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Mini Review

Research Frontiers of Enhanced Geothermal System Thermal Reservoir Stimulation

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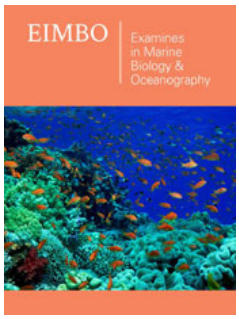

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Abstract

The Hot Dry Rock (HDR) geothermal has huge reserves, clean and environmental protection, and is widely recognized as a renewable energy source with great development potential. Hot Dry Rock contains little or no fluid and is usually developed using Enhanced Geothermal System (EGS) technology. The efficiency of geothermal energy extraction depends on the fracture-making capacity and heat transfer capacity of reservoir and is directly related to the fracture-network structure transformation of reservoir. At present, the reservoir modification mainly includes hydraulic fracturing, chemical stimulation and thermal stimulation. However, how to increase the heat exchange area, increase the heat extraction channel, and stabilize the extraction of geothermal energy are still the challenges of efficient geothermal exploitation.

Keywords: Enhanced geothermal system; HDR; Reservoir stimulation; Hydraulic fracturing

Abbreviations: HDR: Hot Dry Rock; EGS: Enhanced Geothermal System

Introduction

Geothermal energy, characterized by zero carbon emissions, clean and environmental protection, wide distribution and high heat storage, is regarded as a renewable energy source with great potential [1,2]. Deep HDR resources are abundant. It is estimated that the geothermal energy stored in hot dry rock at the depth of 3.0km~10.0km in Chinese mainland is equivalent to 860 trillion tons of standard coal [3], which has high development value and broad application prospects. However, the hot dry rock development project has just started. The HDR mass is compact and has minimal permeability, so it is difficult to effectively extract energy using the traditional direct geothermal extraction method. Therefore, it is necessary to establish an Enhanced Geothermal System (EGS), which is to transform the reservoir of the hot dry rock mass through hydraulic fracturing mainly to form large fractures and extract the geothermal energy in the hot dry rock through the circulation of heat carrying fluid [4]. The main methods of heat reservoir modification include hydraulic fracturing, chemical stimulation and thermal stimulation. EGS engineering projects mainly focus on hydraulic fracturing, assisted by chemical stimulation and thermal stimulation [5]. In the process of reservoir reconstruction, problems such as small scale of thermal reservoir, insufficient heat transfer network, serious fluid loss, and earthquake induced by hydraulic fracturing are prone to occur [6,7]. In order to solve the above problems, this paper focuses on the analysis of three ways of reservoir reconstruction and existing problems, and points out the content of future research, with a view to providing reference for thermal reservoir reconstruction.

Reservoir Stimulation Method

Hydraulic fracturing

There are few HDR development projects in the world, and most of the research focuses on the simulation of the formation environment in the laboratory and the experimental research

of hydraulic fracturing. At the same time, on the basis of actual investigation and theoretical hypothesis, numerical simulation is carried out. Zhou et al. [8] carried out the hydraulic fracturing test on rock samples in the laboratory, and the study showed that the fracture propagation of hydraulic fracturing was controlled by in-situ stress and natural fractures, while the injection amount had little influence. Wang et al. [4] established a fluid-solid coupling model of fracture propagation based on extended finite element method and found that the fracture initiation pressure decreased with the increase of fracturing fluid injection amount, while the fracture propagation length and width increased gradually. The fracture propagation length decreased with the increase of fracturing fluid viscosity, and the width increased with the increase of fracturing fluid viscosity. Chen et al. [9] established a three-dimensional intersected fracture model to simulate the flow and heat transfer. The study showed that the hydraulic fracture needed to form a large angle with the natural fracture to better extract geothermal energy. These conclusions still need to be verified by field development. At present, hydraulic fracturing still plays a leading role in hot dry rock development projects. By the end of 2021, there were 41 EGS projects in the world [7]. The most successful project is the soultz project in France, which has a megawatt generation capacity [10]. It should be noted that hydraulic fracturing is faced with a series of problems:

a) Hydraulic fracturing is difficult to control, and excessive reservoir reconstruction causes instability of reservoir and cap rock, which can directly induce earthquakes or activate faults to induce earthquakes

b) Uncontrolled crack propagation will lead to large-scale loss of injected heat transfer working medium

c) Due to the damage of the reservoir and cap layer and the diffusion/flow around the injected fluid, the geothermal energy attenuation is fast and the thermal extraction short-circuit problem occurs.

