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The stratigraphic and operating parameters influence on economic analysis for enhanced geothermal double wells utilization system

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A B S T R A C T

As one of the renewable energy systems, the enhanced geothermal system (EGS) played an important role in relieving energy crisis as a supplement for the existing energy systems. The costs were a key factor restricting the practical application of an EGS project. Therefore, an economic analysis before the establishment of EGS is particularly important to conduct. The aim of this research is to discuss the influences of stratigraphic and operating parameters on the total net costs of geothermal system. In this article, a thermal transfer and economic analysis model was established and the operation of EGS in ten years was simulated. The effects of the parameters including well spacing, injection flow rate, geothermal gradient and drilling costs on total net costs were analyzed. Results showed that the well spacing was one of the most important factors affecting the total net costs. And the total net costs were the lowest in the well spacing around 200 m. During the system operation, there was an optimum injection flow rate which made total net system costs the lowest. The optimum injection flow rate was significantly affected by the well spacing. A higher geothermal gradient could also reduce the total net costs.

1. Introduction

With the rapid development of the global economy, the consumption of fossil energy continues increasing, and it not only brings the global energy crisis, but also causes serious environmental problems. Many states around the world are trying to relieve the energy crisis and environmental problems relying on renewable clean energy. In recent years, as a kind of renewable clean energy, the geothermal energy gradually became a supplement to the existing energy structure because of its advantages. For instance, geothermal energy has strong assets over other renewable energy due to its huge world-wide potential and its base-load capacity.

Geothermal energy is a huge natural thermal energy with abundant reserves, and the total amount of geothermal energy contained in the world is about 1.26 × 1027 J, equivalent to 4.6 × 10 16 tons of standard coal according to existing research data. China's Ministry of Land and Resources (MLR) recently released the official figures that the total geothermal resources distributed at depths 3–10 km were equivalent to 260,000 times the capacity of annual energy consumption of mainland China [1].

Hydraulic stimulation is the main mechanism used to create the subsurface heat exchanger in an Enhanced Geothermal System (EGS), and the costs of drilling and stimulating wells are very high [2]. It is estimated that the sub-surface activities ranging from well drilling to stimulation account for 60–80% of the costs of an EGS [3]. In low temperature areas, recent data for geothermal power production showed that the costs of energy were particularly high in the German low enthalpy region using binary cycle technology [4]. It can be seen that the drawbacks of geothermal energy extraction without economic benefits analysis are enormous. This will not only result in increased costs, but also cause the waste of resources. Therefore, it is particularly necessary to carry out the economic analysis before establishing the EGS.

At present, some researchers also discussed the economic analysis of EGS project. Ali Keçebaş et al. [5,6] optimized the insulation thickness of pipes used in district heating pipeline networks, energy savings over a lifetime of 10 years, and calculated the payback periods for five different pipe sizes and four different fuel types in the city of Afyonkarahisar/Turkey. Erdogmus Berkan et al. [7] evaluated the Balcova-Narlidere geothermal district heating system from an economic perspective by using internal rate of return method. Bing Wei et al. [8] analyzed and evaluated

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Nomenclature

Variables

a	thermal transfer area, m^2
A_c	cross sectional area, m^2
C	wetted perimeter, m
C_{ai}	annual investment cost payments, $
C_{ao}	annual operating costs, $
C_{ap}	annual profits, $
C_{atot}	annual total net costs, $
C_c	costs of system's components, $
C_d	costs of drilling well, $
$C_{d\&p}$	costs of design and prospecting, $
C_e	electricity costs, $
C_f	costs of initial operating fluid, $
C_{in}	total initial investment, $
C_{lr}	labor resources costs, $
C_m	maintenance costs, $
C_{sf}	supplement fluid costs, $
Cp	specific heat at constant pressure, $J \cdot kg^{-1} \cdot k^{-1}$
$CRF(i,n)$	capital recovery factor
C_{tot}	total net costs
D_h	hydraulic diameter, m
g	gravity, $m \cdot s^{-2}$
h	convective thermal transfer coefficient, $W \cdot m^{-2} \cdot k^{-1}$
H	depth of the well, m
i	annual compound interest rate
K	permeability, Darcy
n	lifetime of system, year
Nu	nusselt number
P	pressure, Pa
P_u	unit-price of the heat energy, $\$ \cdot kW^{-1} \cdot h^{-1}$
PW	present worth of the aggregate investment
$PWF(i,n)$	present worth factor
Q	thermal power, kW
S	spacing between wells, m
t	time, hour
T	temperature, k
T_0	land surface temperature, k
ΔT	geothermal gradient, $k \cdot m^{-1}$
u	velocity,$m \cdot s^{-1}$
z	thermal reservoir depth, m

