ISSN 2004-2965 Energy Proceedings, Vol. 19, 2021

International Conference on Applied Energy 2021
Nov. 29-Dec. 2, 2021, in Bangkok, Thailand
Paper ID: 0302

NUMERICAL SIMULATION OF ENHANCED GEOTHERMAL SYSTEM POWER GENERATION PERFORMANCE

Qiang Zhu, Lide Su, Jiansheng Wang*, Jintao Niu

Key Laboratory of Efficient Utilization of Low and Medium Grade Energy, MOE, School of Mechanical Engineering, Tianjin University, Tianjin, 300350, P. R. China

ABSTRACT

Enhanced geothermal system can efficiently extract heat, while Organic Rankine Cycle system can generate electricity with heat extracted by Enhanced geothermal system. A combination of underground heat extraction and ground power generation systems is proposed in present work. The underground heat extraction system consists of an enhanced geothermal system coupled with hydraulic-thermal horizontal wells with five disc-shaped fractures. The ground power generation system is comprised of the basic Organic Rankine Cycle system, and R245FA is used as the working fluid. The performance of combined system is numerically investigated. The results show that with the increase of geothermal fluid flow rate, the geothermal fluid outlet temperature decreases more rapidly and the reservoir life is exhausted earlier. Case 7 (geothermal fluid flow rate of 50kg/s and injection temperature of 40℃) can obtain the maximum power generation performance, with net output work and heat absorption of 13.3 MW and 13.4%, respectively. It's also found that the geothermal fluid flow rate has a greater impact on the power generation performance compared that on the geothermal fluid injection temperature.

Keywords: renewable energy resources, enhanced geothermal system, organic Rankine cycle, energy systems for power generation

NONMENCLATURE

Abbreviations	
EGS	Enhanced Geothermal System
ORC	Organic Rankine Cycle
HDR	Hot Dry Rock
Symbols	
u_m	Darcy velocity in rock matrix, m/s
Q_f	transferred mass between the rock matrix and fractures
k_m	rock matrix permeability, m^2
Pi	Injection pressure, MPa
∇z	direction of depth
T	production temperature, K
φ_m	porosity of rock matrix
μ_w	water dynamic viscosity, Pa·s
$(\rho C_p)_{eff}$	effective heat capacity
λ_{eff}	effective thermal conductivity, W/(m·K)
$Q_{f,E}$	energy source
W_t	turbine work output, MW
m	organic working fluid mass flow rate, kg/s
h_1	enthalpy of turbine inlet, kJ/kg
h_2	enthalpy of turbine outlet, kJ/kg
W_{pump}	working fluid pump power consumption, MW
h_3	enthalpy of working fluid pump inlet, kJ/kg
h_4	enthalpy of working fluid pump outlet, kJ/kg
Q_{boi}	heat input of evaporator, MW
W_{net}	net work output for ORC, kW
η_p	thermal efficiency of ORC
T_{eva}	evaporation temperature of working fluid, K
T_i	Injection temperature of geothermal fluid

1. INTRODUCTION

The depletion of fossil energy sources and the growing problem of environmental pollution have led to an increasing urgency to find new clean energy sources in many countries around the world [1,2]. In recent years, geothermal energy has been increasingly studied as a renewable, sustainable and clean energy source. According to the report, China's total HDR resources located 3-10 km underground are equivalent to 260,000 times the annual energy consumption of China [3].

Because geothermal energy is more stable, higher temperature, safer, and not affected by the season, it has more advantages than solar, wind, tidal energy and other new energy sources [4-6]. Therefore, it is very important to study geothermal energy development and promote efficient utilization. Enhanced Geothermal System (EGS) is a technology proposed to extract thermal energy based on dry heat rock. In EGS, the lower temperature working fluid is injected into the reservoir through the injection well and exchanges heat with the rock in the fractured reservoir thereby absorbing heat and warming it up. then, the higher temperature geothermal fluid is pumped out to the surface through production wells. At the ground surface, the hot water enters the evaporator to transfer heat to the secondary fluid. Then, it is injected into the reservoir through an injection well to complete the cycle. The Organic Rankine Cycle (ORC) is a type of Rankine Cycle that utilizes low boiling point organics as the working fluid [7,8]. ORC mainly consists of four parts: evaporator, turbine, condenser, and working fluid pump. In the ORC, the secondary fluid in the evaporator absorbs the heat of the geothermal fluid to evaporate and then enters the turbine to drive the turbine blades to do work to generate electricity (Fig. 1).

