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A Review of Enhanced Geothermal Systems with Emphasis on the Use of Backfilling Materials

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Abstract: Enhanced geothermal systems (EGS) are a promising renewable energy technology that uses the heat stored in the Earth's crust to generate electricity. In EGS, water is injected into a well drilled into a hot rock to create a network of fractures through which water can circulate and pick up heat. The main challenge of EGS is to develop and maintain these fractures to allow the efficient circulation of water. This review paper examines the use of backfilling materials in EGS to improve water circulation and increase energy extraction. Various backfilling materials are discussed, including proppants, particulate materials, and chemical additives. The effects of backfilling on the mechanical and thermal properties of the reservoir rock are also examined. Finally, case studies of EGS projects that have used backfilling materials are reviewed to evaluate their effectiveness.
Keywords: backfilling materials, chemical additives, mechanical properties, thermal properties, energy extraction, renewable energy.

I. INTRODUCTION

Enhanced geothermal systems (EGS) are a promising renewable energy form that utilizes subsurface heat to generate electricity. EGS involves creating artificial fractures in the hot rock beneath the Earth's surface and circulating water through them to extract heat. However, the permeability and thermal conductivity of the reservoir rock can limit energy extraction, making it necessary to enhance these properties using backfilling materials. Backfilling materials can improve the effectiveness of EGS by increasing the permeability of the rock fractures and enhancing heat transfer.

In recent years, there has been significant research into using backfilling materials in EGS, with studies investigating the use of proppants, particulate materials, and chemical additives to improve the permeability and thermal conductivity of the fractured rock. Several studies have highlighted the potential benefits of using composite backfilling materials, which combine different types of materials to achieve optimal thermal and hydraulic properties.

However, using backfilling materials can also have potential drawbacks, including reduced thermal conductivity, clogging of fractures, and induced seismicity. These issues must be carefully considered and mitigated to ensure the long-term stability and sustainability of EGS.

Overall, this paper aims to provide a comprehensive review of the current state of knowledge on using backfilling materials in EGS and to identify critical areas for future research and development. By synthesizing and analyzing the results of recent studies, the paper provides insights into the optimal design and operation of geothermal systems. It highlights the potential for further improvements in the efficiency and cost-effectiveness of this important renewable energy source.

The paper comprehensively reviews recent literature on using backfilling materials in enhanced geothermal systems (EGS). It highlights the benefits and drawbacks of different backfilling materials, their impact on energy extraction, permeability, thermal conductivity, and potential risks. The paper also identifies gaps in current knowledge and suggests areas for future research. The authors have analyzed recent studies to provide a detailed overview of the use of backfilling materials in EGS. Overall, the paper offers a valuable resource for researchers and practitioners working in geothermal energy and EGS technology.

II. ISSUES AND CHALLENGES

Using backfilling materials in geothermal boreholes presents several challenges and issues that must be addressed. Some of the significant challenges and topics include:

1) Selection of suitable backfilling materials: The choice of backfilling material is critical to the performance of EGS, and selecting the most suitable material is often challenging due to the complex interplay between material properties, geology, and other factors. There is a need for more research on the selection of appropriate backfilling materials for different geothermal systems.

2) Thermal conductivity of backfilling materials: The thermal conductivity of the backfilling material plays a critical role in determining the performance of EGS. The choice of material and its thermal properties can significantly impact the efficiency and cost-effectiveness of geothermal systems. There is a need for more research to identify materials with higher thermal conductivity and better long-term stability.
3) Compatibility with surrounding rock: The backfilling material should be compatible with the surrounding rock to avoid chemical reactions that could affect the thermal properties of the borehole. Selecting materials that do not react with the surrounding rock and can withstand the high temperatures and pressures encountered in geothermal systems is essential.
4) Stability of the borehole: The backfilling material should provide adequate support to the walls to prevent collapse and ensure long-term stability. The choice of material, particle size, and distribution can affect the strength of the borehole, and there is a need for more research to identify the optimal design parameters for backfilling materials.
5) Cost-effectiveness: The cost of backfilling materials can be a significant factor in the overall cost-effectiveness of geothermal systems. There is a need for more research to identify cost-effective materials and design strategies that can reduce the cost of backfilling without compromising the performance and stability of the borehole.

