

Promising Biotechnology on Selective Plugging and Wettability Alteration for Enhanced Oil Recovery



Moon Sik Jeong, Eunji Hong and Kun Sang Lee*

Department of Earth Resources and Environmental Engineering, Hanyang University, Korea

Submission: April 05, 2018; Published: June 22, 2018

*Corresponding author: Kun Sang Lee, Department of Earth Resources and Environmental Engineering, Hanyang University, Republic of Korea, 222 Wangsimni-ro Seongdong-gu, Seoul 04763, Korea, Tel: +82-2-2220-2240; Fax: +82-2-2220-4428; Email: kunslee@hanyang.ac.kr

Abstract

Biotechnology can play an important role in Enhanced Oil Recovery (EOR) process employing physical and chemical features of microbes. The process, known as Microbial Enhanced Oil Recovery (MEOR), includes injecting *ex-situ* bio-products or stimulating indigenous microbes to generate specific metabolites for oil recovery. This paper focuses on the most actively research area of MEOR involving selective plugging and Wettability alteration. The role of biomass and biopolymers for oil recovery is briefly described. Bio-surfactants for wettability alteration are also represented. The review describes how to utilize the biotechnology in EOR process and shows the potential of MEOR.

Keywords: Microbial enhanced oil recovery (MEOR); Bio-surfactant; Biopolymer; Wettability alteration; Selective plugging

Introduction

Though renewable energy resources are growing in the market recently, crude oil is still used as a major resource [1]. Such trends motivate efforts to find environment-friendly alternative methods to enhance oil recovery. To meet the rising demand of these alternatives, Microbial Enhanced Oil Recovery (MEOR) has shown potential [2,3]. MEOR has similar mechanisms with Chemical Enhanced Oil Recovery (CEOR) as it applies biologically-produced surfactant or polymer to improve oil recovery. The main advantages of MEOR compared to CEOR are that these bio-products are generally not only biodegradable but cheap. Earlier studies have shown that MEOR is sufficient to be a tertiary enhanced oil recovery tool with these advantages [4]. There are two major areas of research that have been most actively studied such as selective plugging and wettability alteration. These two major mechanisms will be briefly investigated through this review.

MEOR Strategies

Selective plugging

One of the most crucial problems in oil recovery is the existence of highly permeable regions called thief zones. In this circumstance, the control of fluid path is an important factor for successful oil production. Selective plugging attempts to selectively clog the thief zones to divert the fluid path. This method is often implemented by using the biomass or biopolymers. When indigenous microbes grow in oil reservoirs, bacteria tend to create a bio-film with substrates in the porous media [5]. These microbes generate colonies and clusters with biomass which have an evolutionary advantage [6]. Some MEOR

studies have focused on utilizing the biomass. The biomass accumulates in high permeability zones and diverts the injected water to remaining oil zones [7]. Furthermore, such biomass can alter the wettability of rock surface to more favourable condition for oil recovery [5]. The method needs the stimulation of indigenous bacteria or injection of selected bacteria. It also improves sweep efficiency by increasing accessible regions [1]. For the successful use of biomass in MEOR process, some criteria should be satisfied. During MEOR process, cells can be transported through the rock pore, proper nutrients are supplied, bio-products are generated adequately, and the growth rate of bacteria must not be so fast that it blocks the well [8]. A previous study showed that *Bacillus licheni* form is BNP29 satisfies the criteria and generates suitable bio-products for MEOR [9].

Various organisms produce polymers which can be used in oil recovery process. Xanthomonas, Aureo asidium, and Bacillus are considered for EOR [2]. Xanthan gum and curdlan are focused as important biopolymers. Some biopolymers function to increase cell adhesion and preserve the cells from predation and desiccation [10]. Others, such as xanthan gum, are utilized as thickening agents for water in MEOR process [2,9,11]. Because of high tolerance to high temperature and salinity, xanthan gum is an established polymer in oil industry [12]. It increases the viscosity of injected water and improves recovery efficiency over simple water flooding. Curdlan mixture with acid-producing bacteria can reduce the permeability [13]. Dextran produced by *Leuconostoc* is also studied as permeability reduction agent for MEOR [14,15]. Typically, the biopolymers

have directly mixed with injected water as opposed to in-situ generating by stimulating the indigenous microbes [16]. In addition, emulsions and other bio-products can selectively plug to make better channelling for oil recovery [17].

Wettability alteration

Most of oil reservoirs have the characteristic of mixed and oil-wet with fractured carbonate rock [18]. It causes the difficulty of oil to produce, contributing to lower displacement efficiency. Problems posed by mixed and oil wet condition of reservoir rock can be solved by bio-surfactant [19]. Bio-surfactant has significant effect on lowering surface and interfacial tension [20]. It affects adsorbed oil on reservoir rock by changing the interfacial tension between oil and water. Several studies have been shown that oil recovery is improved by this mechanism [21-33].

