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Research Progress of Sandstone Geothermal Reservoir Reinjection

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Abstract: With the deepening of the development and utilization of geothermal energy, the study of sandstone geothermal reservoir reinjection technology is particularly important. This paper systematically discusses the mechanism and influencing factors of sandstone geothermal reservoir reinjection, and makes an in-depth analysis on how to optimize the reinjection strategy and technical measures. Firstly, this paper expounds the basic principle of reinjection, including the fluid mechanics and thermodynamic behavior in the reinjection process. Then, the geological factors, reinjection parameters and other related factors that affect the reinjection effect are analyzed in detail, such as water quality and reinjection methods. On this basis, this paper proposes an optimization strategy for sandstone geothermal reservoir reinjection, including numerical simulation optimization and experimental research optimization methods of reinjection parameters, as well as chemical treatment methods and water quality optimization measures to prevent geothermal reservoir blockage. In addition, the strategies to improve the efficiency of reinjection are also discussed, such as improving the completion process and optimizing the surface process. Through the research of this paper, it aims to provide theoretical basis and practical guidance for the development of sandstone geothermal reservoir reinjection technology, so as to realize the efficient and sustainable development of geothermal resources.

Keywords: Sandstone geothermal reservoir; reinjection mechanism; influencing factors; optimization strategy.

1. Introduction

With the transformation of the global energy structure to clean and low-carbon, the development and utilization of geothermal energy, as a kind of renewable energy with abundant reserves, wide distribution and high stability, has been highly valued by all countries in the world. Among many types of geothermal reservoirs, sandstone geothermal reservoirs have become the main target horizons for the development of sedimentary basin-type geothermal systems due to their good porosity and permeability characteristics. However, with the continuous expansion of mining scale, the importance of sandstone geothermal reservoir reinjection technology has become increasingly prominent, which is mainly reflected in the following aspects.[1]

First of all, reinjection is a key means to maintain geothermal reservoir pressure. In the process of long-term exploitation, the extraction of a large amount of fluid will lead to the continuous decline of reservoir pressure, which will affect the production capacity and service life of geothermal wells. By recharging the geothermal tail water to the reservoir, it can effectively supplement the formation energy, maintain the pressure balance, and ensure the long-term stable operation of the geothermal field. Secondly, reinjection is an important measure to reduce the environmental impact of geothermal tail water. Geothermal tail water usually has the characteristics of high temperature, high salinity, and may contain harmful components. If it is directly discharged, it will cause thermal pollution and chemical pollution to surface water and soil ecosystems. Through the reinjection technology, the tail water is reinjected into the underground reservoir, which can realize the closed-loop utilization of geothermal fluid and minimize the impact on the environment. Finally, reinjection is the core link to realize the sustainable development of geothermal resources. As a renewable but non-infinite resource, the development of sandstone geothermal reservoirs must follow the sustainable concept of " taking heat without taking water. " Through the establishment of an efficient production and irrigation balance system, it can not only improve the utilization efficiency of geothermal reservoirs, but also promote the natural reinjection and heat regeneration of geothermal reservoirs.

Therefore, it is not only of great scientific value, but also of practical significance to promote the sustainable development of geothermal industry to systematically study the key issues such as reservoir response mechanism, blockage prevention and control methods, and optimization design theory in sandstone geothermal reservoir reinjection technology[2]. In the future, with the advancement of the ' double carbon ' target, sandstone geothermal reservoir reinjection technology will play a more important role in geothermal development[3].

2. Analysis of Reinjection Mechanism and Influencing Factors of Sandstone Geothermal Reservoir

2.1. Reinjection Mechanism

The geological characteristics of sandstone geothermal reservoir are one of the key factors affecting the reinjection effect. Sandstone geothermal reservoirs have specific porosity and permeability, which determine the migration and storage capacity of geothermal tail water in geothermal reservoirs. In the reinjection process, the fluid flow and heat transfer in the geothermal reservoir follow the basic principles of fluid mechanics and thermodynamics. There will be heat exchange and mass exchange between the reinjection water and the formation water in the geothermal reservoir, which will affect the temperature field and pressure field of the geothermal reservoir. Specifically, the pore structure and throat size distribution of the sandstone reservoir affect the flow resistance and permeability of the fluid. Permeability reflects the flow capacity of fluid in geothermal reservoirs,

