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Microbial Enhanced Oil Recovery-State of The Art

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Abstract

During the last years scientific efforts in the laboratories of Petroleum Engineering Section at Cairo University has established the basic start for Microbial Enhanced Oil Recovery (MEOR) research technology in the Arab World. It is expected that MEOR may recover up to 30% of the residual oil under the reservoir conditions In Egypt, about 24% of the existing reservoirs are good candidates for MEOR. The actual recovery, however can only be determined through extensive laboratory research and pilot tests under field conditions. A new technology should be developed in order to be able to apply a successful MEOR under the environmental control conditions.

MEOR technology is the process of introducing or stimulating viable microorganisms in an oil reservoir for the purpose of enhancing oil recovery. Microbes produce chemicals and acids that may release the residual oil and thus improve oil recovery. This paper presents and analyzes the oil displacement by microbes in the light of different mechanisms operating in this process. A review of a field application is given. Advantages, disadvantages, and screening criteria of MEOR is also discussed

Introduction

Bacteria are the only microorganisms that have been proposed for enhanced oil recovery processes. They are small in size, grow exponentially and produce metabolic compounds such as gases, acids, surfactants and polymers. Bacteria also tolerate harsh environments such as high formation water salinity, high pressure and high temperature. In 1983, Bubela [1], found that the optimum metabolic temperature and rate of growth of rod-shaped bacteria increased with an increase in pressure. Moses and Springham [2] observed that bacteria have been found to be catalytically active at high pressure. Grula et al [3], readily grew Clostridium in up to 75,000 ppm salt concertrations.

The earliest realization that bacteria are beneficial to the production of oil was suggested by Beckman [4]. ZoBell [5] presented a process for the secondary oil recovery using anaerobic, sulfate reducing bacteria in situ. ZoBell [6] used other types of bacteria to enhanced oil recovery in laboratory tests.

In 1963, Kuznetsov et al [7], found that bacteria discovered in some oil reservoirs in the Soviet Union produced 2 gm of CO_2 per day per ton of rock. Later, Synyukov et al [8] employed microorganisms to aid the recovery of oil.

The laboratory study of specific microorganisms is done either for the surface production of various compounds or for the injection of cells into a reservoir for in situ production of metabolic production. Both will enhance oil recovery. Grula et al [9] carried out laboratory tests to isolate salt-tolerant strains of some types of bacteria and then conducted field tests using them. Donaldson and Grula [10] found that some species of bacteria produce emulsifiers in salt concentrations up to 75,000 ppm. Laboratory results by Torbati et al [11] showed that the larger pores of Berea sandstone are plugged by the bacteria which caused a reduction of permeability leading to increasing oil recovery due to improvement in mobility ratio. Another laboratory research conducted by Bryant and Douglas [12] presented crude oil displacement mechanisms by microorganisms.

A review of many field applications of MEOR was presented by Bryant et al [13]. Bryant [14] found that MEOR screening critria fit 27% of United States oil reservoirs. Many MEOR field applications were presented by Donaldson [15]. Hitzman [16] published a review on MEOR field testing.

During the last ten years extensive research have been carried out at King Saud University, Saudi, Arabia and Cario University, Egypt to investigate the enhanced oil recovery by bacteria. Several publications presented the results of these studies [17-28].

Mechanisms

Many species of microorganisms produce carbon dioxide and other gases, such as nitrogen (N_2) hydrogen (H_2) and methane (CH_4), that can improved oil recovery by increasing pressure and by reducing the crude oil viscosity leading to an improvement in mobility ratio.

Because many types of microorganisms produce polymers, these micro-organisms have been used to plug high-permeability zones in petroleum saturated sandstones to improve sweep efficiecy and displace bypassed oil. However, these microorganisms have been shown to reduce rock permeability [13, 14, 29, 30, 31] The work in the Netherlands (Hitzman, D O [32]), was a selective plugging experiments using Betacoccus dextranicus and a significant increase in oil production has been reported.

Recently, the research in China reported novel microorganisms that produce polymer, (Wang [33]) Researchers at the Universty of Calgary reported a methodology for using ultra micro-bacteria to plug the formation [34]

Evaporation of volatile hydrocarbons and destruction of paraffinic compounds by microorganisms led to high in polynuclear aromatic compounds [35] that degrade asphaltic material.