Many researchers have conducted studies on geothermal development. Guodong Cui et al. [9] proposed a new method of closed-loop recycling of heat transfer fluids in horizontal wells and found that the use of horizontal wells in geothermal mining can increase the heat transfer between hot dry rock and geothermal fluids. Xianbiao Bu et al. [10] proposed a Shallow Depth Enhanced Geothermal System (SDEGS) and investigated its performance for power generation using Organic Rankine Cycle. The results show that the shallow depth enhanced geothermal system can output heat stably for nearly 23 years while the net output work and thermal efficiency of ORC reach 8053.6 kW and 13.54 %, respectively. Few studies have analyzed the effect of geothermal fluid flow rate and injection temperature on the power generation performance of EGS.

In this study, we established an artificial reservoir model with five circular disc-shaped hydraulic fractures. The main purpose of this study is to evaluate the power generation performance of EGS at different geothermal fluid injection temperatures and flow rates.

2. GOVERNING EQUATIONS AND SIMULATION DETAILS

2.1 Basic governing equations

The velocity along the *x*-direction (flow direction) can be defined as Eq. (1):

$$\frac{\partial(\rho_w \varphi_m)}{\partial t} + \nabla \cdot (\rho_w u_m) = -Q_f \qquad (1)$$

According to Darcy's law, the momentum conservation equation is:

$$u_m = -\frac{k_m}{\mu_w}(\nabla P_m + \rho_w g \nabla z) \qquad (2)$$

The energy conservation equation for heat transfer expressed as:

$$(\rho C_p)_{eff}\frac{\partial T}{\partial t} + \rho_w C_{p,w} u_m \cdot \nabla T - \nabla(\lambda_{eff}\nabla T) = -Q_{f,E} \qquad (3)$$

The thermoelectric conversion equations of ORC are given as follows:

The power output of turbine is:

$$W_t = m(h_1 - h_2) \qquad (4)$$

The power consumed by the feed pump is:

$$W_{pump} = m(h_4 - h_3) \qquad (5)$$

The heat absorption capacity of the ORC system is:

$$Q_{boi} = m(h_1 - h_4) \qquad (6)$$

The net power output of the ORC system is calculated as:

$$W_{net} = W_t - W_{pump} \qquad (7)$$

The ORC system thermal efficiency is defined as:

$$\eta_p = \frac{W_{net}}{Q_{boi}} \qquad (8)$$

2.2 Simulation details

2.2.1 Physical model of EGS

The model consists of an injection well on the upper side, a production well on the lower side, and five circular disc-shaped hydraulic fractures, as is shown in Fig.2. The computational model size is a 600m×600m×600m artificially fractured reservoir located at depths from 2700 to 3300m underground. The parameters of the two wells are the same except for the different positions in the z-axis direction. The injection well is located at z = -2850 m and the production well is located at z = -3150 m.

Both wells are placed in a horizontal arrangement. In addition, the lengths and diameters of the injection and production wells are 200 m and 0.25 m, respectively. Additional detailed physical parameters of the reservoirs and fractures used in this paper are listed in Table 1.

