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Commentary

Microbial Enhanced Oil Recovery for Sustainable Petroleum Production

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DESCRIPTION

Microbial Enhanced Oil Recovery (MEOR) has emerged as a promising biotechnological approach to increase oil recovery from reservoirs that are no longer amenable to conventional extraction methods. With primary and secondary recovery techniques often leaving 50–70% of oil trapped due to reservoir heterogeneity and poor sweep efficiency, MEOR offers a cost-effective and environmentally sustainable alternative. By harnessing the natural metabolic activities of microorganisms, MEOR improves oil mobility, modifies reservoir properties, and enhances hydrocarbon displacement.

The fundamental principle of MEOR involves the application of microorganisms or their metabolic products to oil reservoirs. Specific microbial strains can produce biosurfactants, biopolymers, gases, acids, and solvents that facilitate oil mobilization. Biosurfactants, produced by bacteria such as *Bacillus, Pseudomonas,* and *Rhodococcus*, reduce interfacial tension between oil and water, allowing previously trapped oil droplets to flow more easily. Microbial gases, primarily carbon dioxide and methane, increase reservoir pressure and displace oil toward production wells. Additionally, microbial biopolymers can selectively plug high-permeability zones, redirecting injected fluids into oil-rich, low-permeability areas, thereby improving sweep efficiency.

MEOR can be classified into two main approaches: *Ex situ* and *in situ* applications. In *ex situ* MEOR, microbial cultures or metabolic products are prepared outside the reservoir and injected directly. This approach allows controlled production of metabolites such as biosurfactants or solvents before injection. In contrast, *in situ* MEOR stimulates indigenous microbial communities within the reservoir through nutrient injection (biostimulation). This approach leverages native microbial populations adapted to reservoir conditions, reducing operational costs and minimizing the introduction of foreign species that might disrupt reservoir ecology. Including reservoir temperature, pressure, salinity, pH, and nutrient availability. Thermophilic and halophilic microorganisms are preferred for high-temperature and high-salinity reservoirs, respectively. Optimizing nutrient formulations is critical to promote microbial growth and metabolite production without causing reservoir plugging or souring due to hydrogen sulfide generation. Advances in molecular microbiology and metagenomics now allow precise identification of microbial communities and their metabolic potential, enabling tailored MEOR strategies for specific reservoir conditions.

Field trials of MEOR have demonstrated encouraging results. For example, MEOR applications in mature reservoirs in China, the United States, and the Middle East have shown incremental oil recovery ranging from 5% to 20% of the residual oil. Biosurfactant-producing strains have been particularly effective in reducing oil viscosity and enhancing displacement in heavy oil reservoirs. Furthermore, MEOR is environmentally favorable, as it relies on biodegradable microbial products rather than chemical surfactants or harsh solvents, reducing the ecological footprint of oil recovery operations.

Despite its potential, MEOR faces challenges that limit widespread adoption. Reservoir heterogeneity, limited microbial survival under extreme conditions, and the slow rate of microbial metabolite production can affect performance. Addressing these issues requires multidisciplinary research integrating microbiology, reservoir engineering, and process optimization. Recent innovations in synthetic biology offer the possibility of engineering microbes with enhanced metabolite production, resilience to extreme conditions, and targeted reservoir activity, potentially overcoming current limitations.

In conclusion, MEOR represents a sustainable and cost-effective approach to improving oil recovery from mature or challenging reservoirs. By leveraging microbial metabolism, it provides a dual benefit of enhancing hydrocarbon production while reducing environmental impacts compared to traditional chemical or thermal tertiary recovery methods. Continued research in microbial ecology, metabolite optimization, and reservoir-specific strategies will further establish MEOR as a key technology in the future of petroleum biotechnology.

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