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TRIBOLOGY OF DRILL BITS IN THE GEOTHERMAL INDUSTRY: A LITERATURE REVIEW

TRIBOLOGÍA DE LAS BROCAS DE PERFORACIÓN EN LA INDUSTRIA GEOTÉRMICA: UNA REVISIÓN BIBLIOGRÁFICA

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Abstract

Energy from the earth's heat is critical to the energy supply of countries with this resource. This literature review highlights the tribology applied to drill bits in the geothermal industry. Facing a diverse geological environment, drill bits are critical to energy efficiency, with significant friction, wear and lubrication challenges. This paper addresses the complexity of drill bit interaction with diverse geothermal formations, highlighting the importance of understanding tribological phenomena. Advances in materials and coatings, such as composites, heat-resistant alloys and ceramic coatings, are explored, along with innovative geometric design strategies. Attention on lubrication, cooling and continuous monitoring systems highlights the quest for efficiency and extended drill bit life. This review provides a comprehensive overview of advances in bit tribological research in the geothermal industry, identifying emerging trends and critical challenges for the sustainable development of this form of renewable energy.

Keywords: Geothermal energy, Tribology, Drill bits, Friction, Wear, Lubrication.

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Resumen

La energía del calor de la tierra es fundamental para el abastecimiento energético de países con este recurso. Esta revisión bibliográfica destaca la tribología aplicada a las brocas en la industria geotérmica. Enfrentándose a un entorno geológico diverso, las brocas son fundamentales para la obtención eficiente de energía, con desafíos significativos de fricción, desgaste y lubricación. Este trabajo aborda la complejidad de la interacción de las brocas con diversas formaciones geotérmicas, resaltando la importancia de comprender los fenómenos tribológicos. Se exploran avances en materiales y revestimientos, como compuestos, aleaciones resistentes al calor y revestimientos cerámicos, junto con estrategias innovadoras de diseño geométrico. La atención en sistemas de lubricación, enfriamiento y monitoreo continuo destaca la búsqueda de eficiencia y vida útil prolongada de las brocas. Esta revisión ofrece una visión integral de los avances en la investigación tribológica de las brocas en la industria geotérmica, identificando tendencias emergentes y desafíos críticos para el desarrollo sostenible de esta forma de energía renovable.

Palabras clave: Energía geotérmica, Tribología, Brocas, Fricción, Desgaste, Lubricación

Resumo

A energia proveniente do calor da terra é essencial para o suprimento de energia dos países com esse recurso. Esta revisão da literatura destaca a tribologia aplicada às brocas de perfuração no setor geotérmico. Diante de um ambiente geológico diversificado, as brocas de perfuração são essenciais para a eficiência energética, com desafios significativos de atrito, desgaste e lubrificação. Este documento aborda a complexidade da interação da broca de perfuração com diversas formações geotérmicas, destacando a importância de compreender os fenômenos tribológicos. Os avanços em materiais e revestimentos, como compósitos, ligas resistentes ao calor e revestimentos de cerâmica, são explorados, juntamente com estratégias inovadoras de projeto geométrico. A atenção dada aos sistemas de lubrificação, resfriamento e monitoramento contínuo destaca a busca pela eficiência e pelo aumento da vida útil da broca. Esta análise oferece uma visão geral abrangente dos avanços na pesquisa tribológica de brocas no setor geotérmico, identificando tendências emergentes e desafios críticos para o desenvolvimento sustentável dessa forma de energia renovável.

Palavras-chave: Energia geotérmica, Tribologia, Brocas de perfuração, Atrito, Desgaste, Lubrificação

1. Introduction

The energy transition requires new energy sources (de Souza Alves, Ana Carolina, et al., 2023) (Negrão, Ana Beatriz Gomes Rodrigues, et al., 2023) (Silva, W. K., et al., 2023).

Geothermal energy is a promising energy resource (Lund, John W., and Aniko N. Toth., 2021) (Lebbihiat, Nacer, et al., 2021). In this context, the drilling of geothermal wells emerges as an important phase of character, with drill bits being the key players in the exploration and exploitation of this renewable resource (Harris, B. E., M. F., 2021) (Vivas, Cesar, et al., 2020). Facing a diverse and challenging geological environment, drill bits play an integral role in efficiently obtaining geothermal energy, but not without facing considerable challenges associated with friction, wear and lubrication (Cardoe, Jennifer, et al., 2021) (Imaizumi, Hiroyuki, et al., 2019).

This literature review focuses on tribology as applied to drill bits in the geothermal industry, with the objective of providing a comprehensive overview of the most significant and current developments in this field of study. A search of the scientific literature reveals several research that address the specific challenges and complexities inherent in the interaction of drill bits with varied geothermal formations.

