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Technical Note

Evaluation of coal seam hydraulic fracturing using the direct current method

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1. Introduction

In recent years, Chinese coal mines begun to apply hydraulic fracturing technology for the pressure relief and permeability increase of difficultly extracted coal seams. Laboratory investigations,[1–3] numerical simulations [4–6] and field measurements [7–9] have proven that hydraulic fracturing can effectively relieve pressure and increase permeability of this kind of coal seams, greatly improve gas extraction efficiency, and ultimately achieve good drainage and outburst prevention effects.

What matters in the application of hydraulic fracturing technology of coal seams is the determination of the impact extent of hydraulic fracturing. Once the extent is reasonably determined, it can greatly reduce the construction amount of later gas extraction under the premise of safely mining, while when the extent is not unreasonably determined, it may lead to the inhomogeneous distribution of stress among hydraulic fractured holes or along both flanks of a single hole after the coal rock hydraulically fractured and the stress concentration in the coal seam, even inducing coal and gas outbursts.[10] At present, the impact extent of hydraulic fracturing is still investigated using very traditional methods such as measuring drilling debris amount, moisture content, etc, as well as investigating the effect of gas drainage.[11–13] These works all focus on the "point evaluation" of the potential impacting extent of hydraulic fracturing zone, that is, sampling rock cores at some fixed points in the impacting extent to test their related parameters and use these parameter to determine whether the hydraulic fracturing will affect these points. These methods can not be used for comprehensive, spatialtemporally continuous evaluation of coal rock structure evolution in the whole zone, and will result in the later gas extraction construction blindness to a certain extent, which not only affects coal mine production safety, but also greatly increases construction costs. Lack of good evaluation measures has become one of the bottlenecks in the promotion and application of coal hydraulic fracturing technology.

Geoelectric technologies have been widely used in the field of coal exploration.[14–17] Among them, the direct current (DC) resistivity method is first to supply electricity to coal rock mass in the measured region, then to observe the changes in coal rock apparent resistivity through measuring electric potential or electric potential difference between the embedded electrodes, thus effectively detecting the internal structure of coal seams. In other words, the method is to measure the geological anomaly area in the coal seams by detecting changes in the apparent resistivity of coal rock.[18,19] Due to the sensitive response of apparent resistivity to water, penetration of hydraulic water following crack propagation in the process of hydraulic fracturing into coal rock will lead

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to changes in the apparent resistivity of adjacent areas. In general, the areas to which hydraulic water permeates are considered as the areas affected by hydraulic fracturing. Therefore, the impacting extent of hydraulic fracturing should be able to be determined by monitoring the change in the apparent resistivity of coal rock in the hydraulic fracturing process.

Based on above, in this paper, we first analyzed the principle of the DC resistivity response method of coal and rock mass hydraulic fracturing, then tested its feasibility using a small scale coal rocks in the laboratory, and lastly evaluated its feasibility on the field. The research results are of significance for studying the impacting extent of hydraulic fracturing and ensuring the scientific and safe application of coal mine hydraulic fracturing for permeability-increasing technology.

2. Principle of DC resistivity response to hydraulic fracturing

2.1. Four electrode measurement of earth resistivity

The response of DC resistivity of coal rock mass in the hydraulic fracturing area is related to the four-electrode measurement of earth resistivity. The positive and negative electrodes of the power supply are connected to points A and B, respectively, to form a stable electric field in the earth medium between A and B. The other two electrodes, M and N, are connected to the two terminals of the instrument used to measure their potential difference, based on which the earth resistivity is detected.

No matter where the relative positions of four electrodes are, the resistivity of the medium (earth) can be calculated as [20,21]

$$\rho = \frac{4\pi\Delta U_{MN}}{I}\left(\frac{1}{r_{AM}} - \frac{1}{r_{AN}} + \frac{1}{r_{BN}} - \frac{1}{r_{BM}}\right)^{-1} = K\frac{\Delta U_{MN}}{I} \tag{1}$$

where ρ is the resistivity of the medium, r_{AM} is the distance between points A and M, U_{MN} is the potential difference between the points M and N, I is the intensity of the supply current, and K is the device coefficient with its length dimension.

