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Numerical Simulation Study of Geothermal Energy Extraction in Medium-deep Formation

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Abstract

Geothermal energy is a kind of renewable energy with rich content, relatively low cost and wide distribution. China is rich in geothermal reserves and urgently needs efficient heat extraction technology. Closed cycle heat extraction technology is a new geothermal development model that is suitable for medium-deep geothermal reservoir and has high heat exchange efficiency without taking water. In this system, the circulating working fluid is pumped into the annulus from the ground, and the heat is extracted from the formation through heat conduction, and then returned to the ground through the central pipe. In this paper, the heat recovery capacity of the heat extraction system is numerically simulated. The research results show that the coaxial borehole heat exchanger technology has a good heat recovery capacity, and the designed thermal insulation structure has a positive effect on heat extraction and heating, and the heat extraction 100 days can stably produce 360 Kw of heat.

Keywords

Geothermal Energy; Closed Cycle Heat Extraction Technology.

1. Introduction

Geothermal energy, which is rich in resources and less polluting[1]. The energy contained in the formation 200~3000m below the surface is called the medium-deep geothermal energy, which is a hot research topic in the current field[2].

With the development of heat extraction technology, there are three main heat extraction modes. The first is to extract formation water, which is very difficult to recharge[3]. The second enhanced geothermal model[4] will pollute the formation, and the prospect is not clear. Finally, the buried pipe heat exchange technology[5] is a relatively mild. The effect of this mode is much better than that of heat transfer through soil in the ground heat pump system. In addition, the heat exchange system carries out heat exchange through the whole area in contact with the formation, and the heat exchange area is far greater than that of the single-well U-tube downhole heat exchange system. Through the research of foreign scholars such as Acuña et al. [6], it is pointed that the pressure loss and use cost of the coaxial casing system are lower than that of the U-tube system. Therefore, considering the scope of application, heat extraction efficiency and environmental protection and other factors, the single-well coaxial casing closed heat exchange system is the best choice for geothermal exploitation in most cases.

Previous work has made important contributions to the development of geothermal well coaxial closed heat extraction technology, but the current research content is mainly focused on the theoretical research of single well heat exchange system. In this paper, a coaxial pipe structure is proposed. On this basis, the heat recovery capacity of the heat extraction system is

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numerically calculated, and the feasibility study of single well heat extraction and heating for medium and deep geothermal resources is completed.

2. Heat Extraction System

The system of using closed cycle heat extraction technology to extract medium-deep geothermal energy is shown in Fig. 1. Take the vertical well as the research object. Closed cycle heat extraction technology is composed of outer pipe and inner pipe unit. With water as the circulating working medium, low-temperature water is injected to the annulus, absorbs the formation heat and then returns to the ground through the central pipe. In order to reduce the heat dissipation of high-temperature water in the annulus to the central pipe, the inner tube unit is insulated throughout the whole process. The parameters of formation, borehole and coaxial pipe are shown in Table 1.