Contextualizing the tribological challenges begins with the geological diversity characteristic of geothermal reservoirs. From resistant basalts to more porous sediments, drill bits face changing conditions that require a thorough understanding of the tribological phenomena involved (Mosleh, Mohsen, et al., 2017) (Maslov, A. L., et al., 2017). In addition, the variability in the composition and hardness of geological formations creates a scenario where friction and wear become crucial challenges, directly affecting bit efficiency and life (Wu, Xianzhu, et al., 2020).

Analysis of advances in materials and coatings reveals a trend toward increasingly sophisticated and adaptive solutions (Reddy, R. Hari Nath, et al., 2021) (Ropyak, L. Ya, T. O. Pryhorovska, and K. H. Levchuk., 2020). Research on composite materials, heat-resistant alloys and ceramic coatings are at the forefront of improving the wear resistance of drill bits, while nanotechnology has emerged as a promising tool for refining tribological properties (Piri, Mostafa, et al., 2020) (Cheraghian, G. Goshtasp, and Masoud Afrand., 2021).

The section of geometric design and adaptability deals with innovative strategies for coping with changing geothermal conditions. The application of computational modeling techniques and adaptive response systems offers a dynamic approach to optimize drill bit geometry in real time, thus maximizing its efficiency in different geological contexts.

The review will also explore advanced lubrication and cooling strategies, highlighting the importance of maintaining controlled temperatures and providing effective lubrication to minimize friction and extend bit life. In addition, continuous monitoring systems, which enable real-time data collection to facilitate predictive maintenance and optimize operational efficiency, will be addressed.

This review seeks to provide a comprehensive overview of advances in the tribological study of drill bits in the geothermal industry, identifying emerging trends, critical challenges and future directions for research in this field vital to the sustainable development of geothermal energy.

2. Geothermal Drilling

Geothermal drilling, despite its standing as a promising technology for clean and sustainable energy generation, is confronted with substantial challenges (Capuano Jr, L. E., 2016) (Imaizumi, Hiroyuki, et al., 2019) . In this context, drilling tools play an important role in overcoming these obstacles. Operating in a complex and variable geological environment, drill bits are tasked with cutting through various rock and sediment layers to access underlying geothermal resources (Meier, Thierry., 2017) (Rossi, Edoardo., 2020).

The inherent intricacies of geothermal drilling are rooted in the geological heterogeneity of subsurface formations (Hill, Jenna Emilie., 2022). Consequently, drill bits encounter the need to navigate through a diverse spectrum of materials, ranging from igneous rocks like basalt to sediments characterized by more delicate attributes (AyalaCarcedo, Francisco Javier., 2017 (Knez, Dariusz, and Mitra Khalilidermani., 2021). Each classification of formation introduces specific challenges for drill bits, given the considerable variations in properties such as hardness, abrasiveness, and cohesion. Adapting to these dynamic conditions represents a pivotal challenge in the realm of geothermal drilling (Khalilidermani, Mitra, and Dariusz Knez., 2022) (Amiri, Ardalan., 2016) (Liu, Jianxun, et al., 2019).

Wear and friction pose ongoing challenges for geothermal drilling bits (Boakye, Gifty Oppong, et al., 2021) (Ren, Haitao, et al., 2013). The constant engagement with rock formations results in the generation of heat and wear on the components of the drill bit (Majeed, Y., M. Z. Abu Bakar, and I. A. Butt., 2020) (Gunawan, Fatah, et al., 2018). This not only diminishes the cutting efficiency of the bit but also shortens its operational lifespan. The imperative to develop materials and coatings resistant to wear becomes evident, rendering research in tribology a very important field for enhancing both the durability and efficiency of drilling bits (Sadeghi, Behzad, et al., 2023) (Rouf, Saquib, et al.) (Philip, Jibin T., et al., 2020) (Melentiev, Ruslan, Nan Yu, and Gilles Lubineau., 2021).

Consequently, the selection of drilling locations poses a strategic challenge in geothermal drilling (Purba, Dorman P., et al., 2019) (Purba, Dorman, et al., 2020). The variability in subsurface temperature, depth, and geological composition has a direct impact on the efficiency and profitability of geothermal projects (Jolie, Egbert, et al., 2021) (Akar, Sertac, and Katherine R. Young., 2015) (Hackstein, Fynn V., and Reinhard Madlener., 2021). Drill bits must accommodate these dynamic conditions, and insufficient information regarding subsurface geology can result in suboptimal decisions (Ma, Tianshou, Ping Chen, and Jian Zhao., 2016) (Pastusek, Paul, et al., 2019). The integration of advanced exploration technologies and precise geothermal models is essential to address these challenges and optimize the selection of drill sites (Epelle, Emmanuel I., and Dimitrios I. Gerogiorgis., 2020) (Kabeyi, Moses Jeremiah Barasa., 2019) (Jiménez, Kelly, et al., 2022).

