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Geothermal exploitation from hot dry rocks via recycling heat transmission fluid in a horizontal well

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ABSTRACT

A new method for geothermal exploitation from hot dry rocks by recycling heat transmission fluid in a horizontal well via a closed loop is proposed, in which the costly and complex hydro-fracturing can be avoided. In this paper, numerical simulation models were established to calculate the heat mining rate for the new technology to assess its technical and economic feasibility. Sensitivity studies were performed to analyze the effects of various parameters on heat mining rate, including the injection rate, the horizontal segment length and the thermal conductivity of the tubing. The results show that a high heat mining rate over 1.7 MW can be obtained using a 3000 m long horizontal well to extract geothermal energy from a typical hot dry rock of 235 °C with a water circulation rate of 432 m^3/d. For low-temperature geothermal reservoirs, higher injection rate, longer horizontal wells and better thermal insulation of tubing can be applied to increase the heat mining rate. The cost of geothermal power generation using a single horizontal well is estimated as 0.122 $/kWh, and this could be further reduced to 0.084 $/kWh when the multi-branch horizontal well pattern was adopted, slightly lower than a fractured vertical well case.

1. Introduction

Geothermal energy is abundant and is not affected much by weather conditions [1], which makes it as one of the promising supplements to fossil fuels [2,3]. However, conventional geothermal resources are usually located in tectonic or volcanically active regions where the surface temperature is usually higher, which limits the wide scale application of geothermal [1,4]. Conversely, the unconventional geothermal resources, especially the hot dry rocks (HDR), have wide distributions and large geothermal exploitation potentials, which have attracted more and more attention [5]. It was reported that the total HDR heat in the US and China is above 14×10^{24} J and about 25×10^{24} J respectively, which is far more than the total annual energy consumption in the US or China [6,7]. Moreover, the mined heat can be used to generate electricity with little or no environmental footprint [8]. Therefore, the development and utilization of geothermal in HDR not only can play a role in energy conservation and adjustment, but also can provide energy for residents living in remote areas [9,10].

Due to the fact that porosity and permeability of HDR are very low, large-scale hydro-fracturing usually needs to be used before geothermal exploitation for reservoir creation, which can provide channels for flow and heat exchange [11,12]. Field experiences in US and Austria and so on [13–19] indicated that hydro-fracturing in HDR can easily fracture cap rocks because of high brittleness of HDR and result in huge loss of water [14,15,20]. On the other side, the fractures created by hydro-fracturing can be blocked under geo-stress and water-rock interactions, which makes the geothermal no longer exploitable [21,22]. Large-scale hydro-fracturing is not only expensive, but it can also cause environmental problems or even induce earthquakes [23,24]. Therefore, a simpler economic and secured method needs to be developed for enhanced geothermal exploitation from HDR.

Horizontal well drilling and completion technology was developed rapidly in the 1980s [25,26] and now has been widely applied to sandstone, carbonate and shale reservoirs for enhancing oil and gas recovery [27]. It is a very attractive option to use horizontal

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wells for geothermal exploitation from HDR without hydro-fracturing. For this purpose, a horizontal well can be composed of a casing (i.e. outer pipe) and a tubing (i.e. inner pipe), similar to a double-pipe heat exchanger. Low-temperature water or other heat transmission fluid can be injected into the annulus between the tubing and the casing, and high temperature fluid can be extracted through the inner tubing. The double-pipe heat exchanger has been studied by some researchers. Kujawa et al. investigated the feasibility using renovated abandoned oil/gas wells for geothermal exploitation, and analyzed the effect of injection rate and insulation on heat mining rate [28]. Davis et al. studied the geothermal power production using double-pipe in abandoned wells via recycling of isobutane, taken into the consideration of local geothermal gradients, typical well depths and pipe diameters [29]. Xiao Bu et al. established a numerical simulation to study the feasibility of geothermal exploitation from existing abandoned wells, and conducted parametric studies to specify the optimum values [30]. Weng-Long Cheng et al. analyzed the influence of insulation on the geothermal power generation using the double-pipe heat exchanger [31]. All these research show that the double-pipe heat exchanger can be used for geothermal exploitation and has a wide application prospect.

The research of the double-pipe heat exchanger was mainly focused on vertical wells, and there is a lack of systemic research work on using horizontal wells for geothermal exploitation. For geothermal exploitation using a vertical well, if water injection rate is high, the temperature of the extracted water will be low since the heat loss of the surrounding rock cannot be rapidly compensated by heat conduction. However, in using a horizontal well, water can be continuously heated up in flowing through a long horizontal segment by the surrounding rocks of high temperature, which can make the produced water with very high temperature (even equal to the rock temperature) and maintain a high heat mining rate when applying a high water injection rate.

