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Articles

Extracting the last drops: Microbial Enhanced Oil Recovery (MEOR) from oil wells

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At a time of diminishing oil reserves, together with increasing energy demand and unpredictable prices, there is a need to develop technology for the recovery of the maximum amount of oil from global reserves. There is also the current pressure for green technology and the move away from development of non-renewable resources. Meanwhile, current demand for high usage of oil-based energy is on-going. As 67% of the total petroleum reserves in the world are present as residual crude oil in reservoirs which are difficult to recover, the need for better oil recovery methods and innovative environmentally friendly technology is now a major challenge (Figure 1).

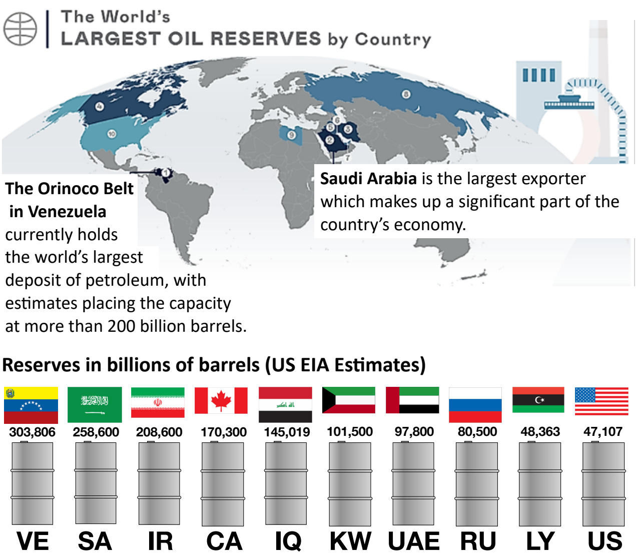

Figure 1 Global oil reserves in 2022

(https://www.worldatlas.com/industries/the-world-s-largest-oil-reserves-by-country.html)

Primary extraction

Crude oil and gas exist as fluid reservoirs trapped within the pore space of the surrounding sedimentary rocks (Figure 2) which are typically sandstones or carbonates and are held in the pores by interfacial tension (IFT), together with the high viscosity of the crude oil.

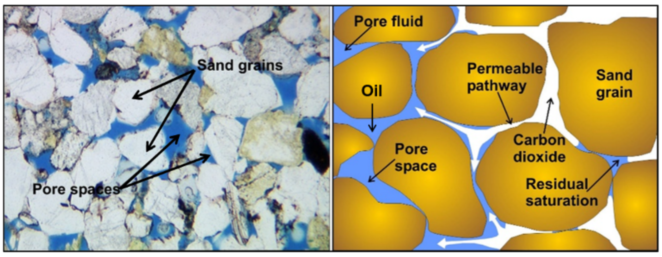

Figure 2 Oil in rock pores

(https://erik-engheim.medium.com/how-do-we-actually-find-oil-4d0e58d67004)

Heavy oil is highly viscous and cannot easily flow from production wells under normal reservoir conditions; it is referred to as heavy because its density or specific gravity is higher than that of light crude oil. In contrast, light crude oil has a low density and low specific gravity and flows freely at room temperature. Current extraction methods e.g., vertical drilling which relies on the natural pressure within the reservoir to push the oil to the surface, recovers between 20% and 40% of readily available oil. Over time, however, the natural pressure within the reservoir falls to a point where production is ineffective and no longer economically viable. Artificial lift is then used to bring the oil to the surface. A popular method is rod or beam pumping involving a submersible pump and a walking beam connected by pistons to the pump. These structures are often referred to as nodding donkeys (Figure 3).

Figure 3 Nodding Donkeys

(https://www.economist.com/business/2015/11/12/nodding-donkeys)

Secondary extraction

To order to increase the percentage of oil recovered by a further 15% to 25% secondary extraction techniques are used but the extraction technologies must be cost effective and, ideally, environmentally friendly. Such enhanced oil recovery (EOR) technologies typically include water flooding, gas injection and gas lift. Currently water flooding is the most widely used and involves injecting water into the oil-bearing rock at a volume similar to the volume rate of extraction of the oil. This prevents the pressure in the oil reservoir from dropping and, as the water moves through the oil-containing rock, it sweeps oil towards the production wells (Figure 4).

