International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 497

HEAT EXTRACTION PERFORMANCE INVESTIGATION OF A COAXIAL DOUBLE-PIPE HEAT EXCHANGER IN A DEEP GEOTHERMAL WELL

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ABSTRACT

Although there is abundant geothermal energy in deep reservoirs, to effectively extract the heat rather than the geofluid is still a challenge. This study investigated the heat extraction performance of a coaxial double-pipe heat exchanger in a deep geothermal well with particular reference to geothermal heating. A numerical simulation model is established and the heat extraction rates (geothermal energy production rates) and their changes with the time of production are analyzed in detail. As a result, either the heat-carrier mass flowrate of 1.5 kg/s for direct heating utilization or 4 kg/s for heating with use of heat pump system has shown a sound performance. Results obtained are useful for better understanding of such geothermal heat extraction technology.

Keywords: geothermal energy production rates, coaxial double-pipe heat exchanger, heating, heat pump

1. INTRODUCTION

The development of renewable energy has become a contemporary theme. Because of the clean and sustainable advantages, geothermal energy bas been widely used for power generation, and heating [1, 2]. The other advantage of geothermal energy is that it can be used regardless of meteorological conditions [3]. Enhance geothermal system (EGS) being developed currently could be used for extracting heat, but problems, such as recharge of geothermal water, corrosion, scaling and so on, have to be solved: [4]. In 1995, Rybach et al. put forward a double-pipe heat exchanger [5], which can effectively avoid these problems.

For better utilizing geothermal energy, Dijkshoorn et al. carried out a study on heating and cooling performances of a building through experiments and simulations in Germany [6]. Some scientists now research on the performances of the ground source heat pumps. Gao et al. studied the temperature change of solid in ground source heat pump systems through numerical simulation and experiments [7]. Yan et al. established a 3-D model and studied the performance of rock temperature recovery [8].

But studies on comparing direct heating mode and the mode with using heat pumps are very few. In this paper, we established a 2-D model and compared the two geothermal heating modes by controlling the inflow parameters.

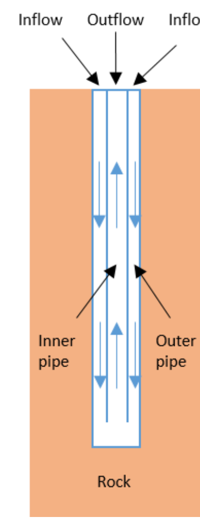

Fig.1 Schematic diagram of a coaxial double-pipe heat exchanger in a deep geothermal well

2. MODELS

2.1 Coaxial double-pipe heat exchanger model

Fig.1 illustrates a schematic layout of a coaxial double-pipe heat exchanger in a deep geothermal well. We established a 2-D model and calculated the heat extraction rates (geothermal energy production rates) using Fluent. Water flows downward in the annular space and absorbs heat from the rocks, and then flows upward in the inner pipe forming the outflow on the top. The inner pipe wall between inflow and outflow is

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).
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insulated. In this model, the radius of the inner pipe and the outer pipe are 0.085m and 0.05m respectively. The well investigated here is about 2600 m deep. The geothermal gradient and the thermal conductivity of rock used in the simulation are 30°C/km and 3.25 J/(kg·K) respectively. The ground temperature is set to be 20°C.

2.2 Model validation

In order to verify the accuracy of the model, the simulation results are compared with the experimental data in the previous work of Penzlau [9] and Aachen [10]. The parameters of the two geothermal wells along with the comparison between measured and simulated results are shown in Table 1.

Table.1 Comparison between measured and simulated results

Region	Penzlau [9]	Aachen [10]
Well depth (m)	2786	2500
Mass flow (kg/s)	1.7	2.8
Inlet temperature (°C)	35	40
Measured outflow temperature (°C)	60	45
Simulated outflow temperature (°C)	62	43

It can be seen from Table 1 that the simulated outflow temperatures are quite close to the measured data, with only 2°C difference in each case. The differences between the simulation and experimental results could be caused by the input values of the specific heat capacity and thermal conductivity of the rocks which are assumed to be homogenous in the numerical simulation; but in reality, those values could be different in the domain, resulting in the differences between the simulated and measured ones.

2.3 Heat pump model

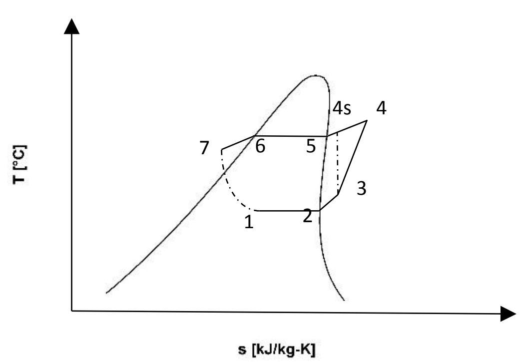

Fig.2 T-S diagram of heat pump system

Fig.2 shows *T-S* diagram of the heat pump system used in this simulation model. R123 is used as the working fluids. The evaporation and condensation temperatures have been optimized by choosing the maximum heat supply (from the condenser) as the objective function.