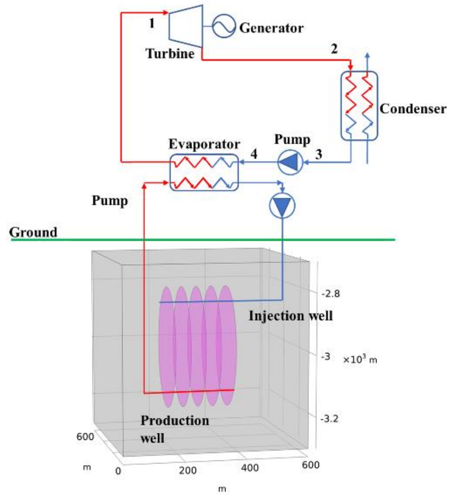

Fig 1 The schematic of the computational model

2.2.2 *Physical model of ORC*

The system diagram is shown in the above-ground part in Fig.1. The Organic Rankine Cycle (ORC) is a proposed way of efficient energy utilization for low and medium temperature heat sources. ORC mainly consists of four parts: evaporator, turbine, condenser, and working fluid pump. The working fluid is R245FA. In ORC, the organic working fluid is evaporated from the evaporator by heat absorption and then enters the turbine. The organic working fluid enters the turbine drives the turbine to produce power. Then, the working fluid flows out of the turbine and flows into the condenser for condensation. Finally, the saturated liquid is re-pumped into the evaporator by the work pump to complete a complete cycle.

2.2.3 *Boundary and initial conditions*

The initial temperature of the artificial reservoir is set as 170°C. The boundary condition of all of surface are adiabatic. In addition, the initial pressure of the reservoir is set as 22MPa. The rest of the surface is set as no flow. In ORC system, the working fluid pump and turbine adiabatic efficiency are taken as 0.8. The working fluid condensation temperature is 38°C. The evaporation temperature of the working fluid in evaporator is given as [8]:

$$T_{eva} = T_1 = T - 25 \tag{9}$$

Where T demonstrates the production temperature of reservoir.

In present investigation, in order to find the optimal combination, three heat source flow rates and injection temperature are considered, and combined into nine operating conditions. The detail parameters are shown in Table 2.

Tab.1 Parameters of rock matrix and fractures

Parameter	*Value*	*Unit*
Rock matrix		
Porosity	5	%
Thermal conductivity	2.8	W/m/K
Density	2800	Kg/m³
Heat capacity	1000	J/kg/K
Permeability	5×10^{-16}	m^2
Fracture		
Porosity	100	%
Thermal conductivity	2.8	W/m/K
Density	2000	Kg/m³
Heat capacity	850	J/kg/K
Permeability	5×10^{-11}	m^2

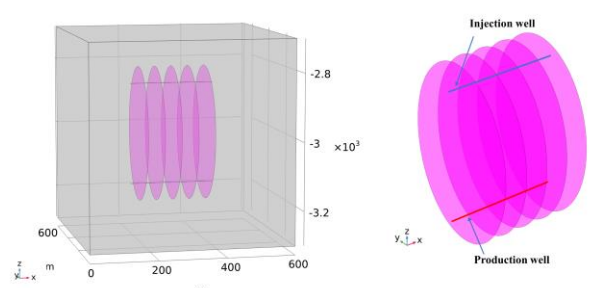

Fig 2 Physical model of the Enhanced Geothermal System

3. RESULTS AND DISCUSSION

Fig. 3 illustrates the effect of the flow rate and injection temperature of the geothermal fluid on the production temperature. As shown in Fig.3, the production temperature in all cases decreases gradually over time. The production temperature curves are divided into three parts based on different flow rate: top (30kg/s), middle (40kg/s), low (50kg/s). It's found that as the increase of

Tab.2 The corresponding geothermal fluid flow rates and injection temperatures for each case

	Case 1	*Case 2*	*Case 3*	*Case 4*	*Case 5*	*Case 6*	*Case 7*	*Case 8*	*Case 9*
M(kg/s)	30	30	30	40	40	40	50	50	50
T_i (°C)	40	50	60	40	50	60	40	50	60

geothermal fluid flow rate, the geothermal fluid outlet temperature decreases more rapidly. The reason is that with the increase of geothermal fluid flow, the heat exchange between the rock and the geothermal fluid within the reservoir increases, which will eventually result in a reduction in reservoir lifetime. It's found that the thermal fluid flow rate has a greater influence on the outlet temperature than that of injection temperature does.