In certain instances, geothermal drilling encompasses activities in challenging environments, such as volcanic zones or areas characterized by unique geothermal attributes (Breede, Katrin, Khatia Dzebisashvili, and Gioia Falcone., 2015) (Reinsch, Thomas, et al., 2017). Unfavorable conditions, including elevated temperatures and the existence of corrosive fluids, present supplementary challenges for drill bits (Katiyar, Prvan Kumar., 2020) (Hossain, M. Enamul, and Muhammad Rafiqul Islam., 2018). Attributes like heat and corrosion resistance emerge as essential requirements, and the advancement of technologies and materials capable of enduring these extreme conditions becomes imperative for the successful execution of geothermal operations in such environments (Casini, Marco., 2016) (Unuofin, John Onolame, Samuel Ayodele Iwarere, and Michael Olawale Daramola., 2023).

3. Tribological Aspects of Geothermal Well Drilling. 3.3

The drilling of geothermal wells, as a renewable and sustainable energy source, poses a distinctive array of challenges, with one of the most crucial being the tribological challenge (Raina, Neelu, et al., 2020) (Nakashima, Y., et al., 2023). Tribology, encompassing the study of friction, wear, and lubrication in interacting systems, becomes a vital discipline when examining the interaction of drill bits with subsurface geothermal formations (Boakye, Gifty Oppong, et al., 2021) (Taleghani, Arash Dahi, and Milad Ahmadi., 2020). This tribological challenge not only affects drilling efficiency but also exerts a direct impact on tool lifespan, thereby influencing the economic viability of geothermal projects (Gabdrakhmanova, K. F., G. R. Izmaylova, and P. A. Larin., 2018) (Purba, Dorman, et al., 2022).

Friction represents an important and pivotal facet of the tribological challenge in geothermal drilling [55,56] (Yasukawa, Kasumi., 2021) (Roy, Ting, et al., 2023). Excessive friction can lead to heightened temperatures in the cutting zone, detrimentally impacting drilling efficiency and accelerating premature wear of the drill bit (Lan, Pixiang, and Andreas A. Polycarpou., 2018) (Shankar, Vijay Kumar, et al., 2020). Consequently, prioritizing friction control becomes imperative to optimize bit performance and guarantee efficient and cost-effective drilling processes (Mosleh, Mohsen, et al., 2019).

Effective lubrication is paramount for mitigating friction and minimizing wear in geothermal drilling bits (Lan, Pixiang, et al., 2020) (Zhou, Shan-shan, et al., 2021). The selection of drilling fluids with sufficient lubricating properties is essential for ensuring optimal performance in demanding geological conditions (Saffari, H. R. M., et al., 2018) (Dougherty, Patrick SM, Randyka Pudjoprawoto, and C. Fred Higgs III., 2014) (Zhong, Lin, et al., 2022). Moreover, lubrication not only impacts cutting efficiency but also plays a key role in influencing the cooling capacity of drill bits. This, in turn, helps maintain controlled temperatures during the drilling process (Perçin, M. U. S. T. A. F. A., et al., 2016).

Technological advancements play a vital role in addressing tribological challenges in geothermal drilling (Teseleanu, Giorgio., 2006). Computational modeling techniques enable the simulation and prediction of the tribological behavior of drill bits in diverse geological scenarios, facilitating more efficient and adaptive design processes (Rahman, Md Hafizur, Sadat Shahriar, and Pradeep L. Menezes., 2023) (Krama, Abdelbasset, et al., 2021). Furthermore, ongoing research in advanced materials, including ceramic composites and nanomaterials, aims to enhance the wear resistance and tribological efficiency of drill bits (Loginov, P. A., et al., 2019) (Xu, Jinyang, et al., 2020).

The integration of real-time monitoring systems serves as another critical tool in managing tribological challenges (Hassan, Mahmoud, et al., 2018). Sensors embedded in drill bits provide continuous data on temperatures, cutting forces, and other tribological variables during drilling operations (Pai, Raghuvir, Gopinath Chattopadhyay, and Gour Karmakar., 2023). This real-time information empowers operators to adjust drilling conditions and implement preventive interventions, optimizing performance and extending the operational lifespan of the drill bit (Lu, Ping, et al., 2021).

