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Developments in Enhanced Oil Recovery Technologies-A Review

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Abstract- With the decline in oil discoveries during the last decades it is believed that Enhanced oil recovery technologies will play a significant role to meet the energy demand in next years. This paper presents a comprehensive review of enhanced oil recovery (EOR) status and opportunities to increase final oil recovery factors in reservoirs ranging from extra heavy oil to gas condensate. Specifically, Enhanced oil recovery opportunities organized by reservoir lithology and offshore and onshore fields.

Index Terms- Enhanced Oil Recovery, Carbon Dioxide (CO2), Microbial Bio-Products, Biopolymers, Plasma-pulse action, Chemical Flooding.

1. INTRODUCTION

In the last few years, Enhanced Oil Recovery (EOR) processes have re-gained interest from the research and development phases to the oilfield EOR implementation. This renewed interest has been furthered by the current high oil price environment, the increasing worldwide oil demand, the maturation of oilfields worldwide [1]. Hydrocarbon recovery occurs through two main processes: primary recovery and supplementary recovery. Primary recovery refers to the volume of hydrocarbon produced by the natural energy prevailing in the reservoir and/or artificial lift through a single wellbore; while supplementary or secondary hydrocarbon recovery refers to the volume of hydrocarbon produced as a result of the addition of energy into the reservoir, such as fluid injection, to complement or increase the original energy within the reservoir [2].
EOR refers to the recovery of oil through the injection of fluids and energy not normally present in the reservoir.
EOR processes are classified in five general categories: mobility-control, chemical, miscible, thermal, and other processes, such as microbial EOR. The injected fluids must accomplish several objectives like Boost the natural energy in the reservoir and interact with the reservoir rock/oil system to create conditions favorable for residual oil recovery that include among others viz., Reduction of the interfacial tension between the displacing fluid and oil, Increase the capillary number, Reduce capillary forces, Increase the drive water viscosity, Provide mobility-control, Oil swelling, Oil viscosity reduction, Alteration of the reservoir rock wettability [3-5].
The ultimate goal of EOR processes is to increase the overall oil displacement efficiency, which is a function of microscopic and macroscopic displacement efficiency. Microscopic efficiency refers to the displacement or mobilization of oil at the pore scale and measures the effectiveness of the displacing fluid in moving the oil at those places in the rock where the displacing fluid contacts the oil. For instance, microscopic efficiency can be increased by reducing capillary forces or interfacial tension between the displacing fluid and oil or by decreasing the oil viscosity. Macroscopic or volumetric displacement efficiency refers to the effectiveness of the displacing fluid in contacting the reservoir in a volumetric sense [6-8]. Volumetric displacement efficiency also known as conformance indicates the effectiveness of the displacing fluid in sweeping out the volume of a reservoir, both areally and vertically, as well as how effectively the displacing fluid moves the displaced oil toward production wells. Figure 1 presents a schematic of sweep efficiencies: microscopic and macroscopic. The overall displacement efficiency of any oil recovery displacement process can be increased by improving the mobility ratio or by increasing the capillary number or both. Mobility ratio is defined as the mobility of the displacing fluid divided by the mobility of the displaced fluid.

For water floods, this is the ratio of water to oil mobilities. The mobility ratio, M, for a Water flood is given by the following expression:

$$M = \frac{Mobility_{water}}{Mobility_{oil}} = \frac{\lambda_w}{\lambda_o} = \frac{K_{rw}/\mu_w}{K_{ro}/\mu_o} = \frac{K_{rw}}{K_{ro}} \frac{\mu_o}{\mu_w}$$

Where, λ_w and λ_o are water and oil mobilities, respectively, in md/cp; krw and kro are relative permeabilities to water and oil, respectively, is μ_o oil viscosity and μ_w is water viscosity.
Volumetric sweep efficiency increases as M decreases, therefore mobility ratio is an indication of the stability of a displacement process, with flow becoming unstable when M> 1.0.