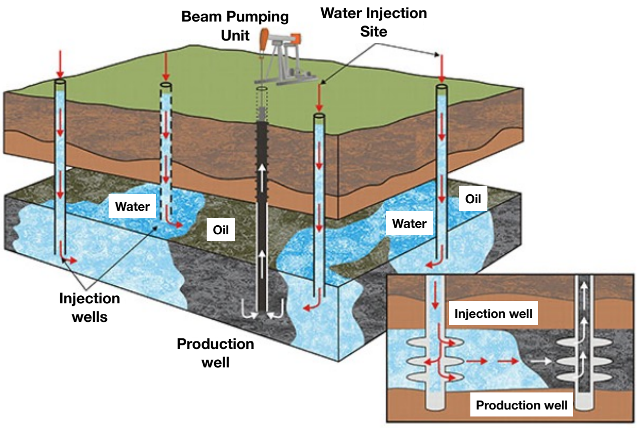

Figure 4 Enhanced oil recovery with water flooding

(https://jakarta-training.com/enhanced-oil-recovery-with-water-flooding/)

Without water flooding, oil recovery levels would be around 10% to 20% of the residual oil remaining in the oil field. Typically, with water flooding the oil recovered is about 30% of the reservoir oil. However, the water cannot sweep out oil contained within some parts of the rock and, at the end of the life of the oil field, up to 55% of the original oil may remain depending on the type of crude oil and the nature of its geological environment.

Tertiary extraction

To further increase oil recovery tertiary extraction processes are used. These enhanced oil recovery (EOR) methods can provide extraction of a further 7-15% of the original oil. Methods used to extract this remaining oil include thermal, gas, chemical, and microbial processes. Thermal processes include hot water injection and steam flooding and *in situ* (i.e. on site) burning or combustion extraction. This involves the burning of a small amount of the reservoir oil in order to heat the surrounding oil resulting in a decrease in its viscosity making it more accessible to extraction. Non-thermal processes are more diverse and mainly involve gas injection; either natural gas, nitrogen, carbon dioxide or chemicals are injected into the reservoir to mix with the oil reducing its density, increasing flow rate and reservoir pressure, and simultaneously pushing it to the surface. Thermal and gas injection (mainly CO_2) methods are most commonly used for sandstone reserves, mainly because CO_2 is plentiful and cheap to obtain. Currently the application of *in situ* combustion is very limited and further field trials are required to prove its viability. Chemical methods involve injection with polymers, surfactants, and alkali all of which reduce the viscosity of the crude oil and increase its flow rate.

Thermal EOR processes are more applicable to known heavy oil fields such as those in Canada, the United States, Venezuela, Brazil and China. Lighter oil recovery is best suited to non-thermal miscible gas injection, water alternating gas (WAG) injection and *in situ* combustion. Chemical EOR methods, especially polymer flooding, were the most popular methods used in the 1980s, but their popularity has since declined as costs increased and because of environmental concerns. Nevertheless, polymer and surfactant flooding are amongst the most widely used chemical EOR methods, but their economic value is strongly linked with fluctuating oil prices. In general, thermal and chemical methods have the major disadvantages of high energy requirements and chemical costs.

The use of microbes

Over the past several decades, the application of microbial processes has been used to recover oil trapped in the porous surroundings of the reservoirs. This is known as microbial enhanced oil recovery (MEOR). It is an *in situ* process involving the indigenous microbes in the reservoir, mainly bacteria classified as methanogenic Archaea, which are stimulated with additional nutrients to produce useful bacterial products inside the reservoir. Alternatively, beneficial bacteria previously isolated from the reservoir may be injected directly into the well or following fermentation and separation of the microbes, the biosurfactants and other microbial products from the fermenters can be injected directly into the reservoir. This method has the advantage that dead microbial cells which build up in the reservoir will be absent and therefore will not clog up the pore spaces and reduce the amount of oil released (Figure 5).