Greek letters

σ	salvage value coefficient
ρ	density, $kg \cdot m^{-3}$
ε	porosity
λ	thermal conductivity, $W \cdot m^{-1} \cdot k^{-1}$
μ	dynamic viscosity, $N \cdot s \cdot m^{-2}$

Subscript

L	liquid
S	solid

seven district heating systems depending on the fuzzy comprehensive evaluation method and obtained the final goodness ranking of the heating systems. Claudiu Costea et al. [9] presented how the thermal efficiency depends by the temperature of the hot reservoir and the temperature of the cold reservoir. Muharrem Imal et al. [10] presented the energy efficiency evaluation and economic feasibility analysis for a geothermal heating and cooling system (GSHP) and a mechanical compression water chiller system (ACHP). And it was found that the geothermal heating and cooling system was more useful and productive for providing substantial economic benefits.

These researchers mainly focused on the influences of structural parameters and reservoir temperature on the energy and economy efficiency. However, the geothermal reservoir parameters and operating parameters might also have influences on the economic analysis of EGS project. There were a few researchers investigated that. Different geothermal reservoir conditions affect the total costs and the heat extraction of EGS project. It was necessary to investigate the economic efficiency while considering the influence of geothermal reservoir. Moreover, the operating parameters such as injection flow rate, geothermal gradient and well spacing also have important influence on the system costs and heat extraction. But there were little researchers discussed.

In this study, further research on the economic analysis was developed based on the results of other researchers. In order to calculate the changes of the total net costs for EGS circulating in ten years, an EGS thermal transfer and economic analysis model was proposed in the present work first. The method investigated the heat transfer process between solid rock matrix and fluid within the thermal reservoir. Further, the economic analysis during the operation of the enhanced geothermal utilization system was focused on. The influence of different stratigraphic and operating parameters such as injection flow rate, geothermal gradient, well spacing and drilling well costs on the economic analysis were focused on. The well spacing and injection flow rate optimization were also carried out for different EGS conditions.

2. Enhanced geothermal system model

According to the multi-cell system model that A.J. Jupe et al. [11] presented, it was composed of vast parallel and independent thermal reservoirs units which had the similar flow characteristics and thermal transfer characteristics. Jiang et al. [12] roughly estimated convective heat transfer coefficient and specific surface area of aperture network based on the parallel plate model, which geometrically approximated the complicated fracture network as equidistant parallel fractures. Then, Cheng et al. [13–17] analyzed the heat transfer process of a single fracture in the thermal reservoirs by adopting the simplified inerratic fracture network model and developed the EGS model. Fig. 1 showed the structure diagram of enhanced geothermal utilization system. In this enhanced geothermal utilization system, water was selected as the formation circulating fluid because of the characteristics of abundant, clean and low-costs. During the EGS operation, the cold fluid was injected into the thermal reservoir from the injection well. And the hot fluid would recover from the production well after exchanging heat fully with high temperature rocks in the thermal reservoir. Then, the heat energy contained in hot fluid was released in the evaporator for daily life utilization and industrial production utilization et al. After that, the fluid was re-injected to the injection well for obtaining geothermal energy.

The EGS model was consisted of wellbore heat transfer model and thermal reservoir heat transfer model. The heat transfer process between fluid and formation or thermal reservoir rocks in injection well, recovery well and thermal reservoir were considered respectively [18]. The heat insulation was adopted in the recovery