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Enhancing geothermal power generation from abandoned oil wells with thermal reservoirs

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ABSTRACT

Using abandoned oil wells for geothermal power generation can relieve energy problem, save drilling cost, and govern the pollution caused by the residual oil of the abandoned oil wells. In this paper, a novel method for enhancing the geothermal utilization efficiency by developing thermal reservoirs is presented. A 2-D thermal reservoirs coupling with 1-D wellbore heat transfer model was set up to simulate geothermal energy production, and the effects of the thermal reservoirs on the geothermal production and electric power output were analyzed. The study results showed that the geothermal well with thermal reservoirs could produce about 4 times the heat and electric power output as that without thermal reservoirs. Moreover, the thermal reservoirs parameters would impact the heat production and power generation significantly. Especially, the heat production and electric power output increased with the thermal reservoirs depth and the fluid injection rate, however increased with the thermal reservoirs length firstly, and then decreased, which indicated that there was a maximal heat production and power generation at an optimal reservoir length. Simultaneously, the fluid loss in the thermal reservoirs increased with the thermal reservoirs depth and length as well as thermal reservoirs porosity.

1. Introduction

At present, the fossil energy has been dominating the energy structure of the world, causing many environmental problems. Simultaneously, as the depletion of fossil fuels such as coal, oil, natural gas, the energy problems are becoming more and more serious [1]. Therefore, developing new renewable and green energy tends to be imperative. Comparing with the conventional fossil energy, the advantages of the geothermal energy are large reserves, no pollutant discharge and renewable. Comparing with other renewable energy sources (ex. wind power, solar energy and so on), the advantages of the geothermal energy are stable properties and small covering area. Therefore, geothermal energy as a renewable energy source has extensive application prospect in the field of energy [2,3].

The hot dry rock with abundant geothermal energy was applied for power generation originally. Li et al. [4] mainly introduced the research process, and investigated the thermal energy which was used for power generation from the high temperature artificial hydraulic fracturing rock mass underground 3–10 km. Tomasz Kujawa et al. [5] presented a single well geothermal power generation system using water as working substance, and established a thermal transfer model between concentric tube heat exchanger and the stratum. However, the development of hot dry rock power generation seems to be limited by the expensive drilling cost.

On the other hand, it is estimated that there are about 20–30 million abandoned oil wells around the world, and the leak of the residue oil lead to serious pollution. Therefore, some researchers presented a kind of geothermal power generation method by utilizing the abandoned oil wells, which not only could save drilling cost but also could control the pollution [5–9]. Cheng et al. [9–11] established a single wellbore heat transfer model for an abandoned oil well with a depth of 6000 m using isobutene as working substance. The result showed that the outlet temperature of fluid gradually decreased with the system operating time and ultimately approached stability. And increasing the inlet injection rate could increase the total heat production but would lower the outlet temperature of the fluid. Bu et al. [6,12] also established a thermal transfer model between the well and the stratum, it concluded that the fluid flow rate and geothermal gradient were two main effect factors on the geothermal power generation. However, the above studies on geothermal power generation just investigated the wellbore heat transfer and the geothermal energy which was produced only from formation. In addition, due to the limited

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Nomenclature

Variables

A_c	cross sectional area, m^2
a	thermal transfer area, m^2
C	wetted perimeter, m
Cp	specific heat at constant pressure, J kg^{-1} K^{-1}
D_h	hydraulic diameter, m
g	gravity, m s^{-2}
h	convective thermal transfer coefficient, W m^{-2} K^{-1}
h_i	specific enthalpy,J kg^{-1}(i = 1,2,3,4)
k	permeability, Darcy
M	mass flow rate, kg s^{-1}
Nu	nusselt number
P	pressure, Pa
P_{Act}	actual generated power, W
P_{net}	net power, W
P_{pump}	pump power, W
Q	thermal power, W
t	time, s
T	temperature, K
T_0	the land surface temperature, K
ΔT	the geothermal gradient, K m^{-1}
u	velocity,m s^{-1}
z	the distance from the thermal reservoirs to the land surface, m

