Numerical Simulation of Transient Temperature Field of Single Fissure Flow in Mining Rock Mass

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Abstract. In this paper, the transient temperature field distribution of single fissure water flow is studied in order to study the fluid-solid coupling heat transfer mechanism of the rock mass. By simulating the flow state of underground water flow along single fissure of rock mass, it establishes the seepage model of single fissure. In addition, the mathematical model of temperature field under the influence of seepage field is established by simplifying the equations of single fissure and temperature control. The results show that the heat balance is closely related to temperature difference and time under fluid-solid coupling, and the greater the change of permeability velocity, the greater the change of temperature distribution. With the increase of time and heat transfer, the temperature difference between the water flow temperature and the wall surface of the rock mass gradually decreases, and the temperature isograde change rate along the flow direction of the water flow decreases gradually.

1. Introduction
Most of the mining rock masses are multiphase discontinuous media, and there are inevitably many cracks of different scales, directions, and properties [1]. The rock body is filled with various discontinuities such as joints, cracks, faults, contact zones, and shear zones. If the rock mass is treated as a continuous medium to study complex Geological problems, it may have unexpected consequences. This is crucial for preventing and controlling coal mine disasters and guiding engineering practices [2]. Therefore, it is necessary to study the mechanism of the interaction between the seepage field and the temperature field by treating the fissure rock mass as a non-continuous medium.

The single fissure is the most basic element of the rock mass fissure system. The study of the transient temperature of the single fissure water flow can reveal the changing law of the fissure water flow temperature over time, and provide a theoretical reference for the study of the complex fissure water flow temperature field. This is not only conducive to the further study of the temperature field of the fissure flow, but also conducive to the study of the relationship between the seepage and temperature of the non-continuous fissure rock mass [3, 4].
2. Concept Model and Analysis of Single Fracture Percolation

2.1. Single Fracture Conceptual Model

Most of the underground natural rock masses are multiphase discontinuous media. The rock body is full of joints, cracks, faults, etc. For the purpose of studying the problems, the model assumes the following:

(1) Ignoring the permeability of the rock mass itself, groundwater flows only within the fissure and the fissure rock mass is treated as a non-continuous medium.

(2) Assuming that there is a single fissure in the rock, the fissure can be regarded as a parallel slab narrow seam. The width of the fissure is unchanged, the gap surface is smooth and infinitely extended, and the length of the fissure is far greater than the gap width.

(3) The water flow in the crack is a stable two-dimensional definite laminar flow, constant property, no internal heat source, and an Incompressible Newtonian fluid.

(4) The mass force has only gravity, the groundwater flows only in the X direction, and the temperature of the water flow changes with time.

A parallel plate fracture model describing the parallel flow of underground water flow in a single rock mass is established [5] (See Figure 1), L represents the length of the crack, 2B represents the width of the crack, L & GT; & GT; 2B; Tw is the groundwater flow temperature at the boundary X = 0, Tm is the wall surface temperature of the rock mass, and the initial temperature of the rock mass Tmo is greater than the initial temperature of the groundwater flow Two. Due to the viscosity of the water flow, the speed distribution of the water flow is similar to the shape of the parabola. The temperature distribution of the underground water flow changes when the water flow is transmitted by heat volume. This model is representative and can represent the distribution of seepage field and temperature field of the entire parallel fracture model [6,7].

![Figure 1. the model of single fissure flow](image)

2.2. Model analysis

According to the basic theory of fluid mechanics [5], the equations are combined to consider the boundary conditions of a single fissure flow:

\[ u_x \big|_{y=b} = 0, \quad u_x \big|_{y=-b} = 0 \]

After solving, the distribution formula of the flow rate function when the water flow in the plate fracture flows in the x-direction can be obtained:
In Formula $\mu = \rho v$, $\mu$ is the dynamic viscosity coefficient of the water flow; $\frac{dp}{dx}$ is the flow pressure gradient. Formula (1), as the velocity field formula for the seepage flow in a single crack, reflects the flow rate distribution of water flow along the x-direction in a single crack, and reflects the movement law of water flow in a single crack. If the formula (1) is further deduced, the famous fissure water flow cubic law can be obtained, so this formula has universal significance.

It can be seen from equation(1) that the distribution of velocity field based on the assumption that the flow velocity field is only related to the pressure gradient, the crack width, and the y value, but it is not related to the temperature field, which means that under the above assumptions, Regardless of whether the temperature of the water flow is higher, equal to or lower than the temperature of the rock mass, the speed field of the water flow in the crack is the same, but this does not mean that the temperature field has no relationship with the speed field [8].

