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Analysis of seepage characteristics of mine fractures based on geothermal utilization

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This paper discusses the feasibility of using the fluid seepage characteristics to develop the underground thermal energy of the mine so as to combine the thermal hazards treatment of underground mine with the utilization of thermal energy. This paper puts forward the idea of using a high-pressure water pump to make cracks, and scouring the underground hot rock with cold water to get the heat energy. The main factor of the natural gushing water in the mine is found out. The causes and characteristics of the rock fracture deformation are analyzed. The data show that the rock fracture deformation and seepage relationship model can be established in the equivalent continuous medium state. In this paper, the relationship between fracture and seepage of rock mass is established, and the relationship between the flow of mine groundwater in rock mass and fracture deformation is obtained.

Key words: Rock mass fracture, Seepage, Heat energy, Storage effect

INTRODUCTION

Various adverse micro-climates may happen in the mine production, which are mainly high temperature and high humidity in the mine. The so-called high temperature refers to the underground temperature of more than 300C; the so-called high humidity refers to the relative humidity of more than 80%. The micro-climate with high temperature and high humidity indicates thermal hazards [1]. To solve the problem of high temperature and high humidity in underground mine can ensure the health of underground workers, satisfy ergonomics requirements and improve working efficiency. In the mining process, a large number of hot water was poured out, which directly led to underground thermal hazards, while these hot water contains massive, exploitable energy. The realization of integrating thermal hazards treatment of underground mine with the utilization of geothermal energy will bring a qualitative leap of China's energy-saving and emission reduction project.

DEVELOPING GEOTHERMAL ENERGY BY SEEPAGE

Exploiting geothermal energy by taking advantage of water seepage was first proposed by the United States in the 1960’s. Japan and European countries developed high-temperature rock technology since that time [2]. The United States performed experiments at Fenton Hill between 1978 and 1986; the Britain did experiments at Cornwall Rosemanowes Quarry; Japan carried out some tests in the elbow area in 1984. And they all achieved some results.

These fractures are usually saturated with water or steam in the thermal rock geothermal reservoir when rock fractures are suitable. After drilling, water and steam can be used as working fluid for the extraction of heat and can be used to generate electricity. There is no water in the dry thermal rock geothermal reservoir, so the geothermal reservoir must be injected with water. In order to keep the permeability high and the flow resistance low, it is necessary to press the rock with water to connect the wells and make the joints open. And then rinse a large area of dry and hot rock with flowing water to obtain high-temperature liquid in the long term. Experiments at Fenton Hill confirmed the feasibility of this approach, and nine months’ experiments from 1978 to 1980, 3 ~ 5MW of geothermal energy was produced. Stratum Due to the low flow resistance, the water is injected into the stratum until it is produced from another well, and the energy used is less than 2% of the heat produced.

The biggest difficulty with the geothermal utilization methods above is how to carry out underground thermal energy surveys and the expensive drilling costs. If the natural underground heat energy can be used when mining is carried out, the problems and costs of surveying technology are completely solved. Therefore, with very little input, inexhaustible and clean energy can be obtained. The mine thermal rock is fractured by the high-pressure water pump so that it has fractures with good seepage effects. Those fractures eventually converge in the designed roadway. A hot water recycling bin was built near the fracture, into which the surface cold water was poured, and then hot

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water was drawn to the ground to use by the pump. That is a viable way.

If the extracted hot water is used in the air conditioning system to cool and heat, it will save about 67% more electricity than electricity by a preliminary economic analysis.

SOURCE OF MINE SPRING

For the development and utilization of geothermal energy, expensive exploration and drilling cost has been plaguing engineering technologists in geothermal development, but in the mining activities, the natural formation of the mine, after the completion of mining tasks, even when mining, the permeability of water can be used as a hot water well.

