Simulation of Temperature Changes in Surrounding Rock during Hot Dry Rock Reservoir Exploitation

Xia Zhao
College of Geo-exploration Science and Technology,
Jilin University,
Changchun, 130026, China
e-mail: 362336620@163.com

Zeng Zhaofa
College of Geo-exploration Science and Technology,
Jilin University,
Changchun, 130026, China

Chen Xiong
College of Geo-exploration Science and Technology,
Jilin University,
Changchun, 130026, China
e-mail: chen1926@qq.com

Li Jing
College of Geo-exploration Science and Technology,
Jilin University,
Changchun, 130026, China

Guo Liangliang
College of Construction Engineering,
Jilin University,
Changchun, 130026, China

Wang Kun
College of Geo-exploration Science and Technology,
Jilin University,
Changchun, 130026, China

Xi Jianjun
College of Geo-exploration Science and Technology,
Jilin University,
Changchun, 130026, China
Hebei Electric Power Design & Research Institute,
Hebei Shijiazhuang, 050031, China

Zhang Yanjun
College of Construction Engineering,
Jilin University,
Changchun, 130026, China

Abstract—In order to get the change of surrounding rock temperature during hot dry rock reservoir productive process, we used the Transport of Unsaturated Groundwater and Heat (TOUGH2) software to simulate the model which attached surrounding rock to hot dry rock (HDR) reservoir. On the condition that we set actual production and reservoir parameters to the model, we calculated change of reservoir temperature and surrounding rock while the HDR reservoir exploitation within 20 years. The result shows that the temperature of surrounding rock which is more than 100m away from injection well almost will not be changed.

Keywords- hot dry rock; surrounding rock temperature; TOUGH2; hot dry rock exploitation

I. INTRODUCTION

As we all known, the world's energy shortage problem is more and more serious, and environmental problems of traditional energy sources is becoming more and more serious. Therefore, the task of developing new alternative energy becomes more and more urgent. Now new energy includes solar energy, hydropower, wind energy and tidal energy, biomass, nuclear energy, geothermal energy and so on. As a new clean energy, geothermal energy is paid attention to by the people day by day [1-3].

Hot dry rock (HDR) is a very important part of geothermal energy, so called the enhanced geothermal systems (EGS). It is characterized by large storage of heat, usually 3~10 km depth. Its temperature range is very wide, between 150~650 ℃[4].

The reliability of the numerical simulation results mostly depends on the understanding of basic properties of rock mass and the reasonable simplification of various geological factors. In the development process of the numerical simulation of hot dry rock reservoir area, the software which is most widely used and successful is TOUGH series [5-10].

During the simulation of hot dry rock reservoir development, previous researchers rarely consider the

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influence of the surrounding rock. It is not enough that only the reservoir internal changes are considered. On the condition of surrounding rock, this paper simulated the productive process of hot dry rock, in order to get the influence range of surrounding rock during hot dry rock exploited.

II. Model Design

In order to simplify the problem, the simple model is established. We put forward a series of assumptions as follows:

(1) Surrounding rock is granite rock, with low porosity and no water inside, electrical parameters is isotropic;

(2) The specific heat and heat conduction coefficient of surrounding rock and groundwater do not vary with temperature and pressure changes;

(3) Don't consider the water volume change with the temperature and pressure (water density is constant, and volume remains the same);

(4) Fracture only exists in reservoir area, so we used the equivalent medium in simulation calculation;

(5) Fluid recovery rate is 100%, (there is no water loss in productive process);

(6) Ignore heat production due to the flow friction of water and rock fractures wall (there is no new heat generated in the rock mass).

We establish a two-dimensional model with reference of article [11], and carry on simulation calculation. To simulate the influence of the temperature of the surrounding rock with reservoir exploited, reservoir is set as 400m*400m, with 100m range of surrounding rock, as shown in Fig .1, transverse model of the whole area is 600m long, vertical depth is 600 m. Model is divided into three areas: the peripheral area (surrounding rock) width is 10m grid; near-well block grid width is 3m; inner reservoir area grid width is 5 m. Injection Well is located in (102,-1998), and Production Well is located in (498,-1602).

The fractured porous reservoir locates within -1600m to -2000m in the vertical and 100m to 500m in the x direction, with higher permeability. Outside surrounding rock have the range of 100m thickness, with an extremely low permeability.