Greek letters

ρ	density, kg m^{-3}
ε	porosity
λ	thermal conductivity, W m^{-1} K^{-1}
μ	dynamic viscosity, N s m^{-2}
η_{co}	comprehensive efficiency of power generation
η_g	generator efficiency
η_m	mechanical efficiency of steam turbine
η_{pump}	pump efficiency
η_{ri}	relative internal efficiency of steam turbine

Subscript

Act	actual
co	comprehensive
g	generator
L	liquid
m	mechanical
ri	relative internal
S	solid

contact area between wellbore and stratum, the heat transfer between the working fluid and stratum is inadequate. On the other hand, with the increase of heat transfer radius, the temperature gradient in radial direction will be smaller and smaller. Therefore, the efficiency of geothermal power generation is lower actually.

Moreover, the studies on the effects of thermal reservoirs on abandoned oil wells geothermal power generation are missing. According to the research in the French Soultz field test site, an effective thermal reservoirs is of a complex network composed of many interconnected fractures. On this basis, some researchers studied the coupling problems for reservoirs heat transfer simulation, Taron et al. [13] built numerical model of the thermal reservoirs with the THMC (Thermal, Hydraulic, Mechanical and Chemical) by coupling flow and the other processes. Pandey et al. [14] analyzed the THMC using the software of FEHM (finite element heat and mass transfer), and mentioned that the alteration of aperture and evolution of overall permeability were directly controlled by the injection conditions such as mass flow rate, injection temperature and concentrations. However, the calculation time of these coupling numerical models was very long [15], and it brought very heavy burden to the computer.

In order to solve the above problems, this paper focused on the effects of thermal reservoirs and working fluid loss on geothermal power generation using abandoned oil wells. Therefore, an enhanced geothermal power generation system was presented by introducing thermal reservoirs. Comparing with the conventional geothermal power generation system, the presented system could expand heat extraction area effectively and increase the radial temperature gradient largely. On another hand, this paper analyzed the effects of some reservoir parameters on heat production and power generation by using a simplified simulation thermal reservoirs model [16–19]. The research results showed that the calculation time of the simplified model was greatly shortened and the simulation results agreed well with the experimental data. Moreover, because in the process of fluid flow in the rock fractures, a certain amount of fluid would permeate to the surrounding rock causing to working fluid loss which not only decreased the geothermal heat production, but also wasted the working fluid. However, the investigation of working fluid loss was neglected in the present studies. Therefore, this paper also considered the effect of working fluid loss in thermal reservoirs on the geothermal power generation system.

2. Basic principle

In the study of using abandoned oil wells for geothermal power generation, single well system is the main object. The cyclic working substance extracts geothermal energy from the stratum in the single well concentric tube heat exchanger. Concentric tube heat exchanger is composed of inner tube and outer tube. The inner tube is wrapped with a layer of thermal-protective coating and the outer pipe contacts closely with the formation. The working fluid downward flow to the thermal reservoirs and extract abundant geothermal energy after being injected into the outer tube relying on the heat conduction between formation and outer pipe and the heat convection between outer pipe and working fluid. Then the working fluid flows back to the wellhead through inner tube after flowing downward to the bottom of the abandoned oil well. Because the bottom of the inner pipe do not connect completely with the bottom of the abandoned oil well, therefore, the working fluid can flow into the inner tube smoothly. The heat loss in the inner tube is reduced due to the existence of the thermal-protective coating. Therefore, the outlet temperature is quite high. Finally the fluid that flows from the inner tube is injected in the outer tube again after transferring heat to the organic working fluid in the evaporator.

Studies showed that the thermal reservoirs are generally structured of modern volcanic intrusive granite and granodiorite of igneous rock. However, there is no thermal reservoirs exist in natural conditions. Therefore, it is need to use hydraulic fracturing method to form small coherent rock fractures which can be used as the thermal reservoirs and the main fluid heat exchange zone.