Water filling source

Mine water disaster refers to the mine in the construction and development process, different forms, different sources of water, through a certain way into the pit, and then cause adverse and harmful effect on mine construction and production. There are three problems that must be considered in the discussion of the source of mine water: 1. Does the water supply exist? 2. Does the water filling pathway exist? 3. What is the water filling strength? Since most mining activities are below the surface of the earth, therefore, groundwater has become the most important water source for underground water supply. As a water filling source, groundwater can be divided into indirect water filling source, direct water filling source and self-filling water source, these 3 basic forms. For most mineral deposits in the north, indirect water filling is the most common. The indirect water filling water source refers to the water source which is mainly distributed around the ore body [3].

Water filling pathway

The mine water filling pathway means the water passage between the filling water source and the mine. In structural water guiding channel, most common type are faults, fractures etc. Rock mass is the composed of rock and structural plane, in the process of the rock formation, the material foundation and macroscopic structure and heterogeneity of the rock mass and the original structural plane of the rock mass are formed, and then a large number of structural planes and secondary structural planes have been developed after the late structural, unloading and weathering processes [4]. The structural plane is also called fracture, so it is also called fracture rock mass. The underground water of rock slope can be called mine slope, fracture rock ground water. After the mine is excavated, along with the downward extension of the stope, it changes the hydrogeological environment nearby, and the groundwater enters the stope and tunnel along the rock fracture, which brings inconvenience to the underground operation. In order to study the water filling strength, it is necessary to understand the seepage of fluid in the rock mass fracture. This paper will focus on the influence of rock mass fracture and deformation on water eepage.

ROCK MASS FRACTURE ANALYSIS

Cause of fracture

Fractures are one of the most common features in rock formations, including nature fracture and man-made fracture according to the rigorous geomechanics. There are many methods of man-made fracture, which are not described in detail here. The reason for the nature fracture is that the increase of stress exceeds the rupture strength of formation rock. It is attributed to various geomechanics factors. Such as the formation of folds and faults when the operation of the crust; the overburden erosion will form a difference, stress, etc. through each weak surface.

Characteristics of rock mass fracture

A large number of primary fractures formed during the diagenetic process of the rock mass. Ore bodies occurred in structural facture zone, during the long process of mineralization, rock masses have experienced many severe tectonic changes, after many tectonic actions, unloading and weathering, a large number of structural factures and secondary fractures have been developed.

Typical rock mass joint fracture simulation next work [5], see Figure 1. Typical mine slope joint fracture statistical results [6], see Table 1. From which we can see that the development of facture of rock mass is dense, and the fracture distribution is obvious. In most mines, rock fractures are intensive, the maximum fracture spacing or average fracture spacing is almost negligible compare with the size of rock mass or surface area, the flow field volume is far greater than the typical characterization of unit volume of REV, so in the establishment of fluid rock deformation crack and seepage relationship model can be assumed to be in the equivalent continuum condition, which can objectively reflect the groundwater seepage characteristics.

ESTABLISHMENT OF RELATION MODEL BETWEEN ROCK MASS FRACTURE DEFORMATION AND SEEPAGE

Fluid Storage Effect Model

Fluid storage effect means when a fluid flows through the pores of a porous medium, The mutual influence of fluid flow and rock deformation, resulting in expansion of rock and compression of pore volume, As a result, the fluid appears to be trapped by the pores of the rock and stored in pores. The storage effect of fluid is the direct manifestation of the influence of rock deformation on seepage flow under fluid-structure interaction, which is very different from the conventional linear seepage.

When the porosity of rock mass reaches a certain extent, the rock mass can be considered as a porous medium, under one-dimensional flow condition, the continuity equation of rock mass with fluid storage effect can be expressed in the lower equation [7-9]:

$$\frac{1}{V_b}\frac{\partial}{\partial t}\left(\rho_f V_b \phi\right)+\frac{\partial}{\partial x_i}\left(\rho_f v_{fi}\right)=0 \quad \cdot(1)$$

where V_B is the rock mass, ϕ - the porosity, ρ_f - the ensity of rhw fluid, v_{fi} - the seepage velocity of the fluid.

On the premise of equivalent continuum which is stated in 3.2 in this paper, we make the following assumptions about Eq. (1).

The deformation of fluid and solid particles is elastic deformation.