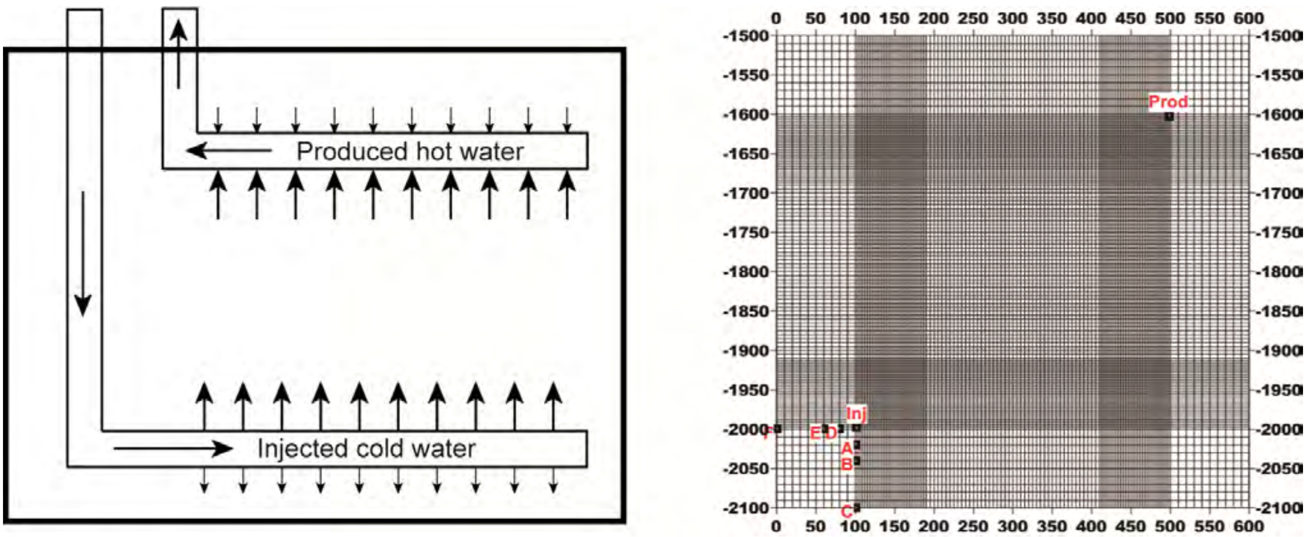

Figure 1. Idealized view of reservoir model of hot dry rock (HDR)

III. Mathematical Equations

2.1 Heat transfer equation [12-15]

In two-dimensional medium, heat transfer equation derivation is acquired based on the law of conservation of energy

$$Q+\lambda\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)-\nabla\cdot(c_w\rho_w T_w\vec{v})=\rho c\frac{\partial T}{\partial t} \qquad (1)$$

Eq. (1) is temperature field differential equation which includes heat source, heat conduction and heat convection. Its initial conditions is that initial temperature is set, when $t=t_0$,

$$T\big|_{t=t_0}=T_0=200 \qquad \in S \qquad (2)$$

Boundary is adiabatic, so

$$\lambda\frac{\partial T}{\partial n}=0 \qquad (3)$$

2.2 Mass conservation equation [11]

$$\frac{d}{dt}\int_{Vn} M^{\kappa} dV = \int_{\Gamma n} F^{\kappa} gnd\Gamma + \int_{Vn} q^{\kappa} dV \qquad (4)$$

Where, integral domain *Vn* represents an arbitrary volume. *M, F* and *q*, respectively represents the quality, flux and source/sink of a material or component.

2.3 Model thermal parameters

Model parameters are set in table 1:

TABLE 1 MODEL PARAMETERS [11]

parameters	value
Rock density	2850 $kg*m^{-3}$
Rock specific heat	1100 $J*kg^{-1}*K^{-1}$
Rock thermal conductivity	2.395 $W*m^{-1}*K^{-1}$
Reservoir porosity	2%
Reservoir permeability	$50*10^{-15}$ m^2
Initial temperature	200℃
Injection rate	1.5 kg/s
Injection specific enthalpy	262.12 kJ/kg (about 60°)
Productivity index	$5.0*10^{-12}$ m^3
Production flow pressure	5 MPa
Injection flow pressure	12 MPa

