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Insights into geothermal utilization of abandoned oil and gas wells

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A R T I C L E I N F O

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A B S T R A C T

Abandoned oil and gas wells (AOGW) with high bottom-hole temperature contain abundant geothermal energy, which can be retrofitted to a novel geothermal system for different utilizations without high-cost drilling. Thus, at recently, some researchers concentrate on evaluation of the performance of thermal energy extraction from AOGW and geothermal power generation using AOGW with Organic Rankine cycle (ORC) systems. The aim of this paper is not only to review advanced geothermal utilizations for AOGW, but also make insights into the thermal simulation methods and power generation as well as working fluids selection for AOGW geothermal system. Due to heat extraction from AOGW dominating the geothermal utilizations; firstly, this paper performed to summarize and discuss the heat transfer models of AOGW geothermal system, which involve wellbore heat transfer and transient heat conduction in surrounding formation. Then, for evaluating the performance of power generation systems using AOGW, three different power plants were compared and the influence factors were examined. In addition, the optimum selection criteria of working fluids were also summarized, and the optimal fluids for different wells were determined. At last, the summary of key problems of the AOGW geothermal utilizations were proposed, and the future development and applications of AOGW were suggested for improving the geothermal utilizations.

1. Introduction

1.1. Review of previous studies

As a renewable and sustainable energy source, geothermal energy is stored in hot rock below the earth surface, which not only shows low impact on environment but also can be utilized regardless of environmental conditions [1]. The continuous availability and reliability of geothermal energy makes geothermal resources more attractive for the power industry in comparison to other energy sources. Especially for the high-temperature geothermal source, the electricity production by geothermal power plants is significantly cheaper than that by fossil fuels, hydroelectric, nuclear, wind and solar energy [2]. Fig. 1 illustrated the global installed capacity of geothermal power plant and Fig. 2 showed the regional contributions to the capacity in 2015 [3]. The International Energy Agency (IEA) Energy Market Report2015 announced that the global geothermal power capacity was expected to rise to over 16 GW in 2020 [4]. By 2050, geothermal power generation can reach 1400 TW h per year, around 3.5% of global electricity production, simultaneously; geothermal heating will contribute 5.8 EJ, 3.9% of projected final energy for heat reported by IEA [5].

Geothermal energy can be utilized for different purposes, mainly determined by the source temperature. Generally, the geothermal source can be classified three types: high-temperature (> 150 °C), medium-temperature (90–150 °C) and low-temperature source. The high-temperature geothermal resource is usually applied indirectly to power generation or more complicate system [6–8]. In another way, the low-temperature and medium-temperature resources are usually used directly for district heating and geothermal source heat pump (GSHP) [9,10]. Even so, numerous researches tended to evaluate the performance of Organic Rankine cycles (ORC) as well as the working fluids for conversation of low-temperature geothermal energy into electricity [11–14]. In general, for most of geothermal systems besides GSHP, the fluid (ground water or steam) is extracted from thermal reservoir carrying the heat to earth surface or shallower depths, which produces an open loop system [15]. This system involves some problems, including groundwater recession, corrosion and scaling problem, high cost of geothermal and re-injection well drilling [16]. Especially, the cost of drilling even can occupy 50% of the total cost of the geothermal project, and the market of geothermal energy application would be expanded significantly if those problems could be solved [1].

More and more oil and gas wells (AOGW) have been abandoned in the world when petroleum reservoir was depleted without economic feasibility. Statistics show that about 20–30 millions oil wells have been abandoned around the world [17], and at least 1.2 million wells had been abandoned for the US in 1987 [18]. the State of Texas has more

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Nomenclature

Variables

A	sectional area of pipe, m^2
A	geothermal gradient, K/m
dQ/dz	heat flux at unit well depth, W/m
f(t)	transient heat conduction function
r	radius, m
R	thermal resistance, (K m)/W
T	temperature, K
U	heat transfer coefficient, W/(m^2 K)
v	injection velocity, m/s
z	well depth, m

Greek letters

α	thermal diffusivity of formation, m^2/s
λ	thermal conductivity, W/(m K)
ρc	volumetric heat capacity, J/(m^3 K)
ω	ratio of formation heat capacity and wellbore heat capacity ($= C_i/C_w$)
τ	time, s

Subscripts

ci	casing inside
co	casing outside
gi	outer tubing inside
go	outer tubing outside
ti	inner tubing inside
to	inner tubing
io	between inner and outer pipe
ow	between outer pipe and wellbore outside
cas	casing
cem	cement
tub	tubing
D	dimensionless
f	fluid
w	wellbore
i	inner pipe
o	outer pipe
e	earth
ei	a certain depth of earth
in	influence of radius

than 364,000 abandoned wells, average well depth is 3500 feet, even at least 18,000 abandoned wells are deeper than 3000 m where the prevailing bottom temperatures are in the range of 125–175 °C [2]. Additionally, there are serious pollution problems caused by abandoned wells which should be concerned, such as: contaminant hazards, exposure pathway-routes and biological receptors [19]. Therefore, if the AOGW can be retrofitted to geothermal system for extracting thermal energy, not only the environmental risk can be reduced effectively, but also the geothermal utilizations will become cheaper without high-cost drilling. Therefore, many researchers begin to study AOGW for heat extraction and power generation.

