been proven [13], is also the world's largest reserve of high-rank coal bed methane fields [14]. Sihe and Hudi coal mines in the southeast edge of the Qinshui Basins are chosen as test area.

3.2. Survey of coal and CBM in the test area

The known geological data of test area shows that major coal strata are the Taiyuan formation of upper Carboniferous, Shanxi formation and Xiahezi formation of lower Permian. Gas source rocks are on the 3rd and the 15th of coal seam. The main gas storage layer is coal seam too. Mudstone and non-infiltration tight sandstone form top cover of the coal bed methane.

In the Sihe test area the mining coal seam consists of three layers, and the total thickness is 10.32 meters, and the depth is 150-300 meters. In the main mining coal seam, average thickness of 3rd coal of is 6.31 meters. The structure is simple, and conditions for mining are good. The type of coal in the area is the low sulphur, low–middle gray, high heat, high mechanical strength anthracite, which is high-quality chemical raw materials and coal power. Recoverable reserve is 0.25855 billion tons. According to report of gas parameters by Chongqing Academy of Coal Science, the reserve of gas is 25 billion m^3. According to the 2004's level identification of gas, the absolute mine gas emission quantity is 386.01m^3/min, and the relative quantity is 25.28 m^3 / t, which belongs to a high-gas coal mine.

In the Hudi test area the mining coal seam also consists of three layers, and the depth of coal seam is 450-650 meters, and thickness of 3rd coal is 5.3 meters, and the average thickness of 15th coal is around 2.5 meters, and it also belongs to high-gas coal mine.

3.3. Testing procedure and data acquisition

According to the known geological data, 3 sites laid in the area of the Sihe Coal Mine and 7 sites laid in the area of the Hudi Coal Mine are measured.

Because of man-made electromagnetic interference, we choose some additional sites near the measuring point and link them to a test line as a comparison. Throughout the test process, all 10 short test lines are laid around the main measuring sites (10). The total of 28 sites are the on test line .On each measuring

sites we rotated detector direction, adjusted magnification, adjusted depth of exploration and detection step, to get the best detection effect. All measuring sites are detected eight times, more than 10 in one or two points. In total, we get 310 data curves.

After optimization of the detection curve, we comprehensively interpreted the high SNR, the significant features curves combined with known information.

4. INTERPRETATION OF ULTRA-LOW FREQUENCY ELECTROMAGNETIC SPECTRUM AND ANALYSIS OF THE ENRICHMENT DEGREE OF GAS

4.1.Comprehensive interpretation of CBM ultra-lowfrequency electromagnetic spectrum

Before comprehensive interpretation the detection curves, we must first establish curve interpretation marks of CBM, coal and surrounding rock .In this process we need compare the curves with borehole histogram to complete interpretation. To establish above interpretation marks in test areas, study group got" comprehensive geological histogram of Sihe Coal Mine" and "three main vertical drilling histogram of Hudi Coal Mine", including HD-010, HD - 011 and HD-015 drilling columnar section. After comparison optimal typical curves of exploration with drilling histogram ,we made sure "step shape" and the high amplitude feature near coal seam as interpretation marks of the coal bed methane, and the exploration curves of the surrounding rock are not same as the above.

With the help of established interpretation marks of the coal bed methane, it can be done to interpret measuring point without known information in the test area. For example, high-gas results of gas well P1-3 and P1-4 and the measuring points nearby are interpreted by established interpretation marks of CBM in Hudi mine. Interpretation of measuring point detection curves in Hudi Coal Mine is as follows:

HD-010 points drilling histogram shows that: Coal $3^{\#}$ is at the depth of 454.26-459.52 meters, and Coal $15^{\#}$ at 543.8-546.5 meters. The whole amplitude in 412-560 meters is significantly higher than the adjacent part, and the step shape is high, and high abnormal amplitude increases nearly 45 percent, and it is forecasted to be the high gas content point, in Figure 1(1). Interpretation result has a good agreement with gas logging data of nearby points where the gas content is 18 m^3 / t.