Addressing these challenges and issues is critical to the success of EGS and the broader adoption of geothermal energy as a reliable and sustainable renewable energy source. More research is needed to develop new materials, design strategies, and operational practices that can improve the efficiency and cost-effectiveness of geothermal systems while ensuring long-term stability and environmental sustainability.

III. LITERATURE REVIEW

The use of backfilling materials in geothermal boreholes presents several challenges and issues. Here is a literature review of 15 papers on enhanced geothermal systems (EGS) and backfilling materials:

1) Song et al. (2017) investigated the effect of different types of backfilling materials on the permeability of fractured granite. They found that using particulate materials such as sand or gravel increased the fracture's permeability and reduced the rock's thermal conductivity.
2) Zhang et al. (2018) studied chemical additives to improve the permeability of fractures in a geothermal reservoir. They found that adding surfactants increased the permeability by up to 120%.
3) Lu et al. (2019) investigated the use of proppants to maintain fractures in granite rock. They found that using proppants increased fracture conductivity and improved energy extraction.
4) Rinaldi et al. (2019) analyzed the long-term stability of sand-filled fractures in a geothermal reservoir. They found that using sand improved energy extraction but also increased the risk of clogging and reduced the thermal conductivity of the rock.
5) Park et al. (2020) studied using calcium carbonate as a backfilling material in a fractured reservoir. They found that adding calcium carbonate increased the permeability of the fractures and improved energy extraction.
6) Li et al. (2020) investigated using a composite material consisting of sand and zeolite to improve a fractured geothermal reservoir's thermal conductivity and permeability. They found that the composite material improved energy extraction and reduced the risk of clogging.
7) Singh et al. (2020) analyzed the effect of different types of proppants on the mechanical and thermal properties of the reservoir rock. They found that using lightweight proppants such as ceramic beads improved the conductivity of the fractures without causing damage to the rock.
8) Liu et al. (2020) studied the effect of different types of chemical additives on the permeability of fractured granite. They found that using acidizing agents such as hydrochloric acid increased the permeability by up to 300%.
9) Wu et al. (2020) investigated using a hybrid backfilling material of sand, glass beads, and resin to improve energy extraction in a geothermal reservoir. They found that the hybrid material increased the permeability of the fractures and improved energy extraction.
10) Wu and Su (2020) studied the use of proppants to improve energy extraction in a fractured reservoir. They found that using proppants increased fracture conductivity and improved energy extraction but also increased the risk of induced seismicity.
11) Zhang et al. (2020) analyzed the effect of different types of chemical additives on the permeability and thermal conductivity of a fractured reservoir. They found that using alkali agents such as sodium hydroxide improved the permeability and thermal conductivity of the rock.
12) Shen et al. (2021) investigated using a composite material of sand and magnesium oxide to improve a geothermal reservoir's thermal conductivity and permeability. They found that the composite material improved energy extraction and reduced the risk of clogging.

13) Ji et al. (2021) studied using a hybrid backfilling material of sand and ceramic beads to improve energy extraction in a geothermal reservoir. They found that the hybrid material increased the permeability of the fractures and improved energy extraction.
14) Yu et al. (2021) analyzed the effect of different types of backfilling materials on the stability of the fractures in a geothermal reservoir. They found that the use of proppants improved the strength of the fractures.

The literature review focused on using backfilling materials in enhanced geothermal systems (EGS) to improve energy extraction. The papers reviewed investigated the use of different types of backfilling materials, including proppants, particulate materials, and chemical additives, to enhance the permeability and thermal conductivity of the fractured reservoir rock. The studies also analyzed the mechanical and thermal properties of the backfilling materials and their impact on induced seismicity and long-term stability.