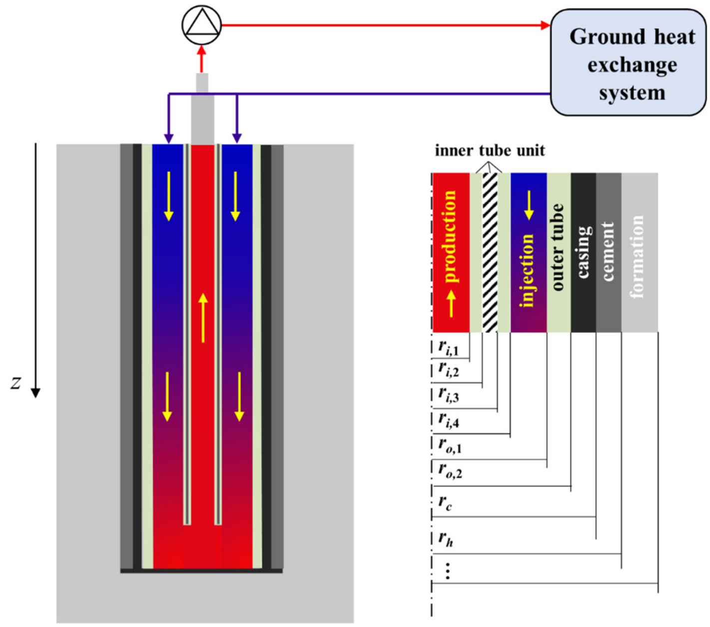

Fig 1. Sketch of the heat extraction system

Table 1. Basic parameters of the system

Part	Description		Value
Formation	Thermal conductivity		3.5W m^{-1} K^{-1}
	Geothermal gradient		0.08℃ m^{-1}
Wellbore	Depth L / radius r_h		1500m / 155.6mm
	Casing, outer radius r_c / thickness t_{cas}		122.3mm / 9.2mm
	Thermal conductivity of cement		1.5W m^{-1} K^{-1}
	Thermal conductivity of casing		17W m^{-1} K^{-1}
Coaxial pipe	*Outer tube*	outer radius $r_{o,2}$ / thickness t_o	44.45mm / 4mm
	Inner tube unit	Outer tube, outer radius $r_{i,4}$ / thickness $t_{i,3}$	19.1mm / 2.1mm
		Inner tube, outer radius $r_{i,2}$ / thickness $t_{i,3}$	12.7mm / 2.1mm
	Absolute roughness K		0.02mm
	Thermal conductivity of steel		17W m^{-1} K^{-1}
	Thermal conductivity of insulation layer		0.02W m^{-1} K^{-1}

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3. Governing Equations

Considering both the thermal properties of water and the heat transfer of the formation, the motion equation and energy equations, describing water flow in the closed cycle heat extraction technology are established.

3.1. The Motion Equation

The pressure variation of the working fluid is related to gravitational potential energy, kinetic energy and energy loss, which is given by the momentum equation:

$$\frac{\mathrm{d}p}{\mathrm{d}z} = \pm\rho_f g - \frac{\tau_f \rho_f {v_f}^2}{2d_e} - \rho_f v_f \frac{\mathrm{d}v_f}{\mathrm{d}z} \tag{1}$$

where p is the pressure; g is the gravitational acceleration; d_e is the equivalent diameter. τ_f is the resistance coefficient, which can be described by Modi's formula:

$$\tau_f = 0.0055\left[1 + \left(20000\frac{K}{d_e} + \frac{10^6}{\mathrm{Re}}\right)^{1/3}\right] \tag{2}$$

where Re is the Reynolds number, K is the absolute roughness of the pipe wall.

3.2. The Energy Equations

The heat transfer process of water is analyzed on two stages, injection flow in the annulus and production flow in the central pipe.

3.2.1. Injection Flow

When the low-temperature water is injected in the annuls, the energy equation of the fluid in the annulus can be expressed as:

$$\frac{\partial\left[(\rho c)_f A_i T_i\right]}{\partial t} + \frac{\partial\left[(\rho c)_f A_i v_f T_i\right]}{\partial z} = -\frac{\mathrm{d}Q_i}{\mathrm{d}z} + \frac{\mathrm{d}Q_p}{\mathrm{d}z} \tag{3}$$

where $(\rho c)_f$ and T_f are the volume specific heat capacity and the temperature of the fluid. The subscript i represents the injection flow. $\mathrm{d}Q_i/\mathrm{d}z$ is the heat flux from formation to injection flow, which is expressed as:

$$\frac{\mathrm{d}Q_i}{\mathrm{d}z} = \frac{T_h - T_i}{R_{An}} \tag{4}$$

where R_{An} represents the heat resistance of the annulus. T_h temperature of the interface between wellbore and formation.

3.2.2. Production Flow

Water in the central pipe exchanges heat with injection flow, and the energy equation is given as:

$$\frac{\partial\left[(\rho c)_f A_p T_p\right]}{\partial t} + \frac{\partial\left[(\rho c)_f A_p v_f T_p\right]}{\partial z} = \frac{\mathrm{d}Q_p}{\mathrm{d}z} \tag{5}$$

in which, $\mathrm{d}Q_p/\mathrm{d}z$ is the heat flux from the injection flow to the production flow, and expressed as:

$$\frac{\mathrm{d}Q_p}{\mathrm{d}z} = \frac{T_i - T_p}{R_i} \tag{6}$$

R_i is the equivalent heat resistance between the production flow and the wellbore boundary. p represents the production flow.

