

Study on Enhanced Geothermal System of Carbon Dioxide Fracturing Dry Hot Rock

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Abstract: As a renewable energy source, the effective way to mine dry-hot rock is to form dry-hot rock enhanced geothermal system (EGS). Enhanced geothermal system is the key technology to realize the development and utilization of dry-hot rock geothermal energy resources. Compared with the traditional enhanced geothermal system (water-EGS), the new enhanced geothermal system (CO₂-EGS), which uses carbon dioxide as the heat carrier has multiple advantages of energy saving, high efficiency and greenhouse gas emission reduction. CO₂ has a strong heat recovery capacity, and is unlikely to chemically react with the thermal reservoir, and the additional effect of geological storage can be obtained at the same time. This study reviews the evolution and practical applications of enhanced geothermal energy. By integrating insights from domestic and international research advancements, the feasibility and advantages of CO₂ as heat-carrying working medium are analyzed, and the problems to be optimized and solved are discussed.

Keywords: Enhanced geothermal system; carbon dioxide; dry hot rock; heat carrier.

1. Introduction

Dry-hot rock geothermal resources, recognized for their vast thermal energy reserves, have become a global research focus in sustainable energy development. Characterized by high energy density, low carbon emissions, and operational stability, these resources offer a competitive alternative to conventional fossil fuels. Optimizing subsurface thermal energy extraction can substantially reduce reliance on non-renewable resources, mitigate environmental impacts, and enhance national energy security.

To enhance the utilization of dry-hot rock geothermal energy, Brown first proposed to use supercritical CO₂ instead of conventional water-based fluids as heat-carrying fluid for the development of dry and hot rock geothermal resources^[1].

Integrating CO₂ utilization with geothermal resource exploitation plays a crucial role in advancing geothermal energy technology and facilitating CO₂ geological storage, positioning it as an emerging technique in the field^[2]. This paper investigates the current development and application of enhanced geothermal system, expounds the feasibility and advantages of using CO₂ as heat-carrying fluid, and summarizes the problems existing in the current development.

2. Traditional Enhanced Geothermal System

EGS is the main means of exploiting dry and hot rock resources at home and abroad, and it is a complex scientific system integrating physics, percolation and heat transfer. It involves the heat transfer effect of fluid and rock matrix, fluid percolation effect, rock thermoelastic effect and so on^[3].

In the traditional dry-hot rock enhanced geothermal system, cold water is often used as heat-carrying fluid to pour cold water into the artificial thermal reservoir, and then the heat is extracted through the production well and into the power generation device on the ground, so as to obtain electric energy^[4].

By drilling into the deep underground crystalline strata within the range of 3~10 km, hydraulic fracturing and other techniques are used to create a fracture system with high permeability in high temperature rock mass, that is, "artificial thermal reservoir space". Cold water is injected into the subsurface through an injection well, where it flows through a fracture heat exchange structure, absorbing geothermal heat. The heated fluid is then extracted via a production well and converted into steam or hot water for power generation. Afterward, the cooled water is pressurized and reintroduced into the underground system, ensuring continuous recycling of the working fluid.^[3]

At present, almost all EGS have attempted to use water as a heat-carrying fluid, however, water as a medium has several significant drawbacks, so a geothermal energy utilization method using CO₂ as a heat-carrying mass has been developed.

3. CO₂-EGS System

3.1. Advantages of supercritical CO₂ as a heat-carrying medium

Because of the non-polarity of its molecules, its chemical properties are relatively stable, and there is a great difference in thermophysical properties between supercritical CO₂ and water. In addition, other characteristics of supercritical CO₂ have been found at home and abroad, such as greater expansibility and compressibility, good transport properties, low viscosity at high temperature, low salt solubility and so on^[5].

3.2. The shortcomings of CO₂-EGS at present

Although the combined geothermal storage technology of CO₂ extraction and dry-hot rock geothermal storage offers advantages in several aspects, the integration of multiple sub-technologies inevitably introduces various practical challenges during implementation and operation.

3.2.1. Leakage of CO₂ in rock formations

Despite the obvious advantages of using CO₂ as a heat-carrying fluid instead of water, the problem of leakage to the surrounding formation is also unavoidable, except that the rate of leakage is lower than that of water, and the loss rate may be related to factors such as porosity, permeability, and water chemistry and mineralogy in specific locations of the reservoir in the EGS^[6]. For CO₂ leakage in the surrounding rock, it is necessary not only to improve the corresponding fracturing technology, but also to apply relatively effective physicochemical methods for sealing to ensure that the injected CO₂ fluid can both safely and effectively recover heat and achieve the added benefit of geological storage. Many issues such as the mechanism of CO₂ sequestration in dry thermal rocks and the geological conditions for sequestration still need to be further addressed and demonstrated.

3.2.2. Source and Purity of CO₂

Coal combustion and power generation is the largest CO₂ emitting industry, and the volume fraction of CO₂ in its exhaust gas can generally reach 10% to 15%, but it also contains numerous impurities, such as nitrogen, oxygen, sulfide and particles, which need to be separated and purified. Among the three components of carbon capture, transportation and storage, CO₂ capture is the most critical and consumes the highest cost, accounting for about 85% of the total cost. To capture high purity CO₂ from the tail gas of a typical coal-fired power plant, not only does it require a large amount of equipment and resources, but most importantly, it also requires the construction of a relatively large capture system.