Acinetobacter, *Bacillus*, *Pseudomonas*, and *Rhodococcus* produce bio-surfactant to have potential application for MEOR. Using these microbes, several types of bio-surfactants can be controlled to improve oil recovery with other chemicals as an ex-situ method [2]. Bio-surfactant produced by *Bacillus subtilis* has been injected and validated the potential in core flood experiments [21-23]. One of the studies investigated and compared three bio-surfactants from different strains for successful ex-situ MEOR application [24]. Since it is important to produce stable bio-surfactant, a number of studies have been conducted to optimize the bio-surfactant production process by adjusting environmental parameters such as temperature and pH. [25]. Furthermore, several experimental studies have been examined to validate in-situ MEOR [26-28]. The in-situ bio-surfactant has shown to improve oil recovery up to 15% or more from a recent core flood studies [29]. To apply in-situ bio-surfactant more efficiently, a structured mathematical modeling is also required. A number of studies established a three-dimensional, multi-component transport model [30-31]. The results show that bio-kinetic model has potential to apply oil industry. In addition, recent studies have quantitatively examined the impact of environmental factors to improve accuracy [32-33]. From these results, it is identified that the analysis of environmental factor is important and the optimal injection design is needed.

Conclusion

MEOR is considered as an eco-friendly and cost-effective method using the microbiological techniques to replace the traditional EOR processes. While various MEOR processes exist, not all of them are possible to implement in oil industry due to recovery efficiency. Selective plugging and wettability alteration, however, are representative methods that increase sweep and displacement efficiency. These methods have tremendous promise for oil recovery. Nevertheless, some problems such as inconsistency and uncertainty of in-situ performances, which retard extensive field applications of MEOR, still remain. In

addition, there is no one universal solution for MEOR operations because each reservoir has different characteristics. Therefore, future study should focus on not only mitigating the uncertainty problems but also optimizing the MEOR strategies.

Acknowledgement

This work was supported by the Energy Efficiency & Resources of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea Government Ministry of Knowledge Economy.

References

1. Patel J, Borgohain S, Kumar M, Rangarajan V, Somasundaran P, et al. (2015) Recent developments in microbial enhanced oil recovery. *Renew and Sustainable Energy Reviews* 52: 1539-1558.
2. Sen R (2008) Biotechnology in petroleum recovery: the microbial EOR. *Progress Energy and Combustion Science* 34(6): 714-724.
3. Nielsen SM, Shapiro AA, Michelsen ML, Stenby EH (2010) 1D simulations for microbial enhanced oil recovery with metabolite partitioning. *Transport in Porous Media* 85(3): 785-802.
4. Lazar I, Petrisor IG, Yen TF (2007) Microbial enhanced oil recovery (MEOR). *Petrol Sci Technol* 25(11): 1353-1366.
5. Karimi M, Mahmoodi M, Niazi A, Al Wahaibi Y, Ayatollahi S (2012) Investigating wettability alteration during MEOR process, a micro/macro scale analysis. *Colloid Surf B Biointerfaces* 95: 129-136.
6. Xavier JB, Foster KR (2007) Cooperation and conflict in microbial biofilms. *Proc Natl Acad Sci* 104(3): 876-881.
7. Satyanarayana T, Johri BN, Prakash A (2012) *Microorganisms in sustainable agriculture and biotechnology*. Springer Science & Business Media, New York, USA, pp. 715-718.
8. Jenneman GE (1989) The potential for in-situ microbial applications. *Developments in Petroleum Science* 22: 37-74.
9. Yakimov MM, Amro MM, Bock M, Boseker K, Fredrickson HL, et al. (1997) The potential of *Bacillus licheniformis* strains for in situ enhanced oil recovery. *Journal of Petroleum Science and Engineering* 18(1-2): 147-160.
10. Poli A, Di Donato P, Abbamondi GR, Nicolaus B (2011) Synthesis, production, and biotechnological applications of exopolysaccharides and polyhydroxyalkanoates by archaea. *Archaea* 693253: 1-13.
11. Sandvik EI, Maerker JM (1977) Application of xanthan gum for enhanced oil recovery. *ACS Symposium Series* 45: 242-264.
12. Palaniraj A, Jayaraman V (2011) Production, recovery and applications of xanthan gum by *Xanthomonas campestris*. *Journal of Food Engineering* 106(1): 1-12.
13. Fink J (2011) *Petroleum engineer's guide to oil field chemicals and fluids*. Elsevier, Amsterdam, Netherlands, pp. 1-854.
14. Surasani VK, Li L, Ajo Franklin JB, Hubbard C, Hubbard SS, et al. (2013) Bioclogging and permeability alteration by *L. mesenteroides* in a sandstone reservoir: a reactive transport modeling study. *Energy Fuel* 27(11): 6538-6551.
15. Vilcáez J, Li L, Wu D, Hubbard SS (2013) Reactive transport modeling of induced selective plugging by *Leuconostoc mesenteroides* in carbonate formations. *Geomicrobiology Journal* 30(9): 813-828.
16. Fox SL, Xie X, Schaller KD, Robertson EP, Bala GA (2003) Permeability modification using a reactive alkaline-soluble biopolymer (No. INEEL/EXT-03-01243). Idaho National Laboratory (INL), Idaho, USA, pp. 1-22.