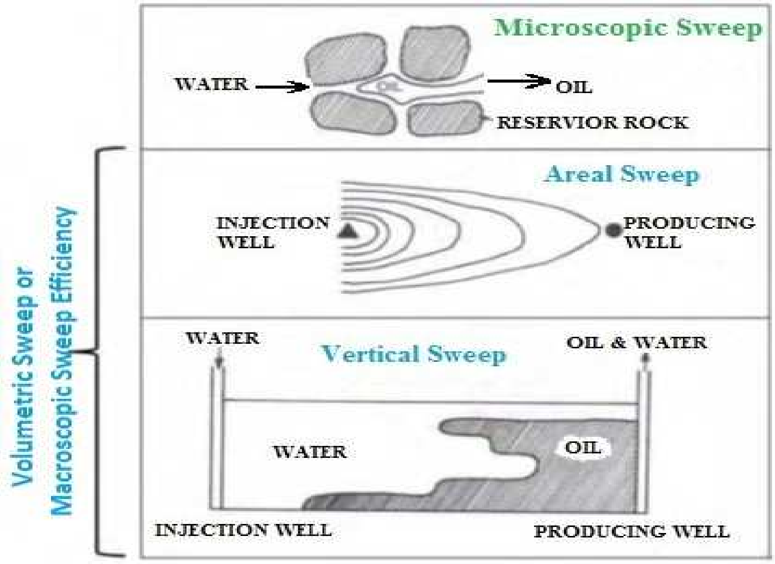

Figure 1: Schematics of microscopic and macroscopic sweep efficiencies

Thus, a large viscosity contrast between the displacing fluid and the displaced fluid causes a large mobility ratio which promotes the fingering of water through the more viscous oil and reduces the oil recovery efficiency. As such mobility ratio can be improved by increasing the drive water viscosity using polymers.
At the end of the water flooding process, experience has shown that at these low capillary numbers an important amount of oil is left behind in the reservoir trapped by capillary forces at the pore scale. Thus, if the capillary number is increased through the application of EOR processes, residual oil will be mobilized and recovered. The most practical alternative to significantly increase the capillary number is through the application of surfactants or alkaline flooding.

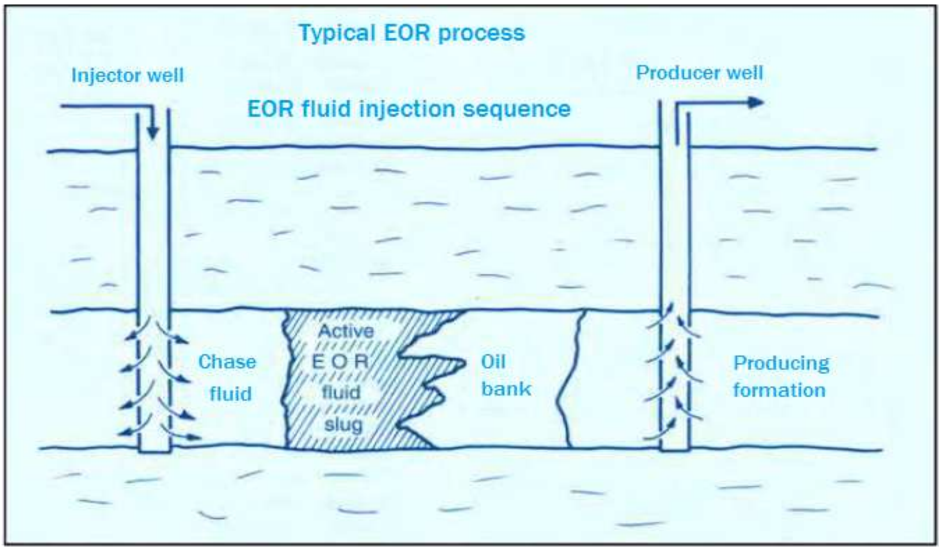

Figure 2: Common EOR fluid injection sequence

Some of the requirements for the ideal enhanced oil recovery: Appropriate propagation of fluids and/or chemicals deep inside the reservoir rock, low or minimum chemical adsorption, mechanical entrapment, and chemical consumption onto the formation rock, fluids and/or chemicals tolerance to formation brine salinity and hardness, fluids and/or chemicals stability to high reservoir temperatures, polymers stability to mechanical degradation, advanced polymer mobility-control to improve sweep efficiency, efficient reductions of interfacial tension between oil and water [6].

Enhanced oil recovery technology has been practiced for decades, and the petroleum industry has actively operated towards the advancement of EOR technology, there are still several challenges to the implementation of EOR projects that must be overcome.

2. LITERATURE REVIEW

[ALIREZA SOUDMAND-ASLI, S. SHAHAB AYATOLLAHI, HASSAN MOHABATKAR, MARYAM ZAREIE, 2007] In the present study the authors have analyzed the microbial enhanced oil recovery (MEOR) technique in fractured porous media using etched-glass micromodels. Three identically patterned micromodels with different fracture angle orientation of inclined, vertical and horizontal with respect to the flow direction were utilized. A non-fractured model was also used to compare the efficiency of MEOR in fractured and non-fractured porous media. Two types of bacteria were employed: Bacillus subtilis (a biosurfactant producing bacterium) and Leuconostoc mesenteroides (an exopolymer-producing bacterium). The results show that higher oil recovery efficiency can be achieved by using biosurfactant-producing bacterium in fractured porous media. Considerable permeability reduction was observed when the biopolymer-producing bacteria were incubated in sand-packed column. The microbial oil recovery efficiency by using biosurfactant-producing bacteria (i.e. B. subtilis) in the fractured porous media is higher than that of the non-fractured media. High oil recovery efficiency was achieved in the fractured porous media when the biosurfactant producing bacteria were used as the microbial treating agent mostly due to the interfacial tension and viscosity reduction. No sign of wettability alteration was observed during the MEOR process using both biosurfactant and biopolymer-producing bacteria [11].