Microbes also produce low-molecular acids, primarily of low-molecular weight fatty acids, that can improve permeability in limestone and sandstone rocks with carbonaceous cementation, and thus improve oil recovery.

A potentially useful group of microorganisms produces alcohols and ketones These compounds are typical co-surfactants that are used in microemulsion solutions for stabilization and lowering of the interfacial tension promoting emulsification.

Microorganisms produce bio-surfactant that can decrease in surface and oil-water interfacial tensions to as low as 5×10^{-3} dyne / cm [36], leading to emulsification Several types of microorganisms that produce bio-surfactants have been separated [37-40].

Microbes have been shown to cause wettability alteration in glass micro-models in Berea sandstone [12]. In 1986, kianipey et al [41] found that the in-situ microbial growth mobilized residual oil by wettability reversal A summary of the different microbial enhanced recovery treatment mechanisms is shown in Table 1.

Screening Criteria

The data of the Middle East oil fields provide the characteristics of oil reservoirs that can be used for MEOR field projects. Extensive research is going on today in order to develop a new technology in the area of bio-technological processes that can be used under reservoir conditions of temperature, pressure, rock permeability and water salinity.

No MEOR field projects have been reported where pressures and temperatures were too high for microbial growth. The usual biological limitation for temperature is about 170 °F and the pressure limitation is about 20,000 psi. Oil reservoirs temperature and pressure range from 140 to 240 °F and from 2000 to 5500 psia, respectively, which means that MEOR processes can be applied with the temperature and pressure constraints. The formation rock permeability in most oil reservoirs ranges from 100 to 3000 md which is a wide range for MEOR application. Sayyouh and Al-Blehed [42, 43] presented a study on the screening criteria for enhanced recovery of some Arabian crude oils. Enhanced recovery methods investigated in that study included thermal and non-thermal processes. MEOR was not considered in the presented non-thermal methods. However, in 1997 Shindy et al [44] considered MEOR process in their developed expert system. The Screening Criteria for MEOR are presented in Table 2

An Example of MEOR Field Application

A good example of the MEOR field applications is the Romanian field test which was performed between 1975 and 1983. The characteristics of the oil reservoirs of the Romanian field are shown in Table 3. A significant increase in oil production was observed. Increased oil production was considered to be dependent on maintaining the nutrient addition. The reservoirs that had an oil viscosity below 10 cp responded best to the microbial treatment.

Limitations of MEOR

The environmental control of MEOR is of great importance. It is necessary to prevent any adverse effects on the environment when applying this recovery method. One of the possible effects is the stimulation of indigenous sulfate-reducing bacteria which causes bio-corrosion in oil fields. The possible contaminations of surface, ground water and agriculture land during bacterial transport are of major environmental concern associated with MEOR field application.

Sometimes the mineral content of the initial water in the oil formation may inhibit the growth of the selected bacteria. Injected and connate water salinities equal or less than 100,000 ppm is required for the application of the MEOR process. Some types of microorganisms, however, can live in higher salinity environment, although great efforts will be needed to identify such organisms that resist high salinity conditions.

The enviromental papameters of the reservoir will limit the types of microorganisms which can be used for the insitu processes. These parameters include permeability, temperature, pressure, salinity, salt composition, pH, the nature of the residual oil and nutrient limitation. A new technology is being considered in the search for ways to apply bacteria to oil recovery. Great effort is being expanded by microbiologists to understand the complex subsurface environment of a petroleum reservoir in relation to bacterial metablism. This may indicate the lack of experience in this new area of enhanced oil recovery.

Economical Advantages of MEOR

Several publications have shown that MEOR is potentially a cost-effective technology for increasing oil production [13, 17]. Many advantages of using MEOR can be cited; some of the most important are the following:

1. The injected microorganisms and nutrients are inexpensive and easy to obtain and handly in the field.
2. MEOR is economically attractive for marginally producing fields.
3. The cost of the injected fluid is not dependent on oil prices.
4. The implementaction of the process needs only minor modifications to existing field facilities, which reduces cost.
5. The method is easily applied with typical surface equipment for waterflooding.
6. MEOR is less expensive to install and more easily applied than any other EOR techique.
7. MEOR products are all biodegradable and will not accumulate in the environment.