According to HD-011 points drilling histogram, coal $3^{\#}$ is at the depth of 531.25-536.36 meters, coal $15^{\#}$ at 618.94-621.84 meters. 2 high amplitude abnormal zone in the curve are in the 500-650 meters, and the first from 500 meters to 541 meters, second from 550 meters to 642 meters. The feature of high step shape can be seen in two abnormal zones, and high abnormal amplitude increases 42 percent. It is forecasted to be high gas content point, in Figure 1(2). Interpretation results agree with gas logging data of nearby points where the gas content is 17 m^3 / t.

HD-015 points drilling histogram shows that: coal $3^{\#}$ is at the depth of 507.62-512.82 meters, coal $15^{\#}$ at 597.73-600.23 meters. The whole amplitude in 482-618 meters is significantly higher than the adjacent part, and high abnormal amplitude increases 49 percent; At the depth of 482 and 618 meters, a significant step can been seen ,and can form high step shape of 482-618 meters. In the curve "high step" is extremely smooth, as high gas feature, in Figure 2(1). Interpretation results agree with gas logging data nearby points where the gas content is 18 m^3 / t.

According to P1-3 around points drilling histogram, it is estimated that coal $3^{\#}$ is in the 534 meters depth. The whole amplitude in 424-525 meters is significantly higher than the adjacent part, and high abnormal amplitude increases 54 percent; At the depth of 482 and 618 meters, a significant step can been seen , and can form high step shape of 482-618 meters. In the curve "high step" is extremely smooth. It is forecasted to be high gas content point in Figure 2(2). Interpretation results agree with gas logging data of nearby points where the gas content is 20 m^3 / t.

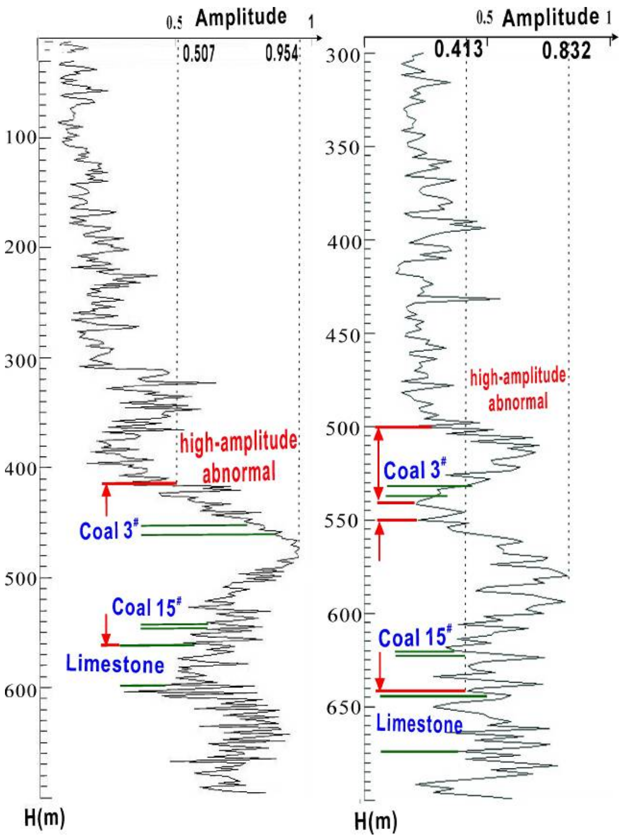
4.2. Analysis of CBM enrichment degree

According to results of the measuring point detection interpretation, the enrichment degree of gas is analyzed. In the all 28 test points, 24 points show the high-gas abnormal feature, and 4 points not; in every local test line, if there is one point showing high-gas abnormal feature, the other points of the line will also show high-gas abnormal feature. This indicates that enrichment degree of gas is good, and spatial distribution is relatively uniform in the whole test areas.