17. Zheng C, Yu L, Huang L, Xiu J, Huang Z (2012) Investigation of a hydrocarbon-degrading strain, *Rhodococcus ruber* Z25, for the potential of microbial enhanced oil recovery. *Journal of Petroleum Science and Engineering* 81: 49-56.
18. Salehi M, Johnson SJ, Liang JT (2008) Mechanistic study of wettability alteration using surfactants with applications in naturally fractured reservoirs. *Langmuir* 24(24): 14099-14107.
19. Vaz DA, Gudiña EJ, Alameda EJ, Teixeira JA, Rodrigues LR (2012) Performance of a biosurfactant produced by a *Bacillus subtilis* strain isolated from crude oil samples as compared to commercial Chemical Surfactants. *Colloid Surf B Biointerfaces* 89: 167-174.
20. Sivasankar P, Govindarajan SK (2016) Modelling the Coupled effects of temperature, injection rate and microbial kinetic parameters on oil recovery by microbial flooding. *Society of Petroleum Engineers*.
21. Schaller KD, Fox SL, Bruhn DF, Noah KS, Bala GA (2004) Characterization of surfactant from *Bacillus subtilis* for application as an agent for enhanced oil recovery. *Twenty-Fifth Symposium on Biotechnology for Fuels and Chemicals, USA*.
22. Al Wahaibi Y, Joshi S, Al Bahry S, Elshafie A, Al Bemani A, et al. (2014) Biosurfactant production by *Bacillus subtilis* B30 and its application in enhancing oil recovery. *Colloid Surf B Biointerfaces* 114: 324-333.
23. Souayah M, Al Wahaibi Y, Al Bahry S, Elshafie A, Al Bemani A, et al. (2014) Microbial enhanced oil recovery at high salinities using biosurfactant at lower concentrations. *SPE EOR Conference at Oil and Gas West Asia, Oman*.
24. Amani H, Sarrafzadeh MH, Haghighi M, Mehrnia MR (2010) Comparative study of biosurfactant producing bacteria in MEOR applications. *Journal of Petroleum Science and Engineering* 75(1-2): 209-214.
25. Sen R (1997) Response surface optimization of the critical media components for the production of surfactin. *J Chem Technol Biotechnol* 68(3): 263-270.
26. Almeida PFD, Moreira RS, Almeida RCDC, Guimaraes AK, Carvalho AS, et al. (2004) Selection and application of microorganisms to improve oil recovery. *Engineering Life Sciences* 4(4): 319-325.
27. Illias RM, Ooi SW, Idris AK, Rahman WAWA (1999) Production of biosurfactant and biopolymer from Malaysian oil fields isolated microorganisms. *SPE Asia Pacific Improved Oil Recovery Conference, Malaysia*.
28. Makkar RS, Cameotra SS (1998) Production of biosurfactant at mesophilic and thermophilic conditions by a strain of *Bacillus subtilis*. *Journal of Industrial Microbiology and Biotechnology* 20(1): 48-52.
29. Daryasafar A, Jamialahmadi M, Moghaddam MB, Moslemi B (2016) Using biosurfactant producing bacteria isolated from an Iranian oil field for application in microbial enhanced oil recovery. *Petrol Sci Technol* 34(8): 739-746.
30. Behesht M, Roostaazad R, Farhadpour F, Pishvaei MR (2008) Model development for MEOR process in conventional non-fractured reservoirs and investigation of physico-chemical parameter effects. *Chemical Engineering Technology* 31(7): 953-963.
31. Bueltemeier H, Alkan H, Amro M (2014) A new modeling approach to MEOR calibrated by bacterial growth and metabolite curves. *SPE EOR Conference at Oil and Gas West Asia, Oman*.
32. Sivasankar P, Govindarajan SK (2015) Numerical modelling of microbial enhanced oil recovery Process under the effect of reservoir temperature, P_{H_2} and microbial sorption kinetics. *SPE Asia Pacific Enhanced Oil Recovery Conference, Malaysia*.
33. Hosseininoosheri P, Lashgari HR, Sepehrnoori K (2016) A novel method to model and characterize in-situ bio-surfactant production in microbial enhanced oil recovery. *Fuel* 183: 501-511.



This work is licensed under Creative Commons Attribution 4.0 License
DOI: [10.19080/CTBEB.2018.15.555918](https://doi.org/10.19080/CTBEB.2018.15.555918)

Your next submission with Juniper Publishers will reach you the below assets

- Quality Editorial service
- Swift Peer Review
- Reprints availability
- E-prints Service
- Manuscript Podcast for convenient understanding
- Global attainment for your research
- Manuscript accessibility in different formats
(Pdf, E-pub, Full Text, Audio)
- Unceasing customer service

Track the below URL for one-step submission

<https://juniperpublishers.com/online-submission.php>