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Geological and Environmental Implications of Enhanced Oil Recovery Techniques: Balancing Efficiency with Sustainability

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Abstract:

This research paper explores the geological and environmental impacts of enhanced oil recovery (EOR) technology, focusing on the balance between efficiency and sustainability in fossil fuel extraction. EOR methods, including thermal recovery, gas injection, and chemical flooding, are critical to maximizing reservoir recovery, especially as global energy demand increases and conventional reserves decline. However, the manipulation of subsurface reservoirs poses significant geological risks, including changes in pore pressure, potential contamination of freshwater aquifers, and impacts on reservoir dynamics and geological stability. Concurrently, the environmental challenges associated with EOR, such as groundwater contamination and geomechanical instability, necessitate careful management and monitoring. The document emphasizes the need to incorporate sustainable practices into EOR operations, such as carbon dioxide injection for recovery and storage, optimization of water use, and the implementation of comprehensive environmental impact assessments. Ultimately, the results suggest a multifaceted approach to EOR that prioritizes energy production and environmental management to ensure a more stable and sustainable energy future.

Keywords: Enhanced Oil Recovery (EOR) techniques and their Importance, Geological and Environmental Implications of (EOR), Assessments of (EOR) techniques. Reservoir Dynamics and Geological stability, Sustainable Practices in EOR.

Introduction:

The interplay between geological processes and environmental sustainability has become increasingly crucial in the context of fossil fuel extraction. With the pressing global need for energy, Enhanced Oil Recovery (EOR) techniques have emerged as significant methods to maximize oil extraction efficiency. However, this drive for higher productivity raises concerns regarding the potential environmental impacts associated with these techniques, which vary widely across different geological formations. The systematic exploration of EOR strategies reveals a complex landscape wherein geological characteristics influence not only recovery efficiency but also the long-term environmental consequences. Factors such as subsurface pressure changes, chemical interactions, and resource depletion necessitate a thorough examination. Thus, understanding these dynamics is essential for balancing the immediate demand for energy against the imperatives of sustainability, ensuring that future energy strategies honor both geological integrity and environmental management. The following sections explore these topics in more depth, setting the stage for a nuanced discussion of the implications of EOR.

Overview of Enhanced Oil Recovery (EOR) Techniques and Their Importance

Among the various techniques developed to optimize hydrocarbon recovery, enhanced oil recovery (EOR) techniques play a key role in maximizing oil recovery from reservoirs beyond conventional methods. These techniques, such as thermal recovery, gas injection, and chemical flooding, are critical to improving sweep efficiency and mobilizing additional oil trapped in rock formations. As global energy demand escalates and conventional reserves decrease, EOR becomes increasingly important for maintaining energy security (Iglauer et al., 2024). Additionally, the integration of sustainable practices in EOR operations addresses environmental concerns associated with fossil fuel extraction. By reducing waste and improving fluid management, EOR can actively contribute to the life cycle of oil production and limit its ecological footprint. As technological developments continue to improve these technologies, it is critical to assess their geological and environmental impacts to strike a balance between the economic feasibility and sustainability of energy production (Asim et al., 2024).

Geological Implications of Enhanced Oil Recovery

The implementation of enhanced oil recovery (EOR) technologies has significant geological implications that must be carefully considered in the context of sustainability. When EOR processes manipulate underground reservoirs to extract more oil, they fundamentally alter geological formations and groundwater flow dynamics. This manipulation can lead to shifts in pore pressure and potential fracturing of rock strata which, if inadequately managed, can result in unintended fluid migration and contamination of freshwater aquifers. Furthermore, the proliferation of CO₂ capture and storage (CCS) within EOR frameworks promises both improved recovery rates and reduced environmental impact. By integrating hydrogeological analysis, stakeholders can more effectively predict and manage thermal performance in CO₂ storage projects, similar to similar technologies used in geothermal energy (Atherton et al., 2014). This integrated approach can ensure that EOR not only improves production, but also protects against geological risks associated with changes in the subsurface environment (Iglauer et al., 2024).

