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Numerical simulation of power production from abandoned oil wells in Ahwaz oil field in southern Iran

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ABSTRACT

Abandoned oil and gas wells can be used as low temperature geothermal resources for heat extraction from geological formations. They can provide valuable potential sources of heat without the extra cost of deep drilling required in traditional geothermal projects. In this study, two oil wells (AZ and DQ) in southern Iran were numerically simulated using a 3D technique for heat extraction. The bottom-hole temperature of wells AZ and DQ were 138.7 °C and 159.8 °C, respectively. Heat transfer between the fluid injected into the well and the surrounding hot rock was simulated. Well casing geometry and an exact thermal gradient for two abandoned oil wells were considered. The simulation results were optimized for parameters such as input and output fluid flow rates and temperatures. The results revealed that, in addition to thermal gradient and input mass flow rate, well casing geometry and the size of injection and extraction pipes were essential to the output heat extraction rate. The small internal diameter of the wells and design of the injection and extraction pipes were limited, resulting in lower mass flow rate and higher power consumption by the injection pump. Total extractable rate of heat from wells AZ-II and DQ-II was 967 kW and 1842 kW, respectively, and net electricity generation using a geothermal binary cycle was 138 kW and 364 kW, respectively.

1. Introduction

Geothermal energy has been used for electricity since the early 20th century; the first power plant was built in Larderello, Italy in 1904. As of 2011, about 11 GW of power was produced by geothermal power plants worldwide. Most power plants have been constructed in the last three decades (Gehringer and Loksha, 2012). Geothermal energy is a commercially proven renewable energy which can provide relatively cheap, low-carbon, base-load power and heat that can reduce dependence on fossil fuels and low CO_2 emissions with high reliability (Gehringer and Loksha, 2012; Noorollahi and Itoi, 2011). Electricity from geothermal sources, however, only represents 0.3% of total global power generation (Gehringer and Loksha, 2012). At present, there is no power generation in Iran from geothermal resources (Saffarzadeh and Noorollahi, 2005). Low-temperature (100–150 °C) geothermal heat sources are valuable potential sources of renewable energy (Tester et al., 2006; Paschen, 2003). Research on this major source of energy can increase the applicability of renewable resources (Walraven et al., 2013; Madhawa Hettiarachchi et al., 2007; George et al., 2013; Quick et al., 2013; Guo et al., 2011a,b).

Ground source heat utilization requires a suitable design of borehole heat exchanger. Yavuzturk and Chiasson (2002) and Hellström (1998, 2002) studied both U-tube and coaxial geometries, and their results suggested that the coaxial geometry may have some advantages in reducing the borehole thermal resistance, which represents the resistance between the circulating fluid and the borehole wall. Decreasing this resistance increases the heat transfer between fluid and the ground. In the field of heat transfer in borehole heat exchanger Kohl et al., is concluded that a deep borehole heat exchanger systems, installed in abandoned boreholes, have been operative in Switzerland for several years and shown high production temperatures (~40 °C) (Kohl et al., 2002). Important factors in heat transfer such as Borehole resistance, vertical temperature profiles (Richard et al., 2013, 2014) and thermal capacity effects in coaxial borehole heat exchangers (Shirazi and Bernier, 2013), have been studied to achieve optimum heat transfer.

Binary power plants convert low grade geothermal resources into electricity. These plants use the heat from hot water to boil

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a working fluid, usually an organic compound with a low boiling point. The working fluid vaporizes in heat exchanger and high pressure vapor drives the turbine, and the exhausted hot water from heat exchanger is then reinjected back into the ground. Researchers have modeled, optimized and examined the properties of different working fluids to improve the net power production of binary geothermal power plants (Yousefi et al., 2010; Ghasemi et al., 2013a,b; Franco and Villani, 2009; Hung et al., 2010; Jalillnasrabady and, Itoi, 2012).

Global geothermal electricity generation is expected to increase from 68 TWh to more than 300 TWh and capacity from 11 GW to over 40 GW by 2035 (Jalillnasrabady and Itoi, 2012). Research efforts have focused on new solutions to improving use of this energy source. An innovative method is the extraction of heat from abandoned oil and gas wells as a renewable energy source. There are significant numbers of abandoned oil and gas wells around the world and in Iran. If these abandoned wells could be used as a heat source to extract thermal energy, they could provide low cost heat by eliminating the cost of drilling and mitigating related environmental impacts (IEA, 2012; Moghaddam et al., 2014).