In this paper, an innovative horizontal well technology is proposed, in which heat transmission fluid is circulated via a closed loop in a single horizontal well with no need of hydro-fracturing. The objective of this work is to estimate the heat mining rate from typical HDR and evaluate the technical and economic feasibility of the new method. Firstly, the mechanism and advantage of the horizontal well technology for geothermal exploitation are described, and then a mathematic model for the heat exchange between the well segment and rocks is established to calculate the distributions of temperature and pressure along the wellbore and the heat mining rate. Sensitivity studies of flow rate, horizontal segment length and thermal conductivity of tubings on the heat mining rate are conducted. A simplified economic model for calculating the cost of geothermal power generation is used for the economic feasibility study of the new technology.

2. Geothermal exploitation using a horizontal well

2.1. Principles of the horizontal well technology

The structure and fluid loop of the horizontal well technology for geothermal exploitation can be seen from Fig. 1, which is similar to the wells used in oilfields. However, the difference with the completion process of horizontal wells in oil and gas fields is that the bottom of the well should be sealed with cement or packer to prevent the direct contact of the injected heat transmission fluid and the rock. When using the horizontal well for geothermal exploitation, the low-temperature heat transmission fluid is injected and flows through the annulus between the casing and inner tubing along the wellbore, being heated up simultaneously by the surrounding hot rocks. At the bottom of the horizontal well, the heated fluid with the highest temperature flows into the inner tubing and returns to the surface for heat exchange. In order to increase the temperature of the produced transmission fluid, larger wellbore and longer horizontal segment length can be applied. Meanwhile, a pre-stressed insulated tubing can be used for reducing the heat loss of the fluid in the inner tubing and avoiding possible tubing damage caused by thermal stress [32]. In addition, the main process of geothermal power generation using the horizontal well technology is also illustrated in Fig. 1. The heated produced fluid will exchange heat with the working medium in the heat exchanger, and after completion of the heat exchange, the cooled produced fluid will return to the annulus. Simultaneously, the working medium steam will drive the turbine to generate electricity and then flow back to the heat exchanger.

2.2. Comparison with hydro-fracturing technology

The enhanced geothermal system (the so-called EGS) has been proposed and widely accepted for geothermal exploitation from tight reservoirs. In the application of the EGS technology, three vertical wells or more wells are needed; one for heat transmission fluid injection and the others for fluid production and heat extraction. In order to connect the injection and production wells, large scale hydro-fracturing and chemical stimulation techniques are applied in both wells to create high permeability channels (man-made fractures) for fluid circulation. Hydro-fracturing can lead to earthquakes with a magnitude higher than 2 and environmental pollutions, which needs to be cautioned and monitored [33]. In addition, a down-hole water pump in the production well is needed to extract the circulation fluids. In contrast to the EGS technology, the proposed horizontal well circulation method only needs a single horizontal well and using one injection pump, in which heat transmission fluid is circulated in a closed loop with injection through the annulus between the wellbore casing and the tubing and returns to the surface through the inner tubing as shown in Fig. 1.

2.3. Advantages of the horizontal well technology

There are many advantages for geothermal exploitation from HDR using the horizontal well technology. (1) Compared with the EGS or the method using several horizontal wells for geothermal exploitation, the geothermal exploitation using a double-pipe heat exchanger horizontal well not only can avoid the high cost of fracturing, its single well injection-production system can further

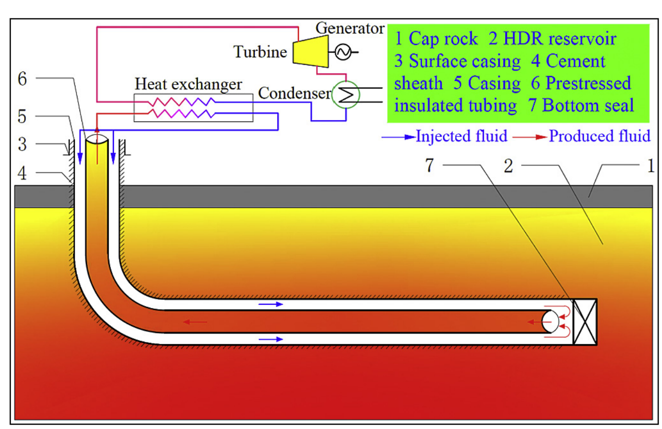

Fig. 1. Schematic diagram of the well structure and geothermal power system cycle for the horizontal well technology.