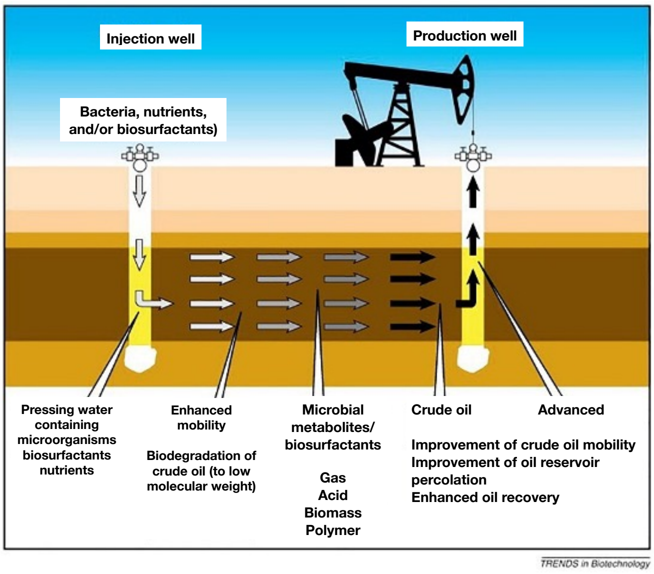

Figure 5 A schematic presentation of MEOR process in an oil reservoir

(Nikolova and Gutierrez, 2020)

The microbial activities during the MEOR process result in the production of useful microbial products including biosurfactants, biopolymers, biosolvents and often biocatalytic enzymes. In combination they work together to reduce interfacial tension and crude oil viscosity and increase rock water wettability and water viscosity. MEOR causes modifications of the chemical and physical properties of both reservoir rocks and crude oil because of the microbial growth and the metabolites produced. These cause a reduction of viscosity of the crude oil, increased permeability of the reservoir and a reduction in interfacial tension between oil, water and rock which 'unlocks' oil trapped in the rocks through capillary tension.

These activities result in enhanced oil flow in the producing wells. The advantages of MEOR over other enhanced oil recovery processes includes reduced energy requirements compared with thermal methods such as steam flooding and reduction in chemical costs of the common chemical methods of extraction, polymer, or alkaline-surfactant-polymer flooding. MEOR is also environmentally less damaging. The major drawback to this method is the limitation of access by the microbes and their products to the surrounding reservoir rocks. Therefore, only a small proportion of the oil in the whole reservoir would be potentially recovered. It is becoming apparent that as conditions vary between different reservoirs the MEOR process must be specifically tailored for the local conditions in each reservoir. A development of a 'universal' formulation, consisting of a mixture of essential nutrients, selected microorganisms and biosurfactants in a buffering solution, contained at the appropriate proportions, would be the answer.

A further microbial application is their potential use for wellbore clean-up. During the drilling and milling of a borehole debris from the surrounding rocks and contamination from the mechanical processes must be removed to ensure free flow of oil. Therefore, wellbore clean-up is undertaken and is currently achieved by a combination of mechanical and chemical operations. However, the application of microbial processes presents a future possibility which would be preferred to the use of toxic chemicals. On-going research and development of innovative technologies are exploring large-scale cost-effective production methods for the injection of biosurfactants into a reservoir and the role of microbes in wellbore clean-up.

The high current demand for oil, coupled with decreasing reserves, is stimulating better extraction from existing oil wells. Currently steam flooding and alkaline-surfactant-polymer remain the most widely used tertiary extraction techniques. However, with increased development of the technologies for microbial oil recovery there is potential for environmentally cleaner and highly efficient cost-effective extraction. Therefore, increased development of MEOR technology is viewed as a future means of extending the life-time of existing sources which are less demanding on their energy requirements and are more environmentally friendly.

Further Reading

Baxter, T. (2017). htps.//www.the chemical engineer.com/features.meor-making-the-case/

Nikolova, C. & Gutierrez ,T. (2020). Use of microorganism in the recovery of oil from recalcitrant oil reservoirs: current state of knowledge, technological advances and future perspectives. Frontiers in Microbiology January 2020, Volume 10, Article 2996.htps./ www.frountiersin.org

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Fuel For Thought. *(/news/fuel-for-thought/13)* Aug26 2014

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Anthony Whalley is Emeritus Professor of mycology at Liverpool John Moores University and visiting professor at Chulalongkorn University, Bangkok, Thailand, where he is active in research and student supervision. He is past president of the British Mycological Society and is currently the society's International Advisor. His research interests are in the ecology, metabolites and taxonomy of ascomycete fungi, the study of which has led to extensive collaboration with international institutes, particularly in Asia and Australia.