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Evaluation of geothermal heating from abandoned oil wells

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ABSTRACT

With continuous petroleum exploitation, more and more oil wells have been abandoned, which contain abundant geothermal energy. For utilizing the geothermal energy, this paper presents a new geothermal heating system using abandoned oil wells (AOW), and a comprehensive model combing wellbore heat transfer, formation and building energy transport is built, parameters including geothermal production, room temperature and fluid production temperature are examined by the built model. Simultaneously, a formation temperature return model was developed to investigate the formation rewarming after heating period. Furthermore, the economic and energy analysis were performed to assessment the thermo-economic performance of the presented system. Particularly, an existing AOW with depth of 3000 m was concerned to heat a virtual building with heating area of 10000 m^2. The results showed that the AOW could keep the building at around 26°C with water flow rate 20 m^3/h, and the maximum heating area could reach 11000 m^2. Also, the bottom-hole temperature could return to a steady point after the 2nd year. The total geothermal energy production was 5.5×10^{12}J during heating period, which could reducing CO_2 emission about 457 ton each year. Specially, the largest total annualized cost of the new heating system was about half of that of conventional heating system.

1. Introduction

As a renewable and sustainable energy source, geothermal energy has been applied widely since the beginning of the 20th century, the global geothermal power capacity is expected to rise to over 16 GW in 2020 [1]. More specially, by 2050, geothermal electricity generation could reach 1400 TWh per year, around 3.5% of global electricity production, and geothermal heating could contribute 5.8 EJ, 3.9% of projected final energy for heat reported by IEA [2].

Geothermal energy can be utilized for different purposes, determined by the source temperature. Usually, the high-temperature geothermal resource is applied indirectly to power generation or more complicate system [3,4]. Generally, the low-temperature resource is used directly for space heating and cooling [5,6]. Nevertheless, the low and medium temperature geothermal also can be converted into electronic power by introducing some innovative and special system layouts [7,8]. In particular, some recent researchers tended to evaluate the performance of Organic Rankine cycles (ORC) [9,10] and organic working fluids used in ORCs [11,12] for low-temperature geothermal power generation. In the above geothermal energy utilization systems, there are some problems should be solved before large-scale application, including groundwater recession, corrosion and scaling problem, high cost of geothermal and re-injection well drilling [13]. Especially, the cost of drilling even can occupy 50% of the total cost of the geothermal project. The social acceptability of geothermal energy would improve significantly if those problems could be solved [3].

With continues production, many petroleum reservoirs are depleted and the oil wells are abandoned. In fact, about 20–30 millions abandoned wells have been produced around the global [14], meanwhile many wells located where the geothermal energy is very abundant due to the relatively high geothermal gradient. If the abandoned petroleum wells can be retrofitted as a geothermal system, it will present an interesting opportunity not only to cut drilling cost but also produce considerable thermal energy and avert environmental problems associated with accidental spillage and pollution of the area around AOW. Therefore, some researchers have focused on utilization of the geothermal energy from AOW at present.

Kujawa et al. [15] initially used a double-pipe heat exchanger to extract heat from AOW by heat conduction in surrounding rocks; the retrofitted geothermal system using AOW is closed loop system

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Nomenclature

Variables

a	geothermal gradient, K m^{-1}
A_i	injection pipe area, m^2
A_p	production pipe area, m^2
A_H	heating pipe area, m^2
A_r	building surface area, m^2
dQ/dz	heat flux from formation, W m^{-1}
dQ_p/dz	heat flux from production pipe to injection pipe area, W m^{-1}
dQ_H/dx	heat flux to building room, W m^{-1}
d_e	feature size of pipe, m
f	two-phase friction factor, dimensionless
$f(t)$	transient heat conduction function, dimensionless
H	well total depth, m
h_1	fluid enthalpy at inlet of building, kJ kg^{-1}
h_2	fluid enthalpy at outlet of building, kJ kg^{-1}
h_{in}	injection fluid enthalpy at wellhead, kJ kg^{-1}
h_{out}	production fluid enthalpy at wellhead, kJ kg^{-1}
h_c	convective heat transfer coefficient, W m^{-2} K^{-1}
h_r	radiative heat transfer coefficient, W m^{-2} K^{-1}
m	fluid injection rate, kg s^{-1}
Q_H	heat flux from heat exchanger to room, W
Q_L	heat loss to outdoor environment, W
Q_t	total heat extraction from abandoned oil well, W
r	radius, m
r_h	radius of interface between wellbore and formation, m
T_{bh}	bottom-hole temperature, K
T_e	formation temperature, K
T_{ei}	virgin formation temperature, K
T_f	fluid temperature, K
T_{fH}	fluid temperature at heat exchanger, K
T_{fi}	fluid temperature at injection pipe, K
T_{fp}	fluid temperature at production pipe, K
T_0	surface earth temperature, K
U	overall heat-transfer coefficient W/(m^2 K)
v_f	fluid velocity, m/s
z	well depth, m