Results of an improvement in recovery using MEOR

The following section summarizes some reports of improvements in recovery using MEOR

The Journal of Petroleum Technology reported in its Technology Digest (September 1991) that tests at the Alton field in Queensland, Australia, showed that Biological oil stimulation (BOS) increased oil output by 70% [45] The same study estimated that MEOR technology could unlock as much as 300 billion barrels of Australian oil left in place after conventional techology

Injection of microorganisms and molasses improved the rate of oil production at the Mink Unit project by about 13% [46]. In the same application, water-oil Ratio (WOR) was reduced in producing wells by as much as 35%. Bryant et al. [12] showed that microorganisms and molasses nutrient can recover an average of 32% more of a light crude oil (Delaware-Childers) from Berea sandstone cores than after laboratory-simulated waterflood. Kianipey et al. [41] reported that the in situ growth metabolism of injected bacteria decreased residual oil saturation in the unconsolidated, thin reservoir flow cells by 9-24%. Another study [47] showed that a field core produced 28% more residual Mink crude oil than the waterflood process. Richard et al. [48] demonstrated that between 10 and 39% of the oil left behind in the cores after waterflood could be recovered.

Conclusion

More extensive laboratery and field research should be carried out in order to develop a technolgy in the area of MEOR under reservoir conditions of temperature, pressure, permeability and formation water salinity Depleted oil fields in Egypt can be activated by injection of microorganisms which can be beneficial in producing more oil

References

[1]. Bubela, B. "Combined Effects of Temperature and Other Environmental Stresses on MEOR."In: Donaldson, E.C. and Clakr, J.B. (editors). Proceedings, 1982 International Conference on Microbial Enhancement of Oil Recovery, Afton, Okla., May 16-21, (1983)

[2]. Moses, V. and Springham, D.G. "Bacteria and the Enhancement of Oil Recovery." London: Applied Science Publishers, (1982).

[3]. Grula, E.A.; Russell, H.H; Bryant, D.; Kenaga, M. and Hart, M. "Isolation and Screening of Clostridium for Possible Use in MEOR." In. Donaldson, E.C. and Clark, J.B. (editors), Proceedings, 1982 Int. Conf. On Microbial Enhancement of Oil Recovery, Afton, Okla., (May 16-21, 1983).

[4]. Beckman, J.W. "The Action of Bacteria on Mineral Oil" Ind. Eng. Chem News, Ed. 4 (1926).

[5]. ZoBell, C.E.: "Bacteriological Process for Treatment of Fluid-bearing Earth Formations." U.S. patent No. 24133278 (Dec. 24, 1986)

[6]. ZoBell, C.E. "Recovery of Hydrocarbons" U.S. patent No. 2641566 (June 9, 1953).

[7] Kuznetsov, S T , Ivanov, M V and Lyalikova, N N L "Introduction to Geological Microbiology" New York, N Y McGGGraw-Hill, (1963).

[8] Senyukov, V M ,; Yulbarisolv, E M , Taldykina, N N and Shishenina, E P "Mmikrobiologicheskii Metod Obrabotki Neftianoi Zalezy Visokoi Mineralizatsey Plastovykh vod Microbiologiya" J Int Microb Vol 39 (1970).

[9] Grula, E A ; Russell, H H and Grula, M M "Field Trials in Central Oklahoma Using Clostridium Strains for Microbially Enhanced Oil Recovery" In Zajic, J E and Donaldson, E C (editors), Microbes and Oil Recovery El Paso, Texas: Bioresources Publications, (1985).

[10]. Donaldson, E C and Grula, E A "These Are Bugs in My Oil Well" CHEMTECH (October 1985).

[11]. Torbati, H M , Raiders, R A ; Donaldson, E C ; Mclnerney, G E and Knapp, R M "Effect of Microbial Growth on Entrance Size Distribution in Sandstone Cores" J Ind Microbiol , 1 (1986).

[12]. Bryant, R S and Douglas, J "Evaluation of Microbial Systems in Porous Media for EOR , SPERE, (May 1988).

[13]. Bryant, R S and Burchfield, T E "Review of Microbial Technology for Improving Oil Recovery", SPE (Reservoir) Journal (May 1989).

[14]. Bryant, R "MEOR Screening Criteria Fit 27% of US Oil Reservoirs" Oil and Gas Journal, (15 April, 1991).

[15]. Donaldson, E C (editor) "Microbial Enhancement of Oil Recovery - Recent Advances" Proceedings of the Int Conference on MEOR Norman, OK, U S A (27 May -1 June 1990).