Impact of EOR on Reservoir Dynamics and Geological Stability

Enhanced Oil Recovery (EOR) techniques significantly influence reservoir dynamics and geological stability, necessitating a thorough examination of their implications. The injection of substances such as water, gas, or chemical agents can alter pressure and saturation levels within a reservoir, potentially leading to unintended consequences like subsidence or fault reactivation. These changes are particularly significant in formations with complex geological structures, where tectonic stability may be compromised (Ali et al., 2023). In addition, the increase in production rates, as evidenced by the rapid increase in well drilling in unconventional play areas such as the Bakken, underscores the urgent need for responsible management of produced water and flowback water to reduce environmental impacts, which are often associated with high salinity and other contaminants (Tomomewo et al., 2021). After all, the balance between these dynamic changes and geological integrity is critical to maintain oil production and long-term ecological health and emphasizes the needs of the EOR implementation of innovative methods.

Environmental Implications of Enhanced Oil Recovery

Enhanced Oil Recovery (EOR) techniques, while boosting hydrocarbon extraction efficiency, pose significant environmental challenges that must be carefully managed. The injection of gases or chemicals into reservoirs can inadvertently alter the subsurface pressure and fluid dynamics, potentially leading to geomechanical instability within geological formations. For example, Project Salah showed that pore pressures can increase significantly, causing surface uplift and potentially threatening surrounding ecosystems and infrastructure (Asim et al. 2024). Additionally, if not properly controlled, EOR practices can lead to groundwater contamination because the injection of solvents or surfactants can migrate outside the intended injection zone. The long-term storage of carbon dioxide in conjunction with EOR also necessitates rigorous monitoring to prevent leakage, reflecting the intricate balance between maximizing oil recovery and ensuring environmental integrity. Ultimately, addressing these implications is crucial for advancing sustainable energy practices that align with global climate objectives.

Assessment of EOR Techniques on Ecosystems and Water Resources

The application of enhanced oil recovery (EOR) technologies poses two challenges that require careful study of their environmental impact. While these methods can significantly increase the efficiency of oil recovery, they often pose significant risks to surrounding ecosystems and water resources. For example, the introduction of chemicals and fluids used in EOR can lead to contamination of surface and groundwater systems. This pollution not only harms aquatic organisms, but also poses long-term risks to human health while destroying local biodiversity. Moreover, the spatial dynamics involved in seafloor characterization through advanced methods such as hyperspectral imaging (HSI) illustrate the intricate interplay between anthropogenic activities and marine environments (Gardner et al., 2011). A comprehensive understanding of EOR's impact on ecosystems and water resources is thus essential to find a balance between energy production and environmental management (University of Texas Marine Science Institute, 2014). Further research is needed to develop strategies to mitigate these negative effects while maintaining operational effectiveness.

Conclusion

The search for improved oil extraction technologies demonstrates the urgent need to reconcile energy needs with environmental management. As the industry faces increasing scrutiny of its ecological footprint, particularly with regard to geothermal technologies and their applications in the energy sector, sustainable practices must be prioritized (Atherton et al., 2014). Furthermore, the impact of global unconventional natural gas production cannot be ignored, as changes in energy markets can significantly affect local economic and environmental policies (ALECU Corina et al., 2012). It is critical for industry stakeholders to adopt a multifaceted approach that combines innovative technologies with responsible resource management to mitigate negative geological and environmental impacts. Ultimately, a commitment to sustainability and continuous improvement will not only protect geological integrity, but also pave the way for a more flexible energy future. Balancing efficiency and environmental considerations is therefore critical to promoting improved oil recovery approaches in a manner that is both economically and environmentally beneficial.

Summary of Findings and Recommendations for Sustainable Practices in EOR

Analysis of enhanced oil recovery (EOR) technologies reveals an urgent need to incorporate sustainable practices to reduce environmental impact while maintaining efficiency. Key findings show that using technologies such as carbon dioxide injection can significantly increase oil production while sequestering greenhouse gases, achieving the dual goal of achieving this goal. In addition, optimizing water use and adopting closed-loop systems can address serious water scarcity and pollution concerns associated with traditional methods.

Recommendations include adopting regulatory frameworks that incentivize the integration of renewable energy sources into EOR operations, as well as fostering partnerships between industry stakeholders and research institutions to introduce newer, lower-impact technologies. In addition, it is very important to carry out a comprehensive environmental impact assessment before starting a project. Implementing these strategies can create a more sustainable EOR landscape that balances energy needs with the need for environmental management in the face of climate change.

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