3. SIMULATION RESULTS

3.1 Temperature variations after heat extraction

In this research, we studied the heat extraction rate of a coaxial double-pipe heat exchanger in a deep geothermal well with particular reference to geothermal heating. Two heating modes have been investigated. One is directly heating mode with a higher outflow temperature; the other is using heat pump to increase the temperature of geothermal water, with relatively lower outflow temperature. In the first mode, the temperature of the inflow is set to be 30°C. In order to compare the influence of mass flowrate on the heat extraction performance, the mass flowrate is set to be 1, 3, and 5 kg/s respectively. In the second mode, the temperature of the inflow is set to be 20°C and mass flowrate is set to be 5, 7, and 9 kg/s respectively. Since heat pump has been used in the second mode, it has higher mass flowrate with lower outflow temperature.

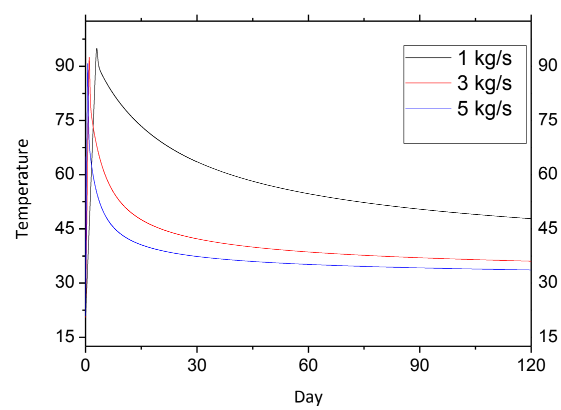

Fig.3 Outflow temperature changes under different flowrate conditions (first heating mode)

In this simulation, the heating season is set for four months, leaving eight months for rock temperature recovery. Fig.3 shows the changes of the outflow temperature under different mass flowrates in the first heating mode. As can be seen, after four months, the outflow temperatures become 47.8°C, 36.1°C and 33.6°C, respectively, corresponding to the flowrates of 1, 3, and 5 kg/s. When the flowrate is increased from 1 kg/s to 3 kg/s, there is an obvious decrease of the outflow temperature; but it is not that obvious when the flowrate increases from 3 kg/s to 5 kg/s. It is worth

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noting that, when the mass flowrate is 5 kg/s, the temperature between the inflow and outflow is only 3.6 °C.

Fig.4 shows the Temperature variations of the rock after four months at different depths in the first heating mode. The mass flowrate is set to be 1 kg/s. As can be seen in this figure, the rock temperature doesn't change when the distance from well is more than 15m. The temperature of the rock near the well decreases obviously after four months. At the depth of 2600m, the maximum temperature decrease is about 50°C.

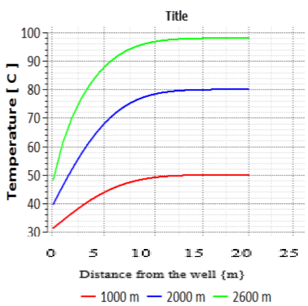

Fig.4 Temperature variations of the rock after four months (first heating mode)

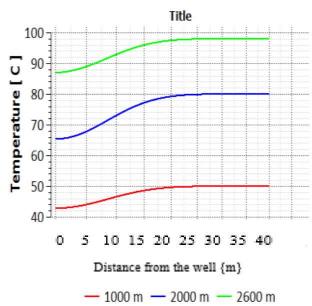

Fig.5 Temperature recovery of the rock after one year (first heating mode)

Fig.5 demonstrates the rock temperature recovery after one year in the first heating mode with a mass flowrate of 1 kg/s. As can be seen, the radius to which the temperature change reaches is about 25.5m. The rock at 2600m depth warms up and its temperature becomes about 87°C. Calculation also shows that, when the mass flowrates are 3 kg/s and 5 kg/s, the temperatures of the rock at 2600 m only recover to 82.35°C and 81.15°Crespectively.

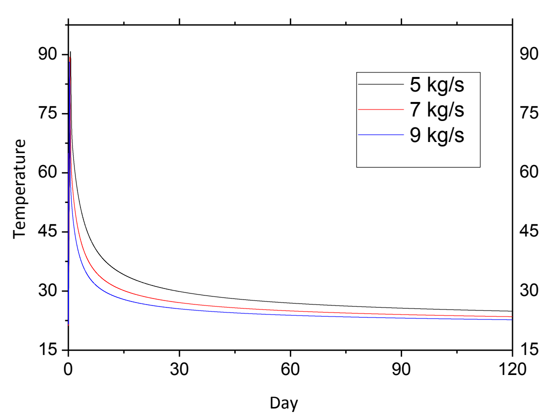

Fig.6 Outflow temperature changes under different flowrate conditions (second heating mode)

When heat pump is used in the second heating mode, lower outflow temperature can meet the requirement. In this case, higher mass flowrates of 5kg/s, 7kg/s and 9kg/s are used. Fig.6 shows the outflow temperature changes under different flowrate conditions. It can be seen that the temperature decrease is obvious within the first 15 days. After four months, the outflow temperatures become 24.9°C, 23.5°C and 22.7°C, corresponding to the mass flowrates of 5 kg/s, 7 kg/s, and 9 kg/s respectively.