[16]. Hitzman, D O "Review of MEOR Field Tests" Symposium on Applications of Microorganisms to Pet Tech., (1988).

[17]. Sayyouh, M H , Al-Blehed, M S , "Using Bacteria to Improve Oil Recovery From Arabian Field" MEOR Book, Edited by Ed Premuzic, Elsevier, (1993).

[18]. Sayyouh, H M , Al-Blehed, M S and Hemieda, A , "Possible Application of MEOR to Arab Oil Fields," K S U (Engineering Siences), vol.5, No.2, (1993).

[19]. Sayyouh, H M , Al-Blehed, M S "Effect of Microorganisms on Solution Interfacial Forces and Phase Variation for MEOE," European Magazine, vol.3, (1994).

[20]. Sayyouh, H M , Al-Blehed, M S "Effect of Micro organisms on Rock Wettability J of Adhesion Science and Tech , vol.9, No 4 (1995)

[21]. Sayyouh, H M "Microorganisms For Increasing Oil Recovery," Series of Articles, (In Arabic), J of Petroleum, vol.31, No5 3-5 (1994), vol 32, No 5 2-7 (1995)

[22]. Sayyouh, H M "Microbial Characteristies and Metobolic Activity of Bacteria for Improved Oil Recovery in the Arabic Area," Proceedinergs, Regional Symposium on IOR of the Gulf region United Arab Emirates (Dec 1995)

[23]. Al-Blehed, M S Sayyouh, H M , Shoaib, M S , Awwad, A , Desouky, S and Hemieda, A "Laboratory Investgation of MEOR," Engineering Science, vol.8, No 2 JKSO, (1996)

[24] Desouky, S., Abdel Daiem, M., Sayyouh, M.H. and Dahab, A. "Modeling and Laboratory Investigation of MEOR," Jpet. Science and Engg. vol. 15, (1996)

[25] Khairy, M., Mahmoud, A., Sayyouh, M.H., Osman A., and Gomoa, A. " Isolation and Indentification of Indigeneous Bacteria in Some Egyptian Crude Oils." Proceedings, of AEIC 97, Cairo, (Dec. 1997)

[26] Khairy, M., Mahmoud, A., Sayyouh, M.H., Osman A., and Gomoa, A. "Laboratary Study of the Effect of Stimulating Indigeneous Bacteria on surface and Interfacial Forces of Crude Oil – Brine system." JEAS, vol. 44, No 4, (1997)

[27] Khairy, M., Sayyouh, M.H., Mahmoud, A., Osman A., and El-Morsy, G. "The Role of Microorganisms on the phase Variation for Crude Oil – Nutrient Solution System, Proceedings of AEIC, 97, Cairo, (Dec. 1997)

[28] Abdel Waly, A., Almalik, M., and Mahrous, M. "Effects Of Indigenous Microorganisms on The properties of oil and water." The Arabian J. for Science and Engg., Vol. 22, No 2 B, (1997)

[29] Knapp, R.M., McInermey, J., Menzie, D.E. and Raiders, R.A. "Microbial Field Pilot Study." U.S. Dept. of Energy Report No. DOE / BC / 14084-6, January, (1989)

[30] Jack, T.R. "Field and Laboratory Results for Bacterial Selective Plugging Systems." Int. Conf. On MEOR, Okla., May 27-31, (1990).

[31]. Torbati, H.M.; Donaldson, E.C.; Jenneman, G.E.; Knapp, R.M.; McInerney, M.J. and Manzie, D.E. "Depth of Microbial Plugging and Its Effects on Pore size Distribution in Berea sandstone Cores." In. Zajic, J.E. and Donaldson, E.C. (editors). Microbes and Oil Recovery, ElPaso, Texas. Bioresources Publications, (1985).

[32]. Hitzman, D.O. "Review of Microbial EOR Field Tests." Proc. Symposium of Application of Microorganisms to Petroleum Technology." Bartlesville, OK (Aug. 12-13, 1987).

[33]. Wang, X.Y.. "Studies of Thermally Generated Gel-agent Produced by PS aeruginosa for EOR." Conf. On MEOR, Okla., May 27-31, (1990)

[34]. Costerton, J.W.; Cusack, F.and Macleod, F.A. "Microbial Process for Selectively Plugging a Subterranean Formation." U.S. Patent No. 4800959, Jan. 31, (1989).