Kujawa et al. [20,21] are the pioneers for geothermal utilization of AOGW; based on their previous study on geothermal borehole heat exchanger (BHE) [22,23], they initially proposed a model introducing a double-pipe heat exchanger to retrofit AOGW for geothermal production. A coaxial wellbore heat exchanger (WHE) was proposed where heat carrier fluid circulates in a closed loop, no fluids are extracted from thermal reservoir and the working fluid doesn't touch directly with rocks, seen in Fig. 3. Thus, the groundwater recession, corrosion and scaling problems can be avoided effectively. Above all, they found that

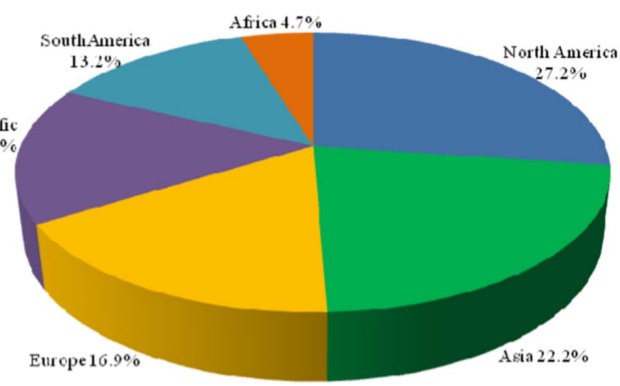

Fig. 2. Regional proportion of installed capacity in 2015 [3].

the flow rate of working fluid, inlet temperature and insulation depth of inner pipe had important influence on the heat extraction. It concluded that with flow rate 20 m^3/h, the heat extraction rate could reach 644 kW and the geothermal energy gained is 5430 MW h. The conclusions suggested the heat extraction from AOGW suitable for heating.

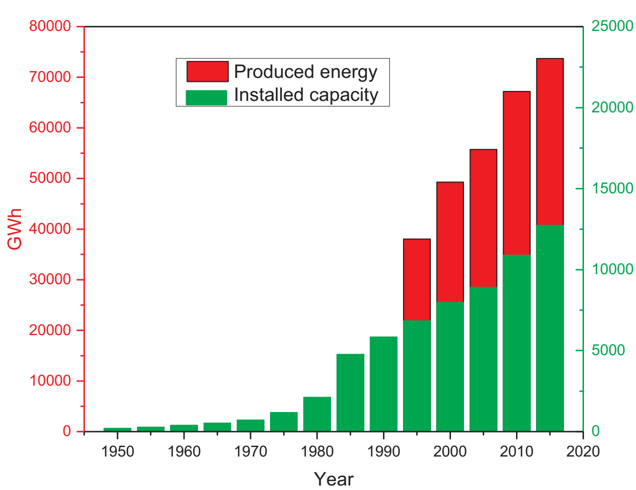

Fig. 1. World geothermal electricity from 1950 to 2015 [2,3,5].

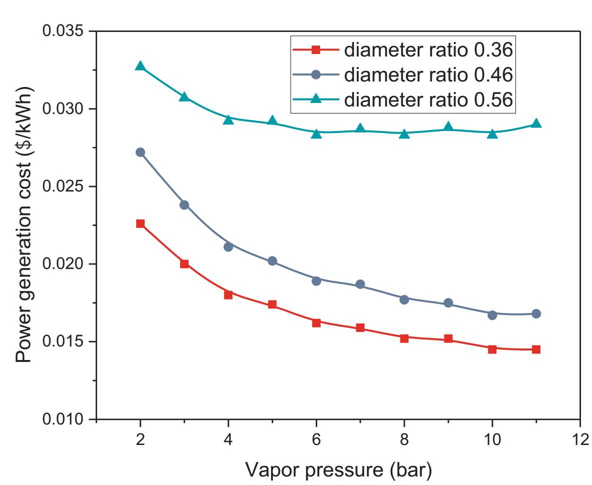

Fig. 3. Power generation cost using AOGW estimated by Mokhtari et al. [47].

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