4. Advances in Materials and Coatings

Advancements in materials and coatings for geothermal drill bits represent a focal point of rigorous research, motivated by the imperative to surmount tribological challenges and enhance drilling efficiency within intricate and variable geological settings (Canbaz, Celal Hakan, et al., 2021) (Li, Chenglong, et al., 2018). These innovations assume a pivotal role in optimizing the performance of drill bits and prolonging their operational lifespan. Consequently, they contribute significantly to the viability and profitability of geothermal projects (Yi, Peng, et al., 2018) (Su, Jiann, et al., 2017). The following sections delve into some of the most notable developments in this domain.

The utilization of composite materials has emerged in enhancing the tribological properties of geothermal drill bits (Luo, Xun, et al., 2022) (Zhou, Shan-shan, et al., 2023). Combining materials such as carbon fiber-reinforced polymers or carbon nanotubes has demonstrated superior wear resistance and increased durability compared to conventional materials (Du, Jinguang, et al., 2019) (Rao, Yermal Shriraj, et al., 2019). These composites offer a distinctive blend of lightweight characteristics and strength, proving advantageous in geothermal applications where efficiency and robustness are paramount (Kumar, Jogendra, Rajesh Kumar Verma, and Kishore Debnath., 2020) (Nagaraj, Arjun, et al., 2022).

Another noteworthy advancement involves the deployment of advanced coatings to shield drill bits.

Polycrystalline diamond coatings (PDC) have proven to be an effective solution for enhancing wear resistance (Tong, Colin, and Colin Tong., 2019) (Zhang, Wenping., 2023) (Ratov, Boranbay, et al., 2023). The incorporation of diamond particles on the cutting surface of drill bits imparts exceptional hardness, resulting in heightened cutting efficiency and increased durability in challenging geothermal environments (Gelfgat, Mikhail Yakovlevich, and Aleksandr Sergeevich Geraskin., 2021) (Gelfgat, Mikhail Yakovlevich, and Aleksandr Sergeevich Geraskin., 2021) (Pastusek, Paul E., et al., 2023) (Hussain, Athar, Hossein Emadi, and Kodjo Botchway., 2021).

Furthermore, the application of tungsten carbide in coatings has proven valuable for abrasion protection (Fanicchia, Francesco, and Sigrún Nanna Karlsdottir., 2023) (Buzaianu, Aurelian, et al., 2019) (Kruszewski, Michal, and Volker Wittig., 2018). This ceramic material exhibits exceptional wear resistance and can be applied as a coating on critical areas of drill bits (Ndeda, Rehema, et al., 2022) (Shaikh, Nahid, et al., 2019) (Zheng, Lei, et al., 2018) (Gao, Chao, Guorong Wu, and Sheng Wang., 2017) (Sharma, Ankit, et al., 2022).

5. Geometric Design and Adaptability for Tribological Optimization of Geothermal Drill Bits.

Geometric design and adaptability play crucial roles in addressing tribological challenges and optimizing efficiency in geothermal drill bits for resource exploration (Su, Jiann-Cherng, et al., 2021) (Sugiura, Junichi, et al., 2021). These elements are instrumental in navigating the diverse geological formations found in the subsurface, ranging from igneous rocks to sediments, and dynamically adjusting to changing conditions in real-time (Xin, Liu, et al., 2023).

The geometric design of geothermal drilling bits encompasses the configuration and shape of the cutting elements in the bit head (Marbun, B. T. H., et al., 2021). Over time, traditional bit geometry has evolved to better accommodate geological complexities, becoming increasingly dynamic and adjustable (Burak, Tunç., 2018). An efficient geometric design not only facilitates penetration into various rock formations but also minimizes friction and wear, thereby enhancing the overall efficiency of the drilling process (Jamali, Shahin, et al., 2019).

Adaptability in geometric design is necessary to cope with variable geothermal conditions. Geological formations can change abruptly, from hard rock to softer layers, and bits must adjust to ensure efficient drilling (Marbun, B. T. H., et al., 2021). Advances in computational modeling and simulation technologies allow engineers to predict subsurface conditions and dynamically adjust bit geometry in real time (Hutchinson, Mark, et al., 2018). This adaptive approach results in increased cutting efficiency and a significant reduction in bit wear.

A prime example of adaptive geometric design is drilling bits with active response systems (Ivanov, Ilya, Ivan Pleshcheev, and Andrey Larkin., 2018). These systems use sensors and actuators to monitor drilling conditions and automatically adjust bit geometry in response to changes in the geological formation (Kamel, Mahmoud A., et al., 2018). This real-time adaptive capability not only improves drilling efficiency, but also contributes to longer bit life by minimizing unnecessary wear (Daireaux, Benoit, et al., 2021).