3. Transient Temperature Field Distribution

3.1. Coupling Basic Equations

With the flow of water in the fissure, the temperature of water flow also changes with time. From basic assumptions, $\frac{\partial T}{\partial z} = 0$, $\frac{\partial^2 T}{\partial z^2} = 0$, $Q_r = 0$ Energy differential equation can be simplified to be (2)

$$\frac{\partial T}{\partial t} + u_x \frac{\partial T}{\partial x} + u_y \frac{\partial T}{\partial y} = \frac{\lambda}{\rho c_p} \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right)$$

According to the single fracture flow model and basic assumptions, the temperature field mathematical model under the influence of the simplified seepage field is obtained:

$$\begin{align*}
\left\{ \begin{array}{l}
\frac{\partial T}{\partial t} + u_x \frac{\partial T}{\partial x} + u_y \frac{\partial T}{\partial y} = \frac{\lambda}{\rho c_p} \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \\
\frac{\partial u_x}{\partial t} + u_x \frac{\partial u_x}{\partial x} + u_y \frac{\partial u_x}{\partial y} = F_x - \frac{1}{\rho} \frac{\partial p}{\partial x} + \nu \left( \frac{\partial^2 u_x}{\partial x^2} + \frac{\partial^2 u_x}{\partial y^2} \right) \\
\frac{\partial u_y}{\partial t} + u_x \frac{\partial u_y}{\partial x} + u_y \frac{\partial u_y}{\partial y} = F_y - \frac{1}{\rho} \frac{\partial p}{\partial y} + \nu \left( \frac{\partial^2 u_y}{\partial x^2} + \frac{\partial^2 u_y}{\partial y^2} \right) \\
\frac{\partial u_x}{\partial x} + \frac{\partial u_x}{\partial y} = 0
\end{array} \right.
\end{align*}$$

Since the mass force is only gravity, $F_z = 0$. The flow of water is a laminar flow, and the gravitational force is negligible compared to the viscous force, that is, $F_y = 0$. Since the groundwater flows only along the X direction, that is, $u_y = 0$, the formula (3) is simplified to:
3.2. Boundary Conditions and Basic Parameters

According to the characteristics and basic assumptions of seepage in parallel plate fissures:

(1) Heat transfer boundary
   Select the wall surface temperature of the upper and lower boundary rocks $T_m = 40 \, ^\circ\text{C}$, and the groundwater flow temperature at $x=0$ is $T_w = 20 \, ^\circ\text{C}$.
   Since the groundwater flows heat in the flow direction, the convection heat boundary is selected at $X = L$, and the heat continues to pass along the X direction.

(2) Percolation boundary
   The left and right opposite boundaries are selected as the inflow and outflow borders, and the upper and lower borders are impervious boundaries.

(3) Calculation parameters
   The study area is selected as 5mm * 40mm, that is, the crack constant opening is $b = 2.5 \, \text{mm}$, the crack length is $L = 40\, \text{mm}$, Density of underground water flow is $\rho = 1000 \, \text{kg/m}^3$, viscosity coefficient of water flow movement is $\nu = 0.001 \, \text{pa} \cdot \text{s}$, thermal conductivity of water flow is $\lambda = 0.6 \, \text{W/(m} \cdot \text{K)}$, constant pressure heat capacity is $C_p = 4200 \, \text{J/(kg} \cdot \text{K)}$.

3.3. Numerical Simulation

According to the boundary conditions and calculation parameters, the transient temperature field is simulated by finite element software. The simulation results are shown in Figures 2 and 3:

\[
\begin{align*}
\frac{\partial T}{\partial t} + u_x \frac{\partial T}{\partial x} &= \frac{\lambda}{\rho c_p} \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \\
\frac{\partial u_x}{\partial t} &= -\frac{1}{\rho} \frac{\partial p}{\partial x} + \nu \frac{\partial^2 u_x}{\partial y^2} \\
-\frac{1}{\rho} \frac{\partial p}{\partial y} &= 0 \\
\frac{\partial u_x}{\partial x} &= 0
\end{align*}
\] (4)

Figure 2. the single fissure flow of temperature distribution
3.4. Numerical Simulation Results and Analysis

(1) The change of water flow penetration speed in the crack will affect the distribution of temperature field. With the increase of the thermal mass migration caused by the higher permeability rate, the temperature field distribution of the fracture increases when the heat exchange with the surrounding rock reaches equilibrium state.

(2) Because the temperature of the rock wall surface is higher than the temperature of the fissure flow, the heat exchange gradually increases the temperature in the X direction over time; With the increase of time, at X = L, the temperature of the water flow is similar to the temperature of the rock mass and reaches a state of thermal equilibrium.

(3) From the temperature changes at the four sections of X = 0.005 M, X = 0.015 M, X = 0.025 M, X = 0.035 M, the initial wall surface temperature of the rock mass differs greatly from the current temperature. With the increase of time and heat transfer, the temperature difference between the water flow temperature and the wall surface of the rock mass gradually decreases, and the temperature isograde change rate along the flow direction of the water flow decreases gradually.

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