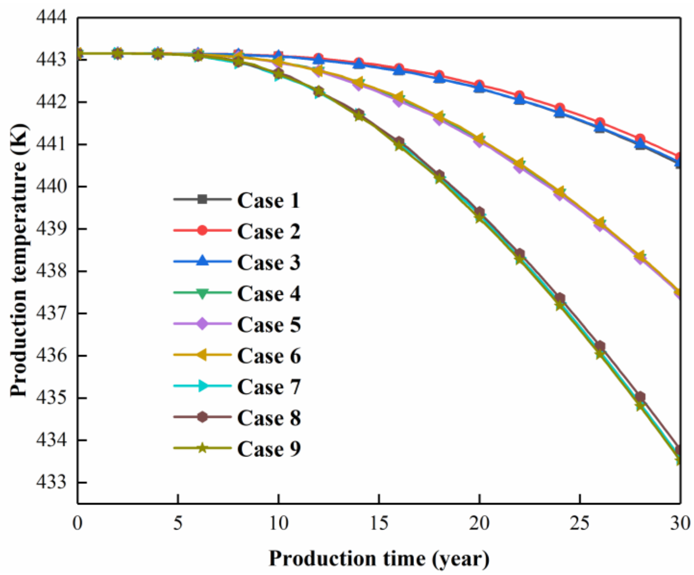

Fig 3 Variation of production temperature with time

Fig. 4 shows the variation of the injection pressure of the geothermal fluid with the operating time. As shown in Fig.4, the injection pressure of all cases increases dramatically during the first two years and then basically reaches stability later. It is worth noting that at each corresponding flow rate, the net output power and heat absorption capacity decrease with the increase of the injection temperature. The reason is that with the increase of the injection temperature, the heat absorption of the organic working fluid in the evaporator decreases, which results in a reduction of net output power and heat absorption capacity.

Tab.2 Comparison of the parameters of the two models

	T	*Pi*	*Wnet*	*cost*
Horizontal well	449.69	41.33	14.31	higher
Vertical well	432.04	40.68	7.6	lower

Fig. 5 shows the variation of the thermal efficiency in orc with time. The trend of thermal efficiency is consistent with the trend of heat source outlet temperature. During the first eight years, the thermal efficiency of all cases remained constant at 14.4%. After the 8th year, the thermal efficiency decreases gradually with time. In addition, the increase in geothermal fluid flow rate is associated with a greater reduction in thermal efficiency. For example, when the heat source fluid flow rate is 40kg/s, the thermal efficiency drops to 14.1% in the third decade. However, when the heat source fluid flow rate is 50kg/s, the thermal efficiency drops to 13.9% in the third decade. It is worth noting that the injection temperature has little or no effect on the thermal efficiency. Therefore, to improve the thermal efficiency is superior to that of geothermal fluid flow.

