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Geothermal energy production utilizing abandoned oil and gas wells

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ABSTRACT

The objective of this study is to demonstrate the feasibility of acquiring geothermal energy from existing abandoned oil and gas wells. The equations describing the heat exchange between fluid and rocks are developed, and parametric studies are conducted in order to specify the optimum values of the main parameters. Computational results indicate that the geothermal energy produced from abandoned wells depends largely on the flow rate of fluid and the geothermal gradient. The temperature of extracted liquid is 129.88 °C, and it drops to 127.92 °C after ten years of operation. It is observed that both hot water and electricity can be acquired from the abandoned wells. Results also indicate that the distance of two wells should not be less than 40 m in order to avoid interaction between them. Furthermore, the financial reward of electricity is 36833.26 US $/year for a retrofitted well.

1. Introduction

Geothermal energy, as natural steam and hot water, has been exploited for decades to generate electricity, and both in space heating and industrial processes. Over the past 20–25 years, worldwide electricity production based on geothermal sources has increased significantly, the installed generating capacity has grown from 1300 MWe in 1975 to almost 10,715 MWe in 2010 [1–3]. These geothermal power projects convert the energy contained in hot rock into electricity by using water in place to absorb heat from the rock and transport it to the earth's surface, where it is converted to electrical energy through turbine-generators [3]. In systems of this kind, there are some problems that are not easy to be solved, which include the injection of waste water, high cost of geothermal well drilling, corrosion and scaling problem [4]. The cost of drilling can run as high as 50% of the total cost of a geothermal project. Geothermal energy will have broad market if these problems can be solved successfully [5].

The number of oil and gas wells drilled by Petroleum China are more than 200,000, but many oil/gas wells in China are abandoned now [6]. If these abandoned wells could be used for producing geothermal energy, it will not only reduce the cost of drilling wells, but also acquire more renewable energy. At the same time, the problems of re-injection, corrosion and scaling can be solved because the circulating system of fluid is closed and the working fluid doesn't touch directly with rocks due to the single well is used for geothermal production. Recently, some researchers have paid much attention to the utilization of abandoned wells. Kujawa et al. [7] investigated the utilization of existing deep geological wells for acquisitions of geothermal energy, and they concluded that the flow rates and insulation had important effects on heat exchange. Davis and Michaelides [8] studied geothermal power production from abandoned oil wells, their analysis taken into consideration local geothermal gradients and well depths. However, the temperature of the rocks was considered invariable with time in this paper, which indicated the power production calculated in this article was higher than the true value. The experiments of extracting geothermal water from oil wells for power generation were carried out in Huabei oil region in China [9], and the experimental results showed that the mass flow rate of hot water was 1932 t/d with temperature of 116 °C. However, few studies considered the heat exchange between rocks and fluid comprehensively. Therefore, it is of great importance to find a good way to estimate the heat exchange between rocks and fluid and geothermal energy production from abandoned wells.

The main purpose of this study is to demonstrate the feasibility of acquiring geothermal energy from abandoned oil and gas wells. We first develop a mathematical model for describing heat exchange between fluid and rocks and solve it by numerical method, and then analyze the impact of the geothermal gradient and the flow rate of working fluid on the heat attainment and the

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power generation from abandoned wells. Lastly, we briefly discuss the flow resistance and the pump power.

2. Physical models

The existing abandoned oil and gas wells can easily be retrofitted as geothermal wells by sealing the bottom of the well and by covering insulation, as shown in Fig. 1. The circulating fluid is injected through the ring-shaped channel and flows downward along the channel being gradually heated by surrounding rocks. The flow is reversed at the bottom of the well, and then the fluid ascends through the inside channel and flows out to the earth's surface [10]. The abandoned oil and gas wells geothermal systems are different from the conventional geothermal systems. In abandoned oil and gas wells geothermal systems, the circulating fluid doesn't touch directly with rocks, just like a double-pipe heat exchanger, thus just heat transfer occurs without mass transfer. While in the conventional geothermal systems the fluid is extracted from the porous rock or soil. Meanwhile, in order to maintain the high temperature of extracted fluid, the fluid flow rate for abandoned oil and gas wells geothermal systems is less than that of conventional geothermal systems due to smaller heat exchange areas between well walls and rocks. The geothermal gradient is generally more than 25 °C/km [7–9], so, we chose an abandoned well, with a depth of 4 km and geothermal gradient of 25 °C/km and 45 °C/km respectively, as the object of study. The inner diameter of the extraction well is 0.1 m. The diameter of injection well on the top part is 0.34/0.3 m with the length of 2500 m, while on the bottom the diameter is 0.33/0.3 m with the length of 1500 m.