Therefore, the following aspects need to be paid attention to in the future: how to explore new reliable reservoir reconstruction technology based on the formation of large fractures by hydraulic fracturing, and the key to this technology is the formation of accurate communication channels, solving the problem of uncontrolled fractures and reducing water loss. It is also necessary to innovate the micro seismic monitoring methods to ensure timely understanding of rock strata movement and instability caused by fractures. Therefore, the theoretical studies involved mainly include but are not limited to fracture extension prediction and control technology, micro-seismic fracture real-time monitoring, mechanism of complex fracture conductivity, and mechanism of hydraulic fracturing induced fault slip [11].

Chemical stimulation

In the chemical stimulation method, chemical stimulants are injected into the fractures of the hot reservoir at an injection pressure lower than the formation fracturing pressure, and the plugging material in the fracture channel of the hot reservoir is dissolved by chemical dissolution to increase the permeability of the formation [12]. Chemical stimulation is often used as an auxiliary method in EGS engineering. Chemical stimulants are divided into acid chemical stimulants, such as mud acid, CO2, alkaline stimulants, such as NaOH, chelating alkali. In recent years, many researchers have conducted laboratory studies and numerical simulations on the transformation of thermal reservoirs by chemical stimulation. Guo et al. [5] carried out a chemical stimulation experiment on granite in Gonghe Basin of Qinghai Province and the study showed that mud acid had the best stimulation effect, and the dissolution effect was the best at a medium injection speed. Wang et al. [13] studied the influence of organic mud acid on the mechanical properties of granite, and the results showed that acetic acid could be used as organic weak acid to participate in reservoir excitation and strengthen corrosion. In the EGS project, Fenton Hill project in the United States uses alkaline chemical stimulant, which reacts with rocks to generate secondary minerals to block new fractures and reduce permeability, thus failing to achieve good transformation effects. The Soultz project in France used mud acidification chemical stimulants to enhance the hydraulic connectivity between Wells and improve the effect of reservoir reconstruction [12]. At present, the research and application of chemical stimulation method still need to be further discussed mainly:

A. The type and mechanism of chemical stimulation, and the recovery and emission reduction technology of the conversion to acidification chemical stimulation.

B. The influence of the combination of various chemical stimulants on the reservoir transformation.

C. Environmental pollution of rock strata and groundwater caused by chemical stimulation.

D. The source, dosage and cost of chemical stimulants.

E. The suitable conditions of chemical stimulants for geothermal reservoirs.

Heat stimulation

Thermal stimulation mainly takes advantage of the thermal fracture property of rock. The higher the temperature of the thermal reservoir rock mass, the greater the temperature difference between the reservoir rock mass and the fracturing fluid, the higher the thermal stress generated in the rock mass, and the thermal damage will occur in the rock mass, thus increasing the permeability of the rock [7,12]. Therefore, for the area with high thermal reservoir temperature, thermal stimulation can be used to carry out reservoir transformation. Feng et al. [14,15] carried out thermal cycling test on granite and found that the permeability of rock increased with the increase of the number of thermal cycles. At present, there are Northwest Geysers and Newberry projects in the United States and Reykjanes project in Iceland to apply thermal stimulation for reservoir reconstruction [7]. There are few reports on reservoir stimulation by hydraulic fracturing and chemical

stimulation combined with thermal stimulation up to now. In the future, we can pay attention to the combination of two or three reservoir stimulation methods to improve the effect of thermal reservoir transformation.

Conclusion and Prospect

The common ways of reservoir reconstruction and the existing problems are briefly described. In view of the reservoir reconstruction, there are still the following contents to be studied:

a) Research on hydraulic fracturing control technology, innovation and hydraulic fracturing to improve the reservoir fracture network reconstruction technology.

b) Research on the engineering earthquake mechanism and prevention and control technology caused by geothermal reservoir reconstruction.

c) Exploration of the solutions to avoid large-scale water loss in geothermal reservoirs.

d) Study on the effect of chemical stimulation and the environmental and economic problems caused by it.

e) Exploration on the influence of multiple reservoir stimulation methods on reservoir reconstruction.

f) Study on the basic scientific problems under various reservoir reconstruction technologies and methods, including rock mechanics problems, such as rock fracture, seepage mechanics behavior and law, etc.

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