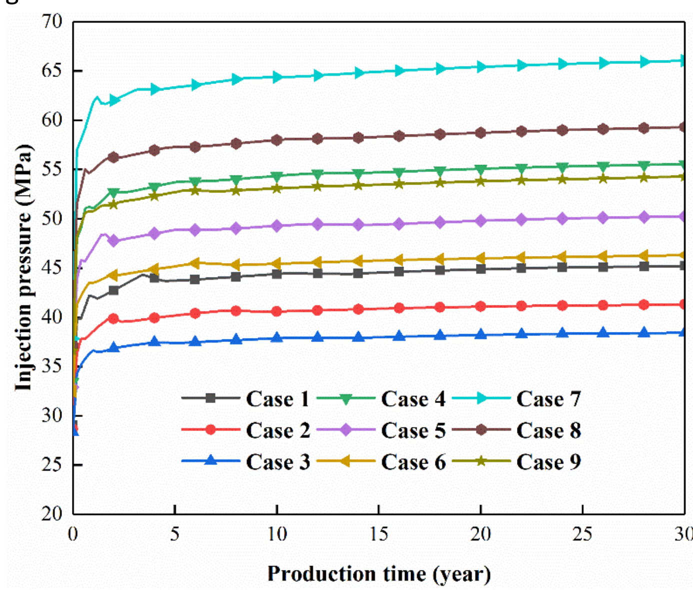

Fig 4 Variation of injection pressure with time

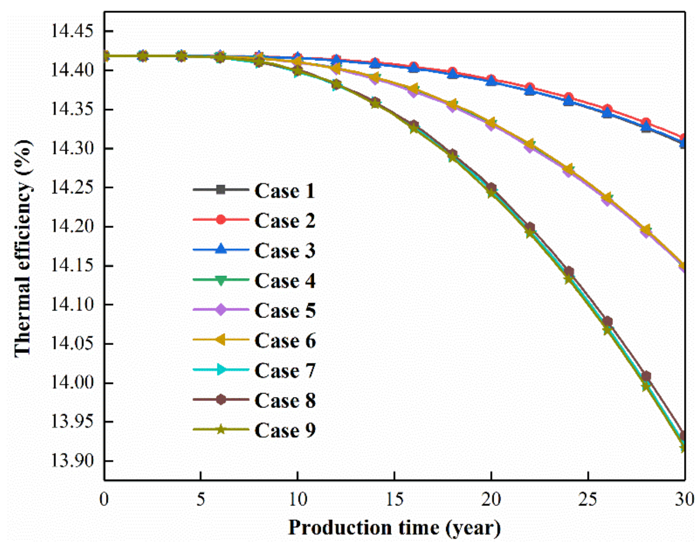

Fig 5 Variation of thermal efficiency with time

Finally, the parameters of the two models, horizontal and vertical wells, were compared and analyzed after 30 years of operation under case2 conditions. As shown in Table 2, horizontal wells have the advantage of high reservoir life and high net output work.

4. CONCLUSIONS

An enhanced geothermal system with five circular disc-shaped hydraulic fractures and organic Rankine cycle for power generation is proposed in present work. The effects of geothermal fluid flow and injection temperature on power generation performance are investigated. The results show that the EGS can output a stable geothermal fluid with a temperature of 170°C during the first ten years. In addition, in terms of net output work and thermal efficiency, the net output work and thermal efficiency reach 13.3 MW and 13.4%, respectively, for a geothermal fluid flow rate of 50 kg/s and an injection temperature of 40°C.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support by the National Key R&D Program of China (No. 2018YFB1501805).

REFERENCE

[1] Mahmoudi, Sms , and M. A. Kordlar . "A new flexible geothermal based cogeneration system producing power and refrigeration." Renewable Energy 123(2018)499-512.

[2] Zare, V., and V. Palideh. "Employing Thermoelectric Generator for Power Generation Enhancement in a Kalina Cycle Driven by Low-Grade Geothermal Energy." Applied Thermal Engineering 130 (2018) 418-28.

[3] Zhao, X. G., and G. Wan. "Current Situation and Prospect of China's Geothermal Resources." Renewable & Sustainable Energy Reviews 32 (2014) 651-61.

[4] Zhang, J., and J. X. Xie. "Effect of Reservoir's Permeability and Porosity on the Performance of Cellular Development Model for Enhanced Geothermal System." Renewable Energy 148 (2020) 824-38.

[5] Han, B. C., et al. "Evaluation of an Ammonia-Water Absorption Long-Distance Cooling/Heating System for Enhanced Geothermal Resources." Energy Conversion and Management 192 (2019) 346-58.

[6] Parikhani, T., H. Ghaebi, and H. Rostamzadeh. "A Novel Geothermal Combined Cooling and Power Cycle Based on the Absorption Power Cycle: Energy, Exergy and Exergoeconomic Analysis." Energy 153 (2018) 265-77.

[7] Yari M. Exergetic analysis of various types of geothermal power plants. Renew. Energy 35(2010) 112-121.

[8] Fontalvo A, Solano J, Pedraza C, Bula A, Quiroga AG, Padilla RV. Energy, exergy and economic evaluation comparison of small-scale single and dual pressure organic rankine cycles integrated with low-grade heat sources. Entropy 19(2017) 476.

[9] Cui, G. D., et al. "Geothermal Exploitation from Hot Dry Rocks Via Recycling Heat Transmission Fluid in a Horizontal Well." Energy 128 (2017) 366-77.

[10] Bu, X. B., K. Q. Jiang, and Y. J. He. "Performance Analysis of Shallow Depth Hydrothermal Enhanced Geothermal System for Electricity Generation." Geothermics 86 (2020).