while porosity determines the storage capacity of geothermal reservoirs. In the process of reinjection, the heat exchange between reinjection water and formation water is mainly realized by heat conduction and heat convection. Heat conduction is the heat transfer caused by temperature difference, while heat convection is the heat transfer caused by fluid flow. At the same time, the mass exchange between reinjection water and formation water will lead to changes in the chemical properties of formation water, which in turn affects the physical and chemical properties of geothermal reservoirs[4]. These changes will eventually affect the temperature field and pressure field of the geothermal reservoir, which will have an important impact on the development and utilization of geothermal resources.

2.2. Analysis of Influencing Factors

There are many factors affecting the reinjection of sandstone geothermal reservoir, including geological factors, reinjection parameters and other factors[5].

2.2.1. Geologic Factor

Geological factors such as porosity, permeability and chemical properties of formation water directly affect the infiltration and storage of reinjection water.

Porosity refers to the ratio of pore volume to total volume in rocks, which is directly related to the storage capacity of geothermal reservoirs. In sandstone geothermal reservoirs, higher porosity means more space to accommodate reinjection water. For example, when the porosity increases from 15 % to 25 %, the water storage capacity of the geothermal reservoir will be significantly improved in theory. The complexity of pore structure is also important. Different types of pores (such as primary pores and secondary pores) have different effects on fluid storage and migration. The primary pores are usually formed in the process of rock formation and have good connectivity. Secondary pores such as cracks, although the porosity may not be high, but it can provide efficient fluid channels, which is conducive to the rapid penetration of reinjection water. The heterogeneity of porosity is also a key factor affecting reinjection. In the actual sandstone geothermal reservoir, the porosity is often different in different locations. This heterogeneity will lead to the uneven distribution of reinjection water in the geothermal reservoir, which may form a dominant channel in the high porosity area, while the reinjection effect is poor in the low porosity area. Therefore, in the design of the reinjection scheme, it is necessary to carry out detailed exploration and evaluation of the porosity distribution of the geothermal reservoir to optimize the layout of the reinjection wells and the reinjection parameters.

Permeability is an index to measure the difficulty of fluid flow in rock, which is closely related to pore structure and throat size. In the sandstone geothermal reservoir reinjection, the high permeability of the geothermal reservoir is conducive to the rapid infiltration and diffusion of the reinjection water The change of permeability will also be affected by many factors. For example, the migration of particles in the formation may block the throat and reduce the permeability. In the reinjection process, if there are more suspended particles in the reinjection water, it may enter the geothermal reservoir with the water flow and block the pores and throats, resulting in a decrease in permeability. In addition, the chemical properties of formation water also affect the permeability. When the chemical composition of formation water changes, it may cause chemical reactions of rocks, such as dissolution or precipitation of calcite in carbonate geothermal reservoirs, thereby changing permeability. Therefore, in the process of reinjection, it is necessary to control the water quality of reinjection water to reduce the negative impact on permeability.

The chemical properties of formation water include its composition, pH (pH value), salinity, etc. These properties will affect the chemical reaction between reinjection and formation water. For example, when the pH value of formation water is low, it may react with bicarbonate ions in reinjection water to form carbon dioxide gas, which affects the flow and storage of reinjection water. At the same time, when the salinity of formation water is high, it may increase the seepage resistance of reinjection and reduce the reinjection efficiency. The chemical properties of formation water also affect the stability of geothermal reservoirs. For example, in some sandstone geothermal reservoirs, the high content of dissolved solids in formation water may lead to chemical corrosion or precipitation of rocks. This chemical action may change the pore structure and permeability of the geothermal reservoir, which in turn affects the reinjection effect. Therefore, it is necessary to analyze the chemical properties of formation water in detail during the reinjection of sandstone geothermal reservoir, and select the appropriate reinjection treatment method according to the analysis results to reduce the adverse effects of chemical reaction on the reinjection process.

2.2.2. Reinjection Parameter

The reinjection parameters such as reinjection volume, reinjection temperature have a significant effect on the temperature field of the geothermal reservoir and the thermal breakthrough time of the production well.