Regional analysis of the gas interpretation results and enrichment degree of 2 test areas will be shown as follows:

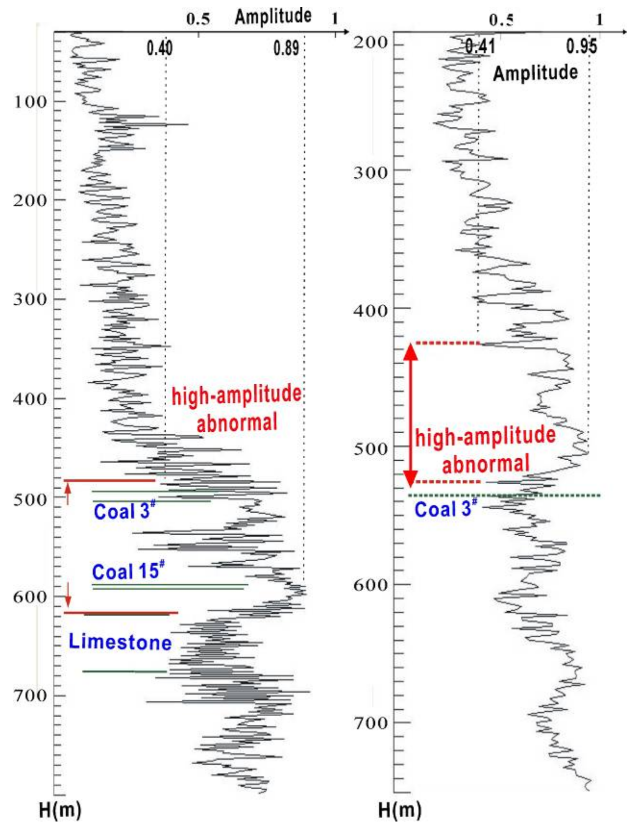
4.2.1. The test area in Sihe Coal Mine

Collected drilling histograms of Sihe mine show that in the east ventilation shaft, depth of the mining coal is 162.96-168.71 meters. In Shangzhuang ventilation shaft the depth is 228.3-235.1 meters. In west ventilation shaft mining the depth is 285.92-291.82 meters.



(1) (2)

Figure 1: interpretation graph of HD-010 and HD-011 measuring point about ultra-low frequency electromagnetic curve in hudi test area



(1) (2)

Figure 2: interpretation graph of HD-015 and P1-3 measuring point about ultra-low frequency electromagnetic curve in hudi test area

Based on the above information of coal distribution, comparison with detection curves, we find that detection curves around the depth of the coal(including the depth of the coal) in above 3 measuring points show "step-shape" and high amplitude feature, and "high enrichment degree of coal bed methane" can be concluded. High step shape feature of the west ventilation shaft （western area）are more significant than the east ventilation shaft and Shangzhuang ventilation shaft (eastern area). It can be concluded in gas content west is larger than east, and in enrichment level west is high than the east in Sihe Coal Mine. Detection results are entirely consistent with the actual gas testing results that gas content in the 3rd coal is 9.03 m^3 / t in the east, but gas content in the 3rd coal is 16.6 m^3 / t in the west.

4.2.2. The test area in Hudi Coal Mine

With the reference to drilling histogram of HD-010 , HD-011 and HD-015, we interpret measuring point curve in Hudi mine. The results show that: the point HD-010 near the HD-010 drilling , the point HD-011 near drilling HD-011,the points HD-015 near the drilling HD-015 and other points near gas wells P1-3 and P1-4 show "step-shape" and high amplitude feature indicating high gas content, consistent with gas testing results near the drilling (17 m^3 / t, 18 m^3 / t, 20 m^3 / t) .

The results also further prove that the gas content and enrichment degree have a positive correlation with abnormal increase of the high amplitude.