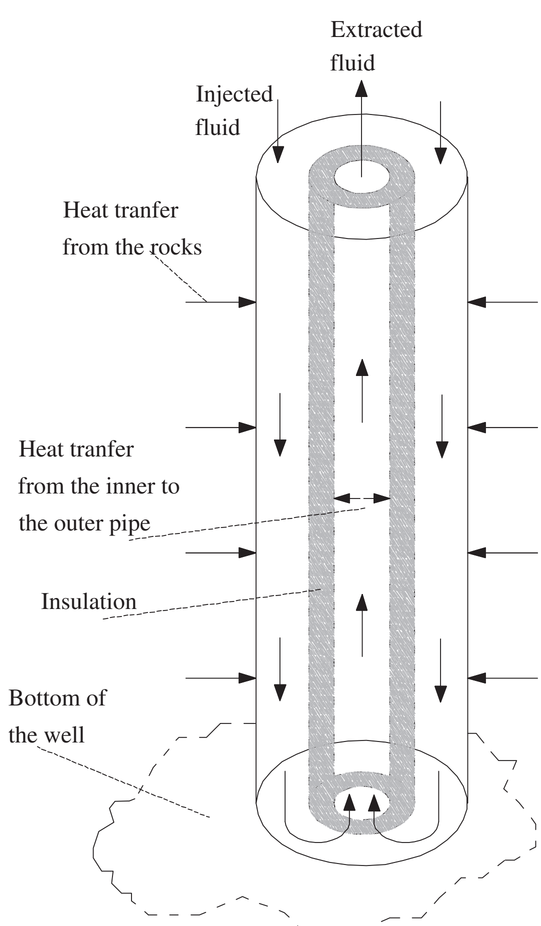

Fig. 1. Schematic representation of heat exchange in the single well.

3. Mathematical models

The mathematical model includes the energy conservation equations and the flow resistance equation. Neglecting the variation of the tube wall temperature of injection well and extraction well, heat exchange takes place between fluid and rocks and between injected fluid and extracted fluid simultaneously [11–14].

3.1. Energy equation in extraction well

The temperature of extracted fluid is higher than that of injected fluid, so heat transfer occurs from extracted fluid to injected fluid, the energy equation in extraction well may be expressed as follows [11,13]:

$$\frac{\partial T_r}{\partial t} + \frac{\partial (VT_r)}{\partial z} = -S_{rR} \tag{1}$$

where

$$S_{rR} = \frac{k_l[T_r - T_R]}{\rho A_r C_p} \tag{2}$$

$$k_l = \frac{\pi}{\frac{1}{2h_{r_1} r_1} + \frac{1}{2\lambda_S}\ln\frac{r_2}{r_1} + \frac{1}{2h_{r_2} r_2}} \tag{3}$$

3.2. Energy equation in injection well

Injected fluid is heated by surrounding rocks and extracted fluid, so the energy equation in injection well may be given by the following equation:

$$\frac{\partial T_R}{\partial t} + \frac{\partial (VT_R)}{\partial z} = S_{rR} + S_{RW} \tag{4}$$

where

$$S_{RW} = \frac{h_W 2\pi R (T_{\text{wall}} - T_R)}{\rho A_R C_p} \tag{5}$$

3.3. Energy equation of the rocks

Energy equation of the rocks is written in following general form [12]:

$$\rho_W C_W \frac{\partial T_W}{\partial t} = \frac{\partial}{\partial z}\left(K_W \frac{\partial T}{\partial z}\right) + \frac{1}{r}\frac{\partial}{\partial r}\left(rK_W \frac{\partial T_W}{\partial r}\right), \quad R \le r \le r_\infty \tag{6}$$

3.4. Pressure loss

Pressure loss, namely the flow resistance along the wells, is presented below [13]:

$$\frac{\Delta P}{\Delta z} = \lambda \frac{\rho V^2}{2d_e} \tag{7}$$

For extraction well: $d_e = 2r_1$, for injection well: $d_e = 2(R - r_2)$.

For laminar flow: $\lambda = 64/Re$, for turbulent flow: $\lambda = 0.11((\Delta/d_e) + (68/Re))^{0.25}$.