Reinjection volume refers to the amount of water reinjected to the geothermal reservoir per unit time. The amount of reinjection directly affects the pressure recovery and temperature field change of the geothermal reservoir. An appropriate amount of reinjection can effectively maintain the pressure of the geothermal reservoir and prevent environmental problems such as land subsidence. For example, in the development of some geothermal fields, by reasonably controlling the amount of reinjection, the pressure of the geothermal reservoir can be kept stable and the exploitation life of geothermal resources can be prolonged. However, if the amount of reinjection is too large, it may lead to excessive pressure in the geothermal reservoir, which may lead to some adverse geological phenomena, such as the generation and expansion of cracks. In addition, the excessive amount of reinjection may cause the flow rate of reinjection in the geothermal reservoir to be too fast, resulting in a decrease in the permeability of the local area, and may even cause the collapse of the geothermal reservoir. Therefore, when determining the reinjection amount, it is necessary to comprehensively consider the geological conditions, exploitation amount and environmental requirements of the geothermal reservoir, and optimize it by means of numerical simulation and experimental research[6].

Reinjection temperature refers to the temperature of reinjection. The difference between the temperature of the reinjection water and the formation temperature will affect the temperature field distribution of the geothermal reservoir. When the re-irrigation temperature is lower than the formation temperature, the re-irrigation will absorb heat after entering the geothermal reservoir, resulting in a decrease in the temperature of the geothermal reservoir. This temperature

change may affect the efficiency of geothermal resource exploitation, because the outlet water temperature of the mining well may be reduced. On the other hand, the reinjection temperature also affects the physical and chemical properties of the geothermal reservoir. Temperature changes may cause thermal expansion or contraction of rocks, thereby changing pore structure and permeability. In addition, the temperature difference may also affect the chemical reaction rate of formation water. For example, when some chemical reactions in formation water are sensitive to temperature, the change of reinjection temperature may change the chemical properties of formation water, which in turn affects the stability of geothermal reservoirs. Therefore, in the process of reinjection, it is necessary to reasonably control the temperature of reinjection according to the geological conditions and mining requirements of the geothermal reservoir to achieve the best reinjection effect.

2.2.3. Other Factor

Other factors such as reinjection water quality and reinjection methods will also affect the reinjection effect.

Reinjection water quality refers to the chemical and physical properties of reinjection water. The suspended particles, dissolved solids, microorganisms and other components in the reinjection water will affect the reinjection effect. For example, suspended particles in reinjection water may block the pores and throats of geothermal reservoirs and reduce permeability. When the content of suspended particles in the reinjection water is high, a blocking layer may be formed at the entrance of the geothermal reservoir, which hinders the entry of the reinjection water. The dissolved solid components in the reinjection water also affect the chemical stability of the geothermal reservoir. For example, high-salinity reinjection water may react chemically with formation water, leading to the dissolution or precipitation of rocks. In addition, microorganisms in the reinjection water may propagate in the geothermal reservoir, forming biofilms that clog pores and throats. Therefore, during the reinjection of sandstone geothermal reservoirs, the reinjection water needs to be treated to ensure that its water quality meets the reinjection requirements. The commonly used treatment methods include filtration, precipitation, chemical treatment, etc., to remove harmful components such as suspended particles, dissolved solids, and microorganisms in the reinjection water.

Reinjection method refers to the way of reinjection water into the geothermal reservoir. The common reinjection methods include direct reinjection and indirect reinjection. Direct reinjection refers to the direct injection of reinjection water into the geothermal reservoir. The advantages of this method are simple operation and high reinjection efficiency. However, direct reinjection may lead to a more intense chemical reaction between reinjection water and formation water, resulting in problems such as blockage of geothermal reservoirs. Indirect reinjection refers to the injection of reinjection water into geothermal reservoirs through some intermediate media or treatment processes. For example, the reinjection water can be first injected into a pretreatment layer, and the harmful components in the reinjection water can be removed through the filtration and chemical reaction of the pretreatment layer, and then the treated water is injected into the geothermal reservoir. Indirect reinjection can reduce the adverse effects of reinjection on geothermal reservoirs, but may increase the complexity and cost of the reinjection system. Therefore, when selecting the reinjection method, it is necessary to comprehensively consider the geological conditions of the geothermal reservoir, the nature of the reinjection water and the economic cost to select the most suitable reinjection method.