Greek letters

α_e	thermal diffusivity of the formation, m^2/s
β	thermal volumetric expansion coefficient
μ	viscosity, Pa s
λ	thermal conductivity, W m^{-1} K^{-1}
ρ	density, kg m^{-3}
ρc	volumetric specific heat capacity, J m^{-3} K^{-1}
τ	injection time,h
τ_D	dimensionless time

Subscripts

cas	casing
cem	cement
ci	inside radius of productive casing
co	outside radius of productive casing
gi	inside radius of outer tubing
go	outside radius of outer tubing
Hi	inside radius of heating pipe
Ho	outside radius of heating pipe
Il	insulation
si	inside radius of surface casing
so	outside radius of surface casing
ti	inside radius of inner tubing
to	outside radius of inner tubing
tub	tubing

where working fluid circulates in double-pipe heat exchanger, without extracting groundwater from stratum, it can avoid groundwater recession, corrosion and scaling problems. In their study, an existing deep AOW was concerned with investigation of the heat production and fluid temperature. Based on Kujawa's work, many researchers paid more attention to using the AOW for geothermal power generation. Davis and Michaelides [16] firstly used an abandoned well with 3000 m depth for power production by a simple Rankine cycle. They concluded that a binary cycle with optimized injection and pipe parameters would produce more power. Bu et al. [17] proposed a model considering the transient heat transfer of surrounding rock in AOW, and simulated the rock temperature distributions during power production. Aiming to abandoned gas wells in Iran, Ebrahimi and Torshizi [18] performed a parametric optimization of the ORC for power generation using AOW; R125 was chosen as the optimal working fluids. Cheng [19] introduced a novel transient heat conduction function to examine the effect of formation heat transfer on geothermal production and power generation from AOW; they also studied on the optimization of working fluids for different power generation system using abandoned wells, 7 types of organic fluids were investigated [20]. Also, some researchers tended to optimize AOW power generation system by economic and exergy analysis [21]. Additionally, the comprehensive system combing AOW geothermal system with enhanced geothermal system (EGS) has been presented for power generation [22].

All above geothermal power generation systems for abandoned oil wells used the ORC; and the depths of most abandoned wells are less than 3000 m, unfortunately, at the depth only low-temperature geothermal source is usually available. Although the low and medium temperature geothermal source can be utilized for power generation when innovative and expensive system layouts are introduced, acquiring satisfactory power generation efficiency is not easy [23,24]. For the existing utilizations of AOW, heat extraction from AOW only by conduction can lower the production temperature. Thus, in some studies, the well depth was set as more than 4000 m, even up to 6000 m for improving production temperature and getting higher efficiency. Although there are some questions in geothermal power generation using abandoned oil wells, it is usual and effective to use the low-temperature geothermal resource directly for space heating. Therefore, it seems to be very reasonable to developing a novel geothermal heating system by using AOW.

The main purpose of this paper is to evaluate the performance of using abandoned oil wells for geothermal heating. A comprehensive mathematical model combining wellbore heat transfer, formation heat transfer, tubing and building energy transport was built firstly. And then, an existing abandoned oil well was used and refitted to support space heating for a virtual building. The building room temperature and heat extraction rate were analyzed by the built model, and the optimized range of fluid flow rate was determined with matching heating area. At last, the economic and energy analysis was performed for evaluating the thermo-economic performance of the presented system.