IV. SIMULATION RESULTS

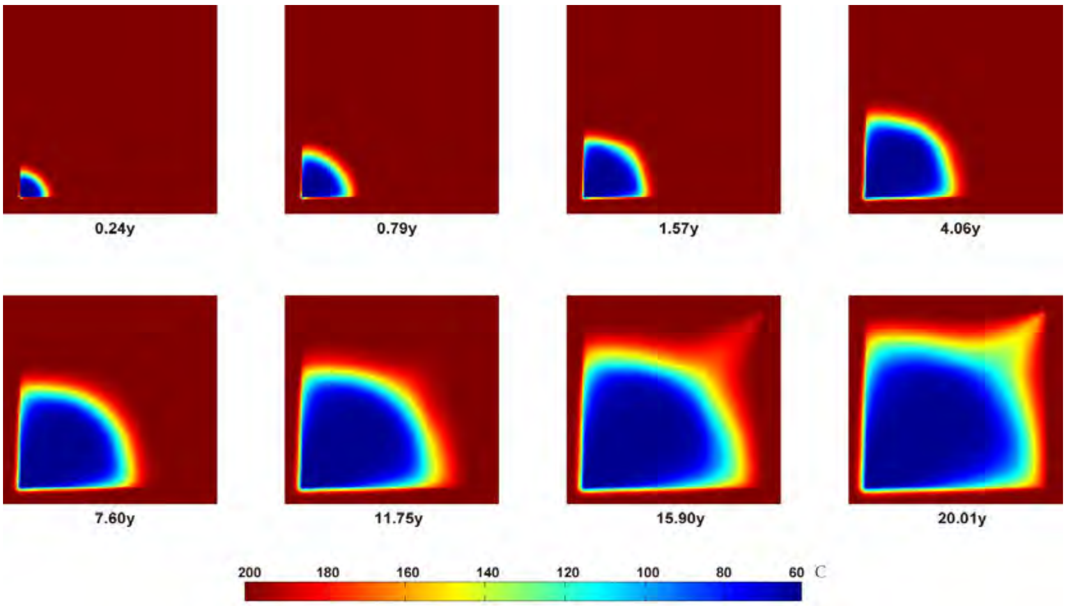

Figure 2. Distribution of reservoir and surrounding rock temperature during the 20 year period

Fig .2 shows changes of reservoir temperature in the productive process within 20 years. Though the figure we know that, at the beginning, temperature of the reservoir near injection well dropped quickly to 60℃ (injected water temperature). While the production processed, low temperature area expands to production well. After 20 years, production well maintains a temperature as high as 176℃. On the other hand, in surrounding rock, temperature decreases only it is very-near injection well. The rest position is hardly affected by production process. For precise digital description of surrounding rock affected by injection well, we selected 6 points in surrounding rock as shown in Fig .1, and we examined their temperature during production processed within 20 years.

Fig .3 shows six points' time temperature change curve (A-F) in surrounding rock while the hot dry rock reservoir is exploited within 20 years. It can be seen from the diagram, only 20m from injection well (point A and point D) is affected; 40m distance (point B and E) doesn't get affected within eight years; 100m from injection well (point C and F) is hardly affected within 20 years, and it has maintained a steady temperature (200℃).

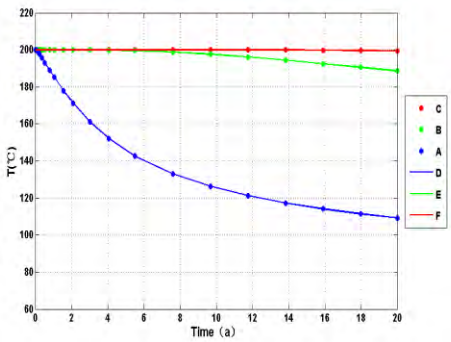

Figure 3. Temperature change of 6 dots in the surrounding rock during the 20 year period

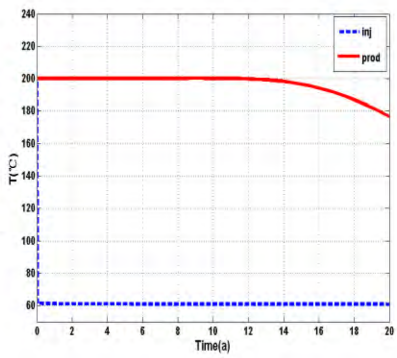

Figure 4. Temperature of Injection & Production well

Fig .4 shows the temperature changes in Injection Well and Production Well. As we see, point near Injection Well is affected by injected water temperature, and it has remained 60℃. Temperature of the production Well hold a high level, until 14 years later it decrease a little, but still as high as 176℃.

V. CONCLUSION

Based on the follow model with three conditions: 1) the temperature of reservoir and surrounding rock are 200℃, respectively; 2) surrounding rock is impermeable; 3) the water injection rate of well is 1.5 kg/s. The model simulation result demonstrates that：

1) The temperature of production well hold a high level for a long time, until 14 years later it will decrease a little, but still as high as 176℃ 20 years later.

2) The surrounding rock which is 20m away from injection well is pretty affected; the measurement point which is 40m away is little affected and it get a little decrease only 10 years later; the point away more than 100m is hardly affected in 20 years while HDR production processed.

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