When the electric property of the medium in the whole space is inhomogeneous, the result calculated according to Eq. (1) is no longer the true resistivity of certain medium, but rather is the integrated representation of a typical variation in certain volume range of the three-dimensional space, called the apparent resistivity in the whole space, namely,

$$\rho_s = K\frac{\Delta U_{MN}}{I} \tag{2}$$

where ρ_s is the apparent resistivity of the medium between M and N.

Following the way of earth resistivity method, the differential expression of the whole space apparent resistivity can be obtained as follows:

$$\rho_s = \frac{j_{MN}}{j_0}\rho_{MN} \tag{3}$$

where ρ_{MN} is the true resistivity of the medium between M and N, j_{MN} is the actual current density between M and N, j_0 is the current density when the whole space is filled with homogeneous medium. It is clear that the apparent resistivity is the outward manifestation of the electric current field distribution state inside the medium.

2.2. Apparent resistivity response of coal rock mass subject to hydraulic fracturing

Coal rock mass is inhomogeneous medium in which randomly distribute various defects including micro-cracks, pores, joints, etc. In the hydraulic fracturing process, the combined action of high pressure water and external stress leads to unstable expansion of various scaled defects in the coal rock mass. At this time, the pressure water will be injected into the cracks of the coal rock mass, resulting in decreased coal rock apparent resistivity.

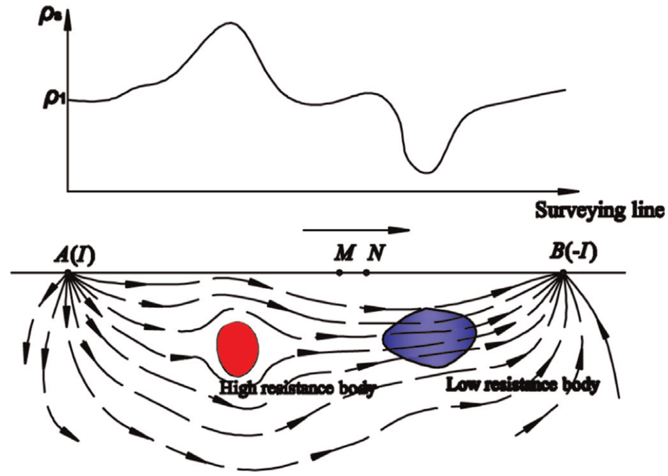

Fig. 1. Low resistance body's "low resistance attraction" of electric field.

In the same way, the coal rock mass of coal seams in the zone affected by hydraulic fracturing is moisturized and becomes a conductor of low resistivity. At this time, applying an external uniform electric field will lead to "low resistance attraction" of the hydraulic fracturing area to the electric field ,[22] as shown in Fig.1, thus changing the apparent resistivity of the coal seam.

It is clear from above analysis that it is feasible by testing the change in the apparent resistivity of adjacent coal rock mass in the hydraulic fracturing process to analyze the change in the adjacent earth electric field, and further evaluate the hydraulic fracturing impacting extent.

3. Feasibility experiment on apparent resistivity response to hydraulic fracturing

3.1. Experimental system

The experimental system included the loading system, hydraulic fracturing system, and DC resistivity method testing systems, as shown in Fig. 2. The loading system was a YAW-type electro-hydraulic servo pressure testing machine consisting of the press machine, automatic load control system and Power Test V 3.3 control program. The hydraulic fracturing system was consisted of high-pressure water-conducting pipe, high pressure water meter, and water pump. The data acquisition system was consisted of electrodes, enamel covered copper wire, and WBD-type network parallel electrical instrument. Among them, the WBD type network parallel electrical instrument was mainly consisted of the measurement host, computer and power modules with self-made multi-channel electrode measuring wires. Its main technical specifications are as follows. Its number of channels is 16, 48, 64 and 128. The 16 channel was used in the experiments. Its A/D conversion is 16 bits. Its voltage measuring range is ±10 V. Its measured voltage and current accuracy is 0.5% (Full). Its maximum emission voltage is 15 V/30 V/60 V/90 V. Its maximum emission current is 100 mA/1 A/2 A. Its input impedance is >20 MΩ. Its power supply square wave is either multi-frequency, positive or negative square waves. Its operating voltage is 12–18 V and its operating current is 1 A (related to the number of channels).