Kujawa et al. (2006) examined the use of existing deep wells to obtain geothermal heat, and concluded that flow rate and pipe insulation had important effects on heat exchange in boreholes. Davis and Michaelides (2009) calculated geothermal power production from abandoned oil wells by considering local geothermal gradients and well depths. In this simulation the mean geothermal gradients of the underground layers were applied instead of actual temperature gradient and the size and geometry of the oil wells are used were not typical for oil wells. Thus it seems the calculated power output is over estimated.

Bu et al. (2012) examined thermal energy production from abandoned oil and gas wells, and conducted parametric studies to specify the optimum values of the parameters. Computational results indicated that geothermal energy extracted from wells, are largely dependent on the flow rate of the injected fluid and the geothermal gradient. Cheng et al. (2013) studied geothermal power generation using abandoned oil wells and concluded that the outlet temperature of the extracted fluid gradually decreases as system operation time increases until it reaches steady state.

In our knowledge there is not any studies to analyze heat transfer between rock and fluid in wells using 3D modeling of an actual abandoned oil well by considering the actual geothermal gradient and simulating the exact well geometry and thickness of the ground layers. These conditions increase the accuracy of the calculations and the precision of heat and power extraction.

Table 1
Thermo-physical properties of the geological layers.

Properties	Density (kg/m^3)	Heat capacity (J/kg K)	Thermal conductivities (W/m K)
Sand-stone	2720	920	3.1
Wet-sand	2600	935	2.3
Lime-stone	2700	908	2.8
Calcite	2730	920	2.8
Marl	2650	880	2.6
Dolomite	2900	911	3.7
Bentonit	2620	650	2.05
Cement coat	2510	840	2.9
Polystyrene	55	1210	0.027
Steel-stainless	8055	480	13.8

The present study simulated two abandoned oil wells in different oil fields in southern Iran and evaluated the effects of geothermal gradient and mass flow rate on fluid outlet temperature. A feasibility study for electricity generation and heat utilization from extracted fluid using binary cycle was examined. The impact of injection pump power consumption and the role of fluid operating pressure on net power output were investigated.

2. Physical models and input data

The techniques for heat extraction from abandoned oil and gas wells are different from conventional geothermal systems, the circulating fluid is not in direct contact with the hot rocks. The fluid circulates in a coaxial double-pipe heat exchanger and heat transfer occurs without mass transfer. The fluid circulates in the well by means of a concentric double pipe. Cold water is injected into the well through the outer pipe and the heat, transfers from the hot rock to the fluid during injection and then the fluid will be heated. The hot fluid rises up through the inner pipe and will be extracted. To avoid heat transfer between the outer and inner pipes, extruded polystyrene thermal insulation surrounds the inner pipe. The abandoned oil wells (AZ and DQ) modeled in this study are located in Ahwaz province in southern Iran. Wells specifications, casings and ground layers are shown in Fig. 1. The thermo-physical properties of the geological layers are shown in Table 1 (Bu et al., 2012; Cheng et al., 2013; Emirov and Ramazanova, 2007; Asaad, 1955).

The depth of well AZ is 3861 m and the diameter of the casing pipe at ground level is 24 in. and narrows to 7 in. at the well bottom. The depth of well DQ is 4423 m and the diameter of the casing pipe at ground level is 20 in. and 7 5/8 in. at the final depth. Two different heat exchangers (coaxial pipe heat exchangers) were proposed for each well which are shown in Fig. 2. The specifications of the

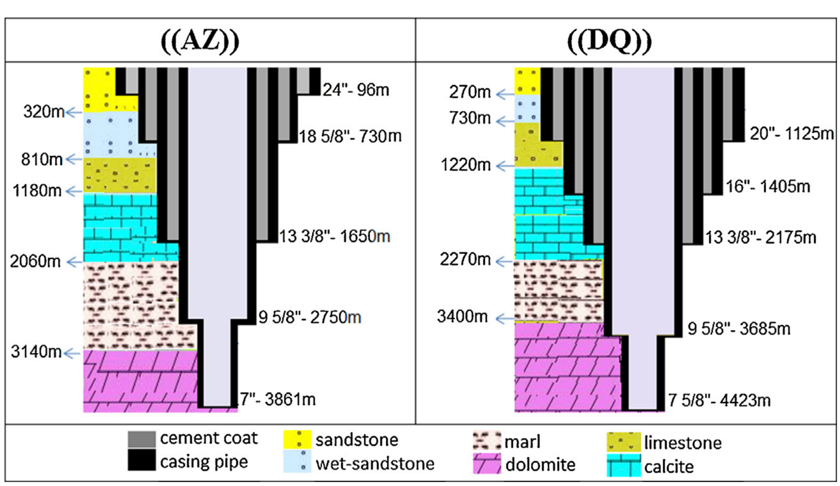

Fig. 1. Schematic representation of wells specifications, casings and ground layers for wells AZ and DQ.