5. CONCLUSIONS AND PROSPECTS

The utilization of natural sources (passive) ultra-low frequency electromagnetic detection method for coal bed methane exploration, can effectively reduce exploration costs and improve exploration efficiency, and provide services for CBM exploration and development, and lay a foundation to enhance exploration efficiency.

Although the ultra-low frequency electromagnetic detector in CBM exploration shows good effect, there is still some further work and test which should be carried out: establishing quantitative relation between the ultra-low frequency electromagnetic detection spectrum and gas content; removing multisolution of ultra-low frequency electromagnetic signals; removing noising signal; according to the test, establishing all kinds of spectrum curve database of lithology, gas and so on. The interpretation given by the paper, need further test and validation referring to drilling and gas testing data in new test areas.

REFERENCES

[1] Qin Yong. Situation and challenges for coalbed methane indusrialzation in china (I)—at the current stage of growing period, 2006, 26(1): 4-7

[2] He Xueqiu,Wang Enyuan, Nie Baisheng. Rheological Electromagnetic Dynamics Of Coal. Beijing:Science Press, 2003

[3] Liu ming ju; He Xue qiu; Xu Kao. Influence of porous gas on ruptured electromagnetic radiation and its mechanism. Journal of China Coal Society, 2002,27(5):483-487

[4] Xue Erlong, He Xueqiu, Nie Baisheng,etc. Research On Coupling Theory Of Coal Or Rock Gas And Electromagnetic Emission, China Mining Magazine, 2005, 14(12):71-73

[5] Li Xuechen, Wei Guoying, Xin Xinping. Application Of Non-contact Electromagnetic Radiation Technology Forecasting Coal And Gas. Safety In Coal Mines. 2005, 36(7):12-16

[6] Liu mingju, He xueqiu,etc. Probing into Rheologically Electro magnetic Radiation Theory of Coal and Gas Outburst. Mining Safety & Environmental Protection, 2001,28(5):30-32

[7] Nie Baisheng, He Xueqiu, Sun Jiping,etc. Effect of Gas Flow on the Spectrum of Electromagnetic Radiation. Journal of University of Science and Technology. 2003,25(6):510-514

[8] Qian Jiansheng, Liu Fuqiang, Chen Zhiguo,etc. Analysis of electromagnetic waves propagating characteristic process of coal rock outbursts. JOURNAL OF CHINA COAL SOCIETY. 1999,24(4):392-394

[9] Yu jingchun, Liu zhixin, Yue jianhua,etc. Development and pospect of geophysical technology in deep mining[j]**.** Progress in Geophysics,2007 ,22(2):586-592

[10] Li Jian; Ding Meilian. Application of ULF Geological Remote Sensing Device in Gas Detection**.** Coal Geology of China. 2005,17(4):54-56

[11] Hou Guiting, Yi Xuelei, Qian Xianglin. The Application of Ultra-long Electromagnetic Wave Remote Sensing to Deep Petroleum Exploration Under Bohai Sea. Acta Scicentiarum Naturalum. Universitis Pekinesis,2001,37(1):81-86

[12] Lin manyi, Wu wenjun, Ye hua. The Application of Ultra-long Electromagnetic Wave Remote Sensing To Geothermal Exploration**.** West-china Exploration Engineering, 2006,(1):107-108

[13] Li wenyang, Wang shenyan, Zhao qingbo. Exploration and Development of Coal Bed Methane. Press of University of Science and Technology Beijing, 2003.8:150

[14] Qin yong. CBM Paper Distribution And Characteristics Of Coalbed Methane Industry Development In China[A] Chief Editor Ye jianpin, Fan zhiqiang. Technological Progress Of coalbed methane Development And Exploration In China. Beijing: Geological Publishing House, 2006:20-26

ACKNOWLEDGEMENTS

The date collection and experiments were conducted with help from leader and staff of Sihe Coal Mines and Hudi Coal Mines of Jincheng Coal Industry Group in Shanxi Province, We would like to sincerely thank them.