3. Optimization Strategy and Technical Measures of Sandstone Geothermal Reservoir Reinjection

The improvement of reinjection efficiency of sandstone geothermal reservoir is of great significance for the sustainable development of geothermal resources. In this paper, the specific strategies and technical means to improve the reinjection efficiency of sandstone geothermal reservoir are discussed in detail from three aspects : reinjection parameter optimization, blockage prevention measures and process improvement.

3.1. Reinjection Parameter Optimization Method

3.1.1. Numerical Simulation Optimization

A numerical model of sandstone geothermal reservoir is established. Considering the geological structure, fluid flow and heat transfer of geothermal reservoir, the reinjection process under different working conditions is simulated by changing the reinjection parameters, and the change of reinjection efficiency is analyzed. Numerical simulation can provide detailed information such as temperature field, pressure field and fluid flow distribution, and provide scientific basis for parameter optimization. For example, the finite element method is used to establish the multi-field coupling numerical model of the geothermal reservoir[7]. By changing the parameters such as reinjection volume, reinjection temperature and well spacing, the response of the geothermal reservoir in the reinjection process is simulated, and the parameter combination is optimized to achieve the best reinjection efficiency[8].

3.1.2. Experimental Research Optimization

The physical simulation experiment was carried out by simulating the reinjection process of sandstone geothermal reservoir in the laboratory[9]. In the experiment, the reinjection parameters can be accurately controlled, the migration and storage of reinjection in the geothermal reservoir can be observed, and the reinjection efficiency can be measured. Experimental research can provide verification data for numerical simulation, and can also find some phenomena and laws that may be ignored in numerical simulation. For example, the sand tank model is used to simulate the reinjection process of sandstone geothermal reservoirs[10]. By changing the reinjection amount and reinjection temperature, the reinjection efficiency under different working conditions is measured, which provides a reference for the optimization of actual reinjection parameters.

3.2. Technical Measures to Prevent Blockage

3.2.1. Chemical Treatment Method

The suspended particles in the reinjection water are one of the main reasons for the blockage of the geothermal reservoir. These suspended particles may enter the pores and throats of the geothermal reservoir during the reinjection process, forming a blocking layer and hindering the flow of reinjection water. Chemical treatment methods, such as adding flocculants, can make suspended particles aggregate into larger particles, which can be easily removed by filtration and

other methods. For example, in the process of reinjection water treatment, an appropriate amount of polyacrylamide flocculant is added to make the suspended particles in the water aggregate into larger flocs, and then removed by filtration equipment such as sand filtration, which effectively reduces the suspended matter content in the reinjection water and reduces the risk of geothermal reservoir blockage.

The presence of iron ions in the reinjection water may also cause geothermal reservoir blockage. Iron ions may undergo oxidation reactions in geothermal reservoirs to form insoluble iron oxides, blocking pores and throats. Through chemical treatment methods, such as the addition of iron ion chelating agents, stable complexes can be formed with iron ions to prevent the oxidative precipitation of iron ions. For example, adding an appropriate amount of ethylenediaminetetraacetic acid disodium (EDTA) as an iron ion chelating agent in the reinjection water can effectively remove iron ions in the water, reduce the formation of iron oxides, and reduce the possibility of geothermal reservoir blockage.

3.2.2. Water Quality Optimization Measure

A perfect water quality monitoring system for reinjection water is established to monitor the chemical composition, suspended solids content, iron ion concentration and other indicators of reinjection water in real time. According to the monitoring results, the water quality treatment process is adjusted in time to ensure that the quality of the reinjection water meets the requirements. For example, by installing an online water quality analyzer, the suspended solids content and iron ion concentration of reinjection water are monitored in real time. When the monitoring value exceeds the set threshold, the corresponding treatment equipment, such as a filter or iron ion removal device, is automatically started to ensure that the reinjection water quality meets the standard.

