利用熱–水–力耦合模式進行斷層型乾熱岩地熱能源的數值模擬

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摘要

乾熱岩(hot dry rock)地熱能源是一種儲存在深部地層中，具有巨大發展潛力的可再生能源。然而，建立人工儲集層(artificial reservoir)是開採乾熱岩地熱過程中一項相當困難的技術。

本研究以位於中國西藏羊八井地熱區的斷層帶作為天然的地熱儲集層，提出了一套針對此類斷層型乾熱岩地熱的抽取方案。研究中建立了一個三維的熱–水–力耦合模型，用於模擬開採地熱能源時，溫度、水流和應力的分布情況。本研究設置了一口注水井及兩口生產井，第一生產井距離注水井較遠，早期的出水量較低，但溫度在模擬經過 22 年後仍保持在 445°C。產能雖然在初期較低，但隨時間增加，後期維持穩定；而第二生產井因為距離注水井較近，從模擬開始一百天左右就有水流產出，但溫度在經過 15 年後從 445°C 下降到 200°C 以下。因此產能雖然一開始高於第一生產井，但在模擬後期逐漸衰減。結果顯示，兩口生產井在不同時期的產能不同，可以達到互補的效果。經過 22 年的開採模擬，最後得出總地熱產能約為 13130 MWa，顯示這種地熱抽取方案是可行的。

關鍵字： 乾熱岩地熱能源、地熱儲集層、熱–水–力耦合

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ABSTRACT

Hot dry rock geothermal energy is a type of renewable energy with great development prospects in deep strata. However, it is quite difficult to construct an artificial reservoir. In this paper, deep large-dip-angle fault zone in the Yangbajing geothermal field in Tibet of China is used as a natural artificial reservoir, and a set of hot dry rock heat extraction schemes for such fault modes is proposed. A three-dimensional thermo-hydro-mechanical coupling model is established for the scheme to study the distributions of temperature, stress and seepage during the process of mining fault-mode hot dry rock geothermal energy. The temperature of #1 production well remains 445 °C after 22-year operation and it decreases from 445 °C to less than 200 °C after 15-year operation in #2 production well. The initial vertical stress near the injection well is 199 MPa, which decreases to 193 MPa after 1 year and remains unchanged. The specific water flow in the fault zone between the wells increases negatively and exponentially with the extraction time. The seepage resistance of the fault rock mass gradually decreases. The total effective heat production is 13130 MWa after 22-year operation.

1. Introduction

In 1970, a team of scientists led by Morton Smith at the Los Alamos National Laboratory in the United States proposed a new concept for the development of HDR (hot dry rock) geothermal energy. In 1984, the first HDR geothermal development experiment was conducted in the dormant volcano of Fenton Mountain in Los Alamos, USA, and a 1 MW power generation capacity was reached. Later, the Roseman owes volcanic area in Cornwell, England, the area of Hijiori in Japan, and the Soultz region in France all carried out small-scale development of geothermal heat via HDR energy, and the installed power capacity was only a few MW. The geothermal development of HDR has been proposed for nearly 50 years and has not yet reached large-scale industrial development [1]. What is the technical bottleneck? This is a problem that puzzles scientists all over the world.

Over the past two decades, based on the expansion of traditional hydrothermal geothermal energy, American scholars have proposed an enhanced geothermal development scheme: the EGS (enhanced geothermal system). The core premise of this scheme is to form vertical fractures by segmental fracturing through the construction of two horizontal wells, which allows for the two horizontal wells that are connected to form a huge artificial reservoir. The lower part of the horizontal well is filled with water, and the upper part of the horizontal well provides hot water to the surface for power generation. Because horizontal wells cannot be constructed in HDR formations above 250 °C, the EGS is limited to use in lower-temperature HDR formations. This limitation is the disadvantage of the EGS system, and other development techniques for large-scale use have not yet been proposed, representing the root cause of the long-term difficulty in the industrialization of HDR geothermal development.

In 2012, Zhao Yangsheng and Feng Zijun [2] proposed “The geothermal development of the HDR in fault mode” scheme and a specific implementation plan for the HDR geothermal field in Yangbajing, Tibet, China. The core of the scheme is to use the natural fault zone commonly found in the surrounding rock of HDR geothermal reservoirs for geothermal development, which is regarded as one of the most attractive new technical schemes for HDR geothermal development.

A large number of studies have been carried out around the world on HDR geothermal energy investigation and developmental experiments [3–12]. To explore various HDR geothermal development technologies and predict changes in the fields of temperature,

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