[35]. Bailey, N.J.L, Jobson, A.J. and Rogers, M.A. "Bacterial Degradation of Crude Oil Comparison of Field and Experimental Data." Chem. Geol., 11, (1973), 203-221.

[36]. Olsen, D.K. and Janshekar, H. "Bio-surfactant Production and Laboratory Application Tests for Heavy Crude Oil", Paper presented at the 1985 UNITAR Conf. On Heavy Oil Recovery, Long Beach, CA. July (1985)

[37]. Cooper, D.G. and Zajic, J.E. "Surface-active Compounds from Micro-organisms." Adv. Appl. Microbiol, 26 (1980)

[38]. Cooper, D.G. "Bio-surfactants and EOR." Proc. Int. Conf. On MEOR, Okla., May (1982)

[39]. Cooper, D G et al. "Isolation and Identification of Bio-surfactants Produced During Anaerobic Growth of Clostridium Pasteurianum " J Ferment Tech 58 (1980)

[40]. Jenneman. G E. et al. "A Halotolerant Bio-surfactant Producing Bacillus Potentially Useful of EOR". In: Development in Industrial Microbiology, Soc For Industrial Microbiology, Arlington, VA Ch. 24 (1983).

[41]. Kianipey. S A and Donaldson, E.C.: "Mechanisms of Oil Displacement by Micro-organisms." Paper SPE 15601, presented at the 61st Annual Tech. Conf And Exnib. Of the held in New Orleans, LA. October 5-8 (1986).

[42]. Sayyouh. M.H. and Al-Blehed, M. "Screening Criteria for Enhanced Recovery of Saudi Crude oils." Energy Sources, 12 (1990).

[43]. Sayyouh. M.H. and Al-Blehed, M. "Applications of the Enchnced Recovery Methods of Saudi Oil Fields". Journal of King Saud University, Vol.4, Engineering Science, No.1 (1991).

[44]. Shindy, A., Darwich, T., Sayyouh, M.H and Osman, A. "Development of an Expert System For EOR Method Selection, " SPE 37708, Presented at the 1997 MEOS held in Bahrain, (March 1997).

[45]. Technology Digest, The Journal of Petroleum Technology (JPT), (Sept. 1991)

[46]. Bryant, R.S., Burchfield, T.E., Dennis, D.M. and Hitzman, D.O. "Microbial Enhanced Waterflooding: Mink Unit Project," SPE (Reservoir Engineering), (Feb. 1990).

[47]. Bryant, R.S., Burchfield, T.E., Douglas, J. and Bertus, K."Laberatery Optimization for Microbial Field Projects," Report NIPER-351, NIPER Bartleslville, OK, (1988).

[48]. Richard, A.R., Raiders, R.A., Knapp, R.M., McInerney, M.J and Menzie, D. "Microbial Selective Plugging and Enhanced Oil Recovery, Proceedires of Symposium Application of Microorganisms of Pet. Tech., (1988).

Table 1. Microbial enhanced oil recovery treatment mechanisms

Process	Type of microorganism used and displacement mechanism
Enhanced waterflooding	Microorganisms that produce low molecular weight acids (improve formation low permeability)
Improved oil recovery by Gases	Microorganisms that produce gases such as CO_2, N_2, H_2 and CH_4 (improve mobility and miscibility)
Microbial permeability Modification	Microorganisms that produce polymer and / or copious amounts of biomass (improve sweep efficiency)
Microbial polymer flooding	Microorganisms that produce polymer (improve mobility)
Microbial surfactant Flooding	Microorganisms that produce surfactant and alcohols (improve miscibility and reduce capillary foces)

Table 2. Screening criteria [14]

Parameter	Range suggested
1-Reservoir rock permeability	>75 md, unless highly fractured
2- Reservoir depth	< 8000 ft
3- Crude oil type	>15° AP, as yet not enough information available for heavier crude oils
4- Reservoir temperature	< 170° F
5- Salinity of reservoir formation	<10% sodium chloride, total TDS may be higher

Table 3. Romanian field characteristics and properties

Type of formation	Sand and sands with a high content of marls and clays
Depth (m)	336-1559
Temperature (°C)	27-55
Permeability (md)	100-1500
Na Cl (g/l)	5-180
Oil viscosity	6-53
Oil density (Kgf/dm³)	0 85-0 908
Oil saturation (%)	71-81

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