Fig.7 shows the temperature variations of the rock at different depths after four months in the second heating mode. After four months, at the depth of 2600m, the maximum temperature decrease is about 73°C. The temperature doesn't changed when the distance from well is more than 16 m. When the mass flowrates are increased to 7 kg/s and 9 kg/s, calculation shows that the temperature at the depth of 2600m are 74.5 and 75.3°C respectively.

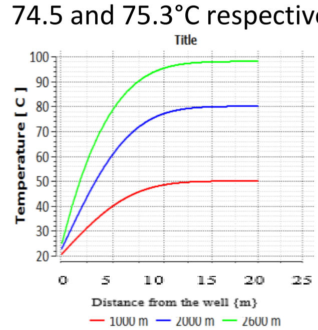

Fig.7 Temperature variations of the rock after four months (second heating mode)

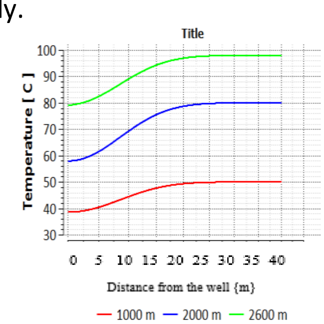

Fig.8 Temperature recovery of rock after one year (second heating mode)

Fig.8 illustrates the rock temperature recovery after one year in the second heating mode when the mass flowrate is 5 kg/s. It can be seen that the temperature of rock at 2600m recovers to 78.95°C, with the radius of rock temperature change being about 27m.

3.2 Heat extraction rates and optimum mass flowrates

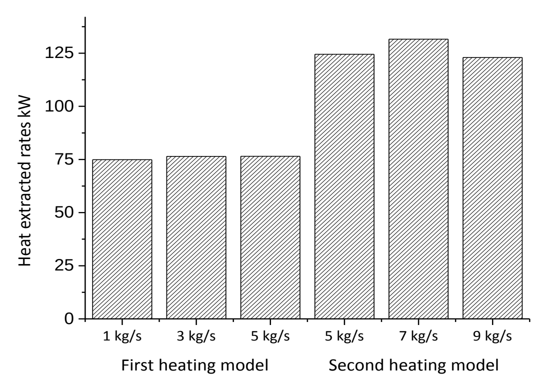

Fig.9 Heat extraction rates of the well at the end of the fourth month under different mass flowrate conditions

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In the case of the first heating mode, the outflow (geothermal water) is used to heat the buildings directly. After releasing the heat, the geothermal water is pumped into the well as an inflow. The temperature of the inflow is set to be 30°C. Fig.9 shows the heat extraction rates (geothermal energy production rates) of the well under different mass flowrate conditions. At the end of the fourth month, the heat extraction rates are 74.86, 76.46 and 76.48 kW corresponding to the mass flowrates of 1kg/s, 3kg/s and 5kg/s respectively. For more calculation results are shown in Table 2. It is seen that the heat extraction rate increases very small when the mass flowrate is more than 1.5 kg/s. Thus, in the first heating mode, there is no need to use a mass flowrate more than 1.5 kg/s.

Table 2 Heat extraction rates under different mass flowrates

	Mass flowrates (kg/s)	Heat extraction rates (kW)
First heating model	0.5	68.7
	1	74.9
	1.5	75.9
	2	76.3
	2.5	76.3
	3	76.5
	5	76.5
Second heating model	4	124.4
	5	124.5
	6	124.5
	7	124.5
	8	124.4
	9	123.5

In the case of the second heating mode, at the end of the fourth month, the heat extraction rates are greater than those in the first heating mode; they are 124.5 kW, 124.5 kW and 123.5 kW, corresponding to the mass flowrates of 5kg/s, 7kg/s and 9 kg/s respectively. Calculation results in Table 2 shows that mass flowrate greater than 4 kg/s has no contribution to the increase of heat extraction rate. So the optimum mass flowrate is considered to be 4 kg/s in the second heating mode.

4. CONCLUSION

In this study, the heat extraction performance of a coaxial double-pipe heat exchanger in a deep geothermal well has been investigated and two geothermal heating modes were compared. The main conclusions are:

(1) With the increase of the wellbore mass flowrate, the outflow temperature decreases. The best rock temperature recovery corresponds to the mass flowrate of 1 kg/s.

(2) In the first heating mode (directly heating scenario), when the mass flowrate is greater than 1.5 kg/s, the extracted heat rate is almost the same, indicating that the mass flowrate of 1.5 kg/s has the best performance in heat production.

(3) In the second heating mode (heating scenario combined with heat pump utilization), the optimum mass flowrate is found to be 4 kg/s in terms of the energy extraction rate.

(4) Further studies on techno-economic analysis should be carried out in determining the optimum mass flowrate and the corresponding extracted heat rate, with considerations of the drilling costs, heating benefits and electricity prices.

ACKNOWLEDGEMENT

This work was supported by the National Key Research and Development Program of the 13th Five-Year Plan of China (No. 2018YFB1501805).

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