The strain of porous medium is small strain and satisfies Eq. (2).

$$\begin{cases} \dfrac{V_b}{V_{bo}} = 1-\varepsilon_v \\ \dfrac{V_{bo}}{V_b} = 1+\varepsilon_v \end{cases} \quad (2)$$

Derive by deduction,

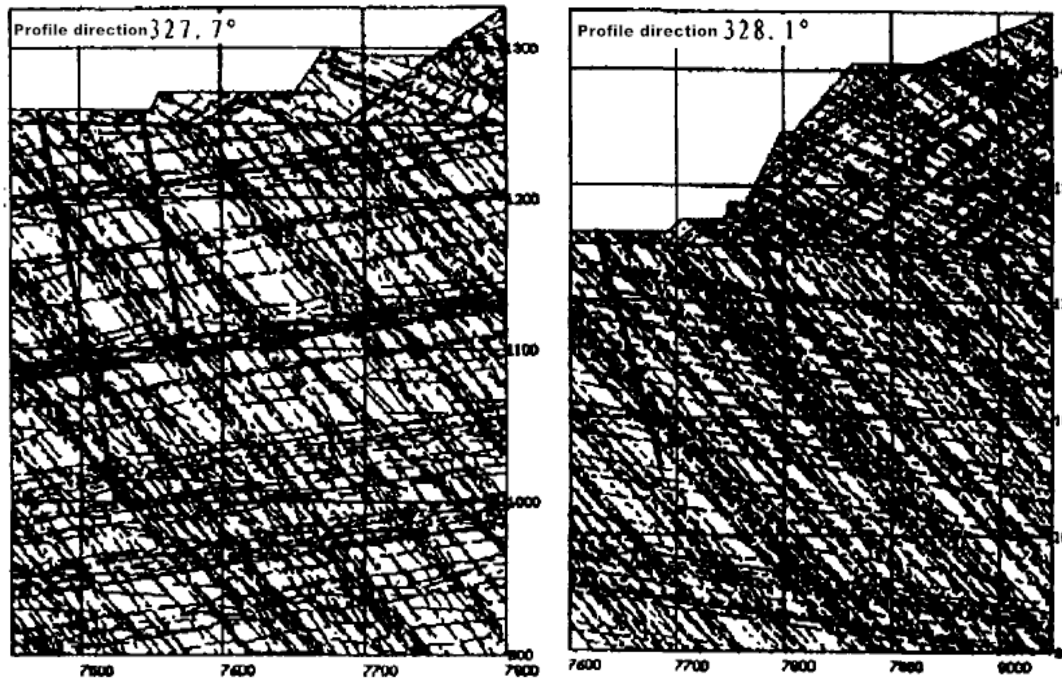

Fig. 1. Pan Gang Zhu jia bao iron mine Nanbang slope edge joints network simulation diagram

Table 1 Jianshan iron mine statistical analysis of slope crack spacing

Measuring point	Lithology	Sample capacity	Mean value (cm)	Standard deviation (cm)	Exponential distribution
1	Amphibolite	66	11.662	7.929	Yes
2	Quartzite	22	16.864	11.576	Yes
3	Chlorite schist	30	19.391	19.322	Yes
4	Grunerite-schist	32	8.933	3.268	Yes

$$\frac{1}{V_b}\frac{\partial}{\partial t}\left(\rho_f V_b \phi\right)=\rho_{fo}\frac{\partial}{\partial t}\left\{-\underbrace{\varepsilon_v}_{\text{骨架}}+\underbrace{\left(1-\phi_0\right)\left[\frac{\sigma_m-p_P}{K_s\left(1-\phi_0\right)}+\frac{p_P}{K_s}\right]}_{\text{固相颗粒}}+\underbrace{\phi_0\left(\frac{p_P}{K_f}\right)}_{\text{流体}}\right\} \quad \cdots\cdots(3)$$

where ϕ_0 is the initial porosity, ρ_{fo} - the initial fluid density, V_{bo} - the initial volume of porous medium, σ_m - the mean stress.

It can be found in Eq. (3), the fluid storage effect is a complex function of skeleton deformation, solid particle deformation and fluid deformation in porous medium.