3.3. Heat Transfer in Formation

The heat from the formation can be expressed as:

$$\frac{\mathrm{d}Q_e}{\mathrm{d}z} = \frac{\mathrm{d}Q_i}{\mathrm{d}z} \quad (7)$$

Use the above Eq.(1) ~ (7) to perform the following numerical calculation.

4. Results and Discussion

For the heat extraction system described in Section 2, the mechanical and calculation method established in Section 3 are used to simulate the flow and heat transfer characteristics of water heat extraction process and evaluate the long-term heat extraction capacity of the system. The basic injection parameters of water are selected as follows: temperature is 15 ℃, pressure is 16MPa, mass flow rate is 1.1kg/s, and the change of heat extraction characteristic parameters of fluid after 100 days (2400hours) of heat extraction is given.

4.1. Heat Extraction Capacity

The change of outlet water temperature and outlet heat extraction power with time is shown in Fig. 2. It can be seen from that in the first 100 hours of production, heat extraction power and outlet temperature are rapidly reduced, which is due to the large initial temperature difference between fluid and reservoir and lack of timely thermal compensation near the wellbore. The outlet temperature and heat extraction power are finally stabilized at 96℃ and 360kW, respectively.

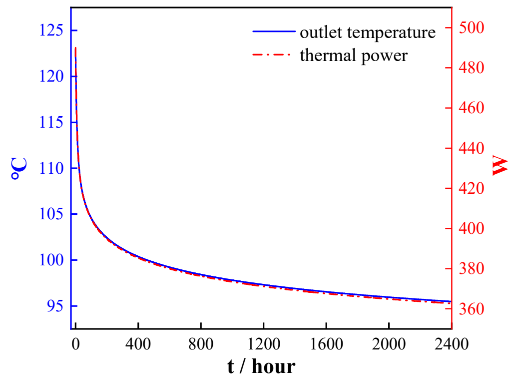

Fig 2. Variations of outlet temperature and heat extraction power with time

4.2. Temperature Distribution of Water

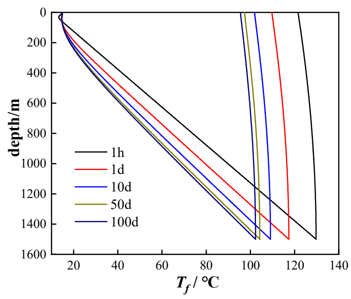

Fig 3. Temperature distribution of water under different heating duration

As shown in Fig. 3, under the condition of full insulation of the central pipe, the temperature of the fluid in the annulus increases approximately linearly with the well depth, because the thermal insulation layer can isolate the heat dissipation between annulus and central pipe during the water return process.

4.3. Linear Meter Power ql

The variation of the linear meter power with the time at the characteristic points (depth 1300m, 1400m and 1500m) at the bottom of the annulus is shown in Fig. 4. The linear meter power at the bottom of the well decreases by 50W/m with time, and finally basically stabilizes around 320W/m.

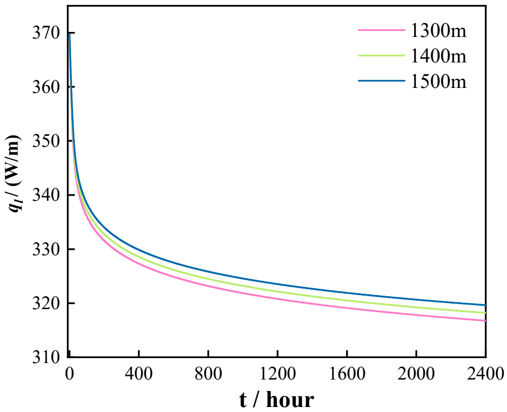

Fig 4. Linear meter power in different depth

5. Conclusion

Closed cycle heat extraction technology for geothermal wells is a new geothermal development model that is suitable for medium-deep geothermal reservoirs, which has highly efficiency and the advantage of without taking water.

(1) For the target reservoir, completing the design of closed cycle heat extraction system and the construction of heat extraction model.

(2) The established thermal model is numerically simulated, and the outlet temperature, heat extraction power, the temperature distribution under different time and the linear meter power at different depths with time are analyzed and discussed.

(3) The research results show that the medium-deep geothermal system built in this paper has a good thermal sustainability and can meet the development needs of the medium-deep geothermal energy. The designed whole-process insulation structure of the inner tube has a positive effect on the heat extraction and heating.

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