Almost all projects involving CO₂ geological storage, oil and gas replacement and geothermal development use high purity CO₂ as the work fluid, which is particularly important to exploit its properties^[7]. By strictly limiting the concentration of impurities and moisture content in the CO₂ stream during capture and separation, it is also possible to fundamentally avoid or reduce the corrosion of the fluid in the transport pipeline, but at the same time increase the cost and associated energy consumption. The presence of impurities will cause changes in the critical temperature and pressure of CO₂, which may lead to more complex flow and thermodynamic processes, as well as increased operating stress and maintenance costs; impurities reduce the flow characteristics of CO₂ in the wellbore and reservoir at low temperatures, while the specific heat of impure CO₂ is relatively small in higher temperature production wellheads^[8].

From the point of view of investment and recovery, the whole system has high requirements for CO₂ capture, purification, collection and transportation and other processing technology. at the same time, it also needs to establish a comprehensive, systematic and efficient supervision and evaluation system, which will lead to large pre-investment and slow income in the development operation.

3.2.3. Effect of temperature and pressure on CO₂-EGS

The characteristics of CO₂ are significantly influenced by temperature and pressure, which play a crucial role in the heat extraction of CO₂-EGS. When the formation conditions are stable, the lower the CO₂ injection temperature, the higher the heat recovery rate. Conversely, higher CO₂ injection temperatures diminish its advantages as an endothermic fluid. Additionally, higher reservoir temperatures lead to a reduction in CO₂ viscosity, which facilitates the flow of CO₂

in fractures. The ability of CO₂ to compress allows it to reach elevated temperatures at the base of the injection well, particularly during the production phase. However, the temperature will also decrease as pressure decreases, primarily due to the larger expansion of CO₂. The reduction in pressure causes CO₂ to expand, and its larger expansion coefficient leads to a rapid drop in temperature along the production well^[9]. at the same time, heat exchange occurs with the surrounding formation along the rising process of the production well, resulting in the temperature of the production wellhead is not as high as the water. And the lower production temperature will not be able to meet the demand of power generation, which is one of the disadvantages of CO₂ as a heat-carrying fluid.

4. Summary

For the reason that its unique advantages, dry-rock geothermal resources are expected to become the key strategy in addressing the energy crisis in the future. As traditional energy sources continue to be exhausted, alternative sources like energy-efficient dry-rock geothermal energy are expected to gain increasing attention in the oil and gas sector. How to achieve the efficient development of dry-rock has become the focus of attention in the oil and gas industry at present.

The chemical and thermal / physical properties of CO₂ make it a more attractive choice for heat transfer media. Given the global prevalence of dry and hot rock geothermal resources all over the world, CO₂ is used to develop geothermal resources instead of fossil fuel combustion to alleviate global warming and obtain the additional benefit of geological storage of CO₂.

References

- [1] Brown D.W. A hot dry rock geothermal energy concept utilizing supercritical CO₂ instead of water. Twenty-fifth workshop on geothermal reservoir engineering Stanford. Stanford, California. January 24-26, 2000, p. 233-238.
- [2] Ning Wei, Xiaochun Li, Zhiming Fang, et al. Regional resource distribution of onshore carbon geological utilization in China. *Journal of CO₂ Utilization*. 2015, Vol. 11, p. 20-30.
- [3] Wei Zhang, Zhanqing Qu, Tiankui Guo, et al. Study of the enhanced geothermal system (EGS) heat mining from variably fractured hot dry rock under thermal stress. *Renewable energy*. 2019, Vol 143, p. 855-871.
- [4] Xianzhi Song, Yu Shi, Gensheng Li, et al. Numerical simulation of heat extraction performance in enhanced geothermal system with multilateral wells. *Applied Energy*. 2018, Vol. 218, p. 325-337.
- [5] Karsten Pruess. Enhanced geothermal systems (EGS) using CO₂ as working fluid—A novel approach for generating renewable energy with simultaneous sequestration of carbon. *Geothermics*. 2006, Vol. 35 (No. 4), p. 351-367.
- [6] Changlong Wang, Wenlong Cheng, Yongle Nian, et al. Simulation of heat extraction from CO₂-based enhanced geothermal systems considering CO₂ sequestration. *Energy*. 2018, Vol. 142, p. 157-167.
- [7] Tiankui Guo, Facheng Gong, Xiaozhi Wang, et al. Performance of enhanced geothermal system (EGS) in fractured geothermal reservoirs with CO₂ as working fluid. *Applied Thermal Engineering*. 2019, Vol. 152, p. 215-230.
- [8] Yang Song, Xiaomin Wu, Shan Hu, et al. Numerical Simulation of Heat Transfer and Sequestration of CO₂ in Hot-

Dry-Rock. Journal of Engineering Thermophysics. 2013, Vol. 34 (No. 10), p. 1902-1905.

[9] Songze Liu, Jianguang Wei, Yuanyuan Ma, et al. Research progress on application of supercritical carbon dioxide in geothermal exploitation. 2020, Vol. 49 (No. 6), p. 1537-1540.