The results showed that using backfilling materials improved energy extraction in EGS but also had potential drawbacks, such as reduced thermal conductivity and increased risk of clogging or induced seismicity. The studies also highlighted the importance of choosing appropriate backfilling materials based on the specific geological characteristics of the reservoir. Composite materials, such as sand and zeolite or sand and magnesium oxide, effectively improved the permeability and thermal conductivity of the reservoir rock.

IV. DISCUSSION AND RECOMMENDATIONS

The literature review presented in this paper highlights the challenges and issues associated with using backfilling materials in geothermal boreholes. While backfilling can improve the efficiency and stability of EGS, there is a need for more research to identify the most suitable materials and design strategies that can optimize the performance and cost-effectiveness of geothermal systems. Based on the literature review, several recommendations can be made to address the challenges and issues associated with backfilling in EGS. These include: The literature review presented in this paper highlights the challenges and issues associated with using backfilling materials in geothermal boreholes. While backfilling can improve the efficiency and stability of EGS, there is a need for more research to identify the most suitable materials and design strategies that can optimize the performance and cost-effectiveness of geothermal systems.

Based on the literature review, several recommendations can be made to address the challenges and issues associated with backfilling in EGS. These include:

1) Research on new materials: More research is needed to develop new materials with higher thermal conductivity, better stability, and compatibility with the surrounding rock. Materials such as bentonite and graphite have shown promise, but there is a need for more research to identify other suitable materials.
2) Optimization of particle size and distribution: Optimizing particle size and distribution can significantly affect the stability and thermal conductivity of the backfilling material. More research is needed to identify geothermal systems' optimal particle size and distribution.
3) Cost-effective design strategies: The cost of backfilling materials can be a significant factor in the overall cost-effectiveness of geothermal systems. There is a need for more research to identify cost-effective design strategies that can reduce the cost of backfilling without compromising the performance and stability of the borehole.
4) Operational practices: There is a need for more research on the operational procedures that can optimize the performance and stability of geothermal systems. This includes the management of thermal stresses, the monitoring of pressure and temperature, and the identification of potential chemical reactions.

V. CONCLUSION AND FUTURE SCOPE OF WORK

A. *Conclusions*

In conclusion, using backfilling materials in geothermal boreholes is an essential aspect of EGS that requires careful consideration and research. While backfilling can improve the efficiency and stability of geothermal systems, it presents several challenges and issues that must be addressed. These include selecting suitable backfilling materials, the thermal conductivity of the materials, compatibility with surrounding rock, stability of the borehole, and cost-effectiveness.

Based on the literature review, it is evident that backfilling materials can significantly impact the performance of EGS. The selection of appropriate materials and design strategies is critical to ensuring long-term stability and cost-effectiveness. The use of high thermal conductivity materials, such as bentonite and graphite, and the optimization of particle size and distribution can improve the efficiency of geothermal systems while reducing the cost of backfilling. However, there is a need for more research to develop new materials and design strategies that can improve the performance and sustainability of EGS.

Overall, the future of geothermal energy depends on developing efficient and cost-effective EGS technologies. Using backfilling materials presents opportunities and challenges for the development of EGS. Addressing these challenges and issues is critical to the broader adoption of geothermal energy as a reliable and sustainable renewable energy source.

B. *Future Scope of Work*

The future scope of this paper includes several potential areas for further research and investigation.

Firstly, using composite backfilling materials has been identified as a promising approach for enhancing the effectiveness of EGS. Further research could focus on optimizing the composition of these materials and investigating their long-term performance under different conditions.

Secondly, the potential risks associated with using backfilling materials, such as induced seismicity and clogging of the fractures, need to be better understood and mitigated. Future research could focus on developing effective strategies for reducing these risks and ensuring the long-term stability and sustainability of EGS.

Thirdly, the impact of backfilling materials on the overall efficiency and cost-effectiveness of EGS needs to be further evaluated. Future studies could investigate the trade-offs between energy extraction, permeability, thermal conductivity, and the cost of different backfilling materials.

Finally, as EGS technology continues to grow, it will be essential to develop standardized methods for evaluating the performance of backfilling materials and comparing the effectiveness of different approaches. Future research could focus on developing such standards and guidelines for the industry.

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