The elastic deformation of a porous medium (3) can be expressed as,

$$\varepsilon_v=\frac{1}{K}\left(\sigma_m-ap_P\right) \quad (4)$$

Another form of expression of Eq. (3) can be derived：

$$\frac{1}{V_b}\frac{\partial}{\partial t}\left(\rho_f V_b \phi\right)=\rho_{fo}\left(\frac{a}{K_b}\right)\frac{\partial}{\partial t}\left(-\sigma_m+\frac{p_p}{B}\right) \quad (5)$$

Where

$$B=\frac{\frac{1}{K_b}-\frac{1}{K_s}}{\frac{1}{K_b}-\frac{1}{K_s+\phi_0}\left(\frac{1}{K_f}-\frac{1}{K_s}\right)} \quad (6)$$

In the formula, K_b —Bulk modulus of rock, K_s —Bulk modulus of mineral particle,

K_f —Bulk modulus of fluid.

Additional stress model induced by fracture

In porous medium, pore pressure changes cause volume changes, this induced deformation will also cause an additional stress acting on the stratum. The variation of stress induced by pore pressure changes can be expressed by the stress coefficient as,

$$\eta=\frac{a\left(1-2\upsilon\right)}{2\left(1-\upsilon\right)} \quad (7)$$

where, η is the stress coefficient, a - the Biot coefficient; υ - the Poisson ratio of the porous medium.

The change of stress caused by the change of pore elasticity can be calculated by the following formula,

$$\Delta\sigma=\Omega\cdot\eta\cdot\Delta p_P\cdot f\left(t\right) \quad \cdot(8)$$

where, Ω is the quantization of boundary and other nonideal conditions, namely, the influence of different boundary conditions, $f\left(t\right)$ - typical time spread function, the value is 1 when steady, the initial value is 0, Δp_P - change in mineral pressure.

The stress coefficient η is not affected by the characteristics of the pore fluid.

The influence of boundary conditions on the elastic stress of holes

A large number of studies abroad show that the variation of pore elastic stress and pore pressure satisfy the following relation formula,

$$\Delta\sigma_x+\Delta\sigma_y+\Delta\sigma_z=4\eta\Delta p_P \quad (9)$$

In the formula, $\Delta\sigma_x,\Delta\sigma_y,\Delta\sigma_z$ —Pore stress increment in the x,y,z direction,

Δp_p —Variation of pore pressure.

The single stress component in the three directions of x,y,z is greatly affected by boundary conditions, for one dimensional boundary problems with free moving top / bottom boundaries, On the basis of Eq. (9), it is concluded that $\Delta\sigma_x,\Delta\sigma_y,\Delta\sigma_z$ satisfies the following relationships,

$$\begin{cases}\Delta\sigma_x=2\eta\Delta p_P\\ \Delta\sigma_y=0\\ \Delta\sigma_z=2\eta\Delta p_P\end{cases} \quad (10)$$

Similarly for two-dimensional plane strain boundary problems, $\Delta\sigma_x,\Delta\sigma_y,\Delta\sigma_z$ satisfies the following relationships,

$$\begin{cases}\Delta\sigma_x=\Delta\sigma_y=\eta\Delta p_P\\ \Delta\sigma_z=2\eta\Delta p_P\end{cases} \quad (11)$$

Similarly, for three-dimensional plane strain boundary problems,, $\Delta\sigma_x,\Delta\sigma_y,\Delta\sigma_z$ satisfies the following relationships,

$$\Delta\sigma_x=\Delta\sigma_y=\Delta\sigma_z=\left(\frac{4\eta}{3}\right)\Delta p_P \quad (12)$$

CONCLUSIONS

Based on the analysis above, we can draw the following conclusions:

(1) For the mines containing massive geothermal energy, certain techniques can be employed to fully

utilize the hot rock and the naturally gushing hot water. The flow of mine groundwater in the rock interacts with the rock fracture deformation.

(2) There is a lot of difference between the flow pattern of groundwater in the fractured rock mass and the conventional linear seepage. The deformation of the rock mass will produce a stress on the stratum, whose value is independent of the nature of the water, but merely related with the external force that leads to rock fracture deformation.

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