The necessary pretreatment is performed before the reinjection water enters the geothermal reservoir. Pretreatment methods include precipitation, filtration, chemical treatment, etc. removing the large particle suspended matter in the reinjection water through the sedimentation tank ; sand filter, activated carbon filter and other filtration equipment were used to remove fine suspended particles. Harmful ions in water, such as iron ions and calcium ions, are removed by chemical treatment. For example, in a sandstone geothermal reservoir reinjection project, the pretreatment system composed of sedimentation tank, sand filter and ion exchange resin filter is used to treat the reinjection water, which effectively improves the quality of the reinjection water and reduces the occurrence of geothermal reservoir blockage.

3.3. Strategies to Improve the Efficiency of Reinjection

Reasonable design of wellbore structure, selection of appropriate well diameter, well depth and completion method can reduce the energy loss in the reinjection process and improve the reinjection efficiency. For example, the use of large diameter wellbore can reduce the flow resistance of reinjection in the wellbore and increase the amount of reinjection. Choosing a suitable completion method, such as screen completion or gravel filling completion, can effectively prevent the formation sand from entering the wellbore and reduce the possibility of wellbore blockage. Strictly control the construction quality of the wellbore to ensure the sealing and stability of the wellbore[11].

4. Conclusion and Foresight

The sandstone geothermal reservoir reinjection technology has important application value in geothermal energy development. Through theoretical analysis, experimental research and numerical simulation, the influencing factors and laws of sandstone thermal reservoir reinjection have been deeply understood. However, there are still some problems that need to be further studied, such as the effect of reinjection under complex geological conditions and the effect of long-term reinjection on geothermal reservoirs. Future research should strengthen multidisciplinary cooperation and develop more advanced reinjection technologies and optimization strategies to achieve efficient and sustainable development of sandstone geothermal reservoir reinjection.

References

[1] Yixin Z ,Song D ,Dingkun L , et al. Influencing parameters of recharge efficiency and well types optimization in middle-deep sandstone geothermal reservoir [J]. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2023, 45 (4): 10144-10161.

[2] Yujuan S ,Fengtian Y ,Bing W , et al. Reinjection of cooled water into sandstone geothermal reservoirs in China: a review [J]. Geosciences Journal, 2018, 22 (1): 199-207.

[3] Ungemach P . Reinjection of cooled geothermal brines into sandstone reservoirs [J]. Geothermics, 2003, 32 (4-6): 743-761.

[4] Qun D,Cong W,Yang L, et al. Research on Sandstone Geothermal Reservoir Reinjection Plugging Mechanism and Measures Against It [J] Advances in Fine Petrochemicals, 2017, 18 (06): 10-13.

[5] Yanyan H,Jin N,Hongwu L. Numerical SimulationI Study of Chemical Clogging of Sandstone Pore Thermal Reservoirs Resevoir BackfillA in Kaifeng Area [J] Acta Energiae Solaris Sinica, 2024, 45 (02): 225-235.

[6] Jialong L ,Fengxin K ,Tong B , et al. Geo-temperature response to reinjection in sandstone geothermal reservoirs [J]. Geothermal Energy, 2023, 11 (1):

[7] Zhao W ,Liu L ,Li J , et al. Reinjection modeling in sandstone geothermal reservoirs: A case study of Dezhou geothermal heating demonstration project [J]. Natural Gas Industry B, 2024, 11 (1): 106-120.

[8] Chao Y ,Yiqun Z ,Yawen T , et al. Simulation study of novel methods for water reinjection efficiency improvement of a doublet system in guantao sandstone geothermal reservoir [J]. Geothermics, 2023, 111

[9] Yanlong G ,Yishuo X ,Huajun W , et al. Experimental investigation of water-rock reaction for the reinjection of sandstone geothermal reservoirs: A case from Neogene Guantao Formation in Tianjin [J]. Renewable Energy, 2023, 210 203-214.

[10] Xia J ,Tian H ,Dou B , et al. Experimental study on optimizing tailwater reinjection technology for weakly consolidated sandstone geothermal reservoirs [J]. Fuel, 2024, 378 132826-132826.

[11] Yixin Z ,Song D ,Dingkun L , et al. Influencing parameters of recharge efficiency and well types optimization in middle-deep sandstone geothermal reservoir [J]. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 2023, 45 (4): 10144-10161.