In addition, research has focused on developing variable geometries along the length of the bit, allowing it to adapt to specific geothermal conditions at different depths (Feito, N., et al., 2018). For example, in drill bit sections where higher wear is anticipated due to the presence of more abrasive rocks, specific geometries can be designed to optimize wear resistance and maintain efficient performance throughout the entire operation (Bailey, Michael James, et al., 2020) (Fan, Haipeng, et al., 2023).

The application of advanced computational modeling and simulation techniques has revolutionized the way geothermal drill bit geometry is designed and optimized (Wayo, Dennis Delali Kwesi, et al., 2023). The ability to predict geological conditions and dynamically adjust the geometric design has enabled significant improvement in bit efficiency and durability, leading to optimized performance in geothermal operations (Ivanov, Ilya I., and Sergey A. Voronov., 2018).

6. Lubrication and Cooling Drilling Bit

In the geothermal environment, characterized by a diversity of geological formations, high temperatures and changing conditions, friction and heat generated during drilling can be significant (Zhou, Shan-shan, et al., 2023). Effective application of lubricants and cooling systems becomes an essential strategy to overcome tribological challenges and ensure efficient and sustainable drilling (Lan, Pixiang, et al., 2020) (Gou, Ruyi, et al., 2023).

Friction, a resistive force that opposes relative motion between two surfaces in contact, is a central concern in geothermal drilling (Liu, Fengbao, et al., 2023). Excessive friction can not only negatively affect the cutting efficiency of drill bits, but also contributes to premature wear of components, thus reducing tool life. This is where tribological lubrication comes into play (Yang, J., et al., 2022) (Ikram, Rabia, Badrul Mohamed Jan, and Jana Vejpravova, 2021) (Rashidi, Masoud, et al., 2021).

Lubrication is primarily aimed at reducing friction and wear between drill bits and geological formations (Zeynalov, Tofig., 2018). The choice of the right lubricant is crucial and must be tailored to the specific geothermal drilling conditions (Abdo, Jamil, and Muhammad Danish Haneef., 2022). The drilling fluids used must have effective lubricating properties, providing a protective layer between drill bits and rock formations to minimize friction and facilitate smooth movement of tools through the subsurface (Fattnes, Lene., 2020) (Rashidi, Masoud, et al., 2021).

The application of advanced technologies in lubrication and cooling has led to significant improvements in geothermal drilling efficiency (Cheng, Liping, et al., 2022). Research into new drilling fluids with improved tribological properties, such as wear resistance and cooling capacity, has been a key area of development (Zhang, Zheng, Youming Xiong, and Fang Guo., 2018). Nanotechnology has also played an important role in providing more advanced lubricants and additives that can operate effectively in extreme geothermal conditions (Li, Ying, et al., 2021) (Zhu, Wenxi, Bingjie Wang, and Xiuhua Zheng., 2023) (Fattnes, Lene., 2020).

In addition, the implementation of continuous monitoring systems has become essential to optimize lubrication and cooling in real time (Mohamed, Abdelmjeed, Saeed Salehi, and Ramadan Ahmed., 2021) (Shirangi, Mehrdad G., et al., 2020). Sensors integrated into the drill bits allow the collection of data on temperature, pressure and cutting efficiency during operation (Liu, Naipeng, et al., 2021). This real-time information allows dynamic adjustments to the lubrication and cooling systems, ensuring optimal conditions at all times and facilitating predictive maintenance (Agwu, Okorie E., et al., 2018) (Taugbøl, Knut, et al., 2021).

7. Conclusions

Drill bit tribology in the geothermal industry is a critical and dynamic area of research, necessary to optimize drilling efficiency and ensure the sustainability of geothermal projects.

The geological diversity of subsurface formations and changing environmental conditions present considerable challenges in terms of friction, wear and lubrication. Proper material selection, adaptive geometric design and the application of effective lubricants are key elements in overcoming these challenges.

The development of advanced materials, such as polycrystalline diamond coatings (PDC) and ceramic composites, has shown promise in improving wear resistance.

In terms of tribological lubrication and cooling, the effective application of drilling fluids with suitable properties has proven essential in minimizing friction, dissipating heat and maintaining controlled temperatures.

This literature review highlights the continuing need for research and development in the field of geothermal drill bit tribology. The integration of technological advances and multidisciplinary approaches will be critical to overcome present and future challenges, thus contributing to the long-term growth and viability of geothermal energy as an essential source of renewable energy.

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