[I. LAZAR, I. G. PETRISOR AND T. F. YEN, 2007] In this paper author study Microbial enhanced oil recovery (MEOR) represents the use of microorganisms to extract the remaining oil from reservoirs. This technique has the potential to be cost-efficient in the extraction of oil remained trapped in capillary pores of the formation rock or in areas not swept by the classical or modern enhanced oil recovery (EOR) methods, such as combustion, steams, miscible displacement, caustic surfactant-polymers flooding, etc. successful MEOR applications should be focused on water floods, where a continuous water phase enables the introduction of the technology or single-well stimulation (including skin damage removal), where its low cost makes it a preferable choice. At the same time, selective plugging strategies and activation of stratal microbiota remain the most promising and should be developed [12].

[H. AL-SULAIMANI, S. JOSHI, Y. AL-WAHAIBI, S. AL-BAHRY, A. ELSHAFIE, A. AL- BEMANI, 2011] In this paper author have proposed the uses and types of different microbial bioproducts available and various recovery mechanisms are discussed. Successful MEOR field trials around the world are summarized which shows the potential of this technology as alternative oil recovery method. However, these processes have not been fully proven and did not receive large attention in the petroleum industry due to several reasons that are also discussed. One major reason is the absence of standardized field results and post-trial analysis and the lack of structured research methodology. Also, the inconsistent technical performance and lack of understanding of the mechanism of oil recovery contributed to the fact that MEOR received little interest in the petroleum industry. MEOR processes to be well accepted and successful, extensive laboratory tests are required prior to field implementation to select the suitable microbes, to understand their growth requirements and production conditions [13].

[K. BROWN, W. JAZRAWI, R. MOBERG, M. WILSON, 2010] In this paper author has concentrated on the Enhanced Oil Recovery Project, the progress of the CO2 flood, and the goals of the Monitoring Project. Particular emphasis is placed on understanding how the monitoring project will help determine the capacity of oil reservoirs to retain CO2 for the long-term. Injection of CO2 into a carbonate oil reservoir in south eastern Saskatchewan, Canada, began on September 22, 2000. Prior to the start of injection, substantial baseline data were obtained from the field. This baseline data include extensive seismic work (3D-seismic, VSP, cross-well and single-well seismic) and geochemical sampling. The monitoring project will evaluate the distribution of CO2 in a carbonate reservoir and will determine the chemical reactions that are occurring within the reservoir between the CO2 and the reservoir rock and fluids. The ultimate goal of the monitoring project is to verify the long-term storage capacity of an oil reservoir, with particular emphasis on reservoir integrity. Understanding how CO2 moves within and interacts with the reservoir fluids and minerals will allow a determination of total reservoir capacity should CO2 storage become the ultimate goal. On a short-term basis, the monitoring will identify new, cost-effective ways to track the path of CO2 in any oil reservoir. The monitoring study will also identify the most effective ways of assessing the motion of CO2 in the reservoir and understanding the optimization of CO2 storage as opposed to necessarily optimizing oil recovery alone. Understanding CO2 movement will help to provide the information necessary to develop strategies to improve sweep efficiency within the reservoir. While not discussed in the text of this paper, one of the goals of this study is to study mobility control in the reservoir. Effective injection strategies, including the possible use of mobility control techniques, will improve sweep efficiency and potentially increase the volume of reservoir holding CO2. While injection has only just begun, initial indications are that there are no immediate injectivity issues. Prior to injection beginning, it was possible to collect a full suite of geochemical samples for analysis and to undertake a number of geophysical surveys using a variety of techniques. The data quality appear to be good from these programs. It should be possible to determine with some confidence the longer-term consequences of greenhouse gas injection into the subsurface and the integrity of storage. The risk analysis will evaluate the potential for leakage, migration paths this leakage may take and future land-use changes that may impact on reservoir integrity [14].

[STEVEN R. PRIDE, EIRIK G. FLEKKOY, AND OLAV AURSJO, 2008] In this paper author provides the pore-scale effects of seismic stimulation on two-phase flow are modelled numerically in random 2D grain-pack geometries. Seismic stimulation aims to enhance oil production by sending seismic waves across a reservoir to liberate immobile patches of oil. For seismic amplitudes above a well-defined analytically expressed dimensionless criterion, the force perturbation associated with the waves indeed can liberate oil trapped on capillary barriers and get it flowing again under the background pressure gradient. Subsequent coalescence of the freed oil droplets acts to enhance oil movement further because longer bubbles overcome capillary barriers more efficiently than shorter bubbles do. Poroelasticity theory defines the effective force that a seismic wave adds to the background fluid-pressure gradient. The lattice-Boltzmann model in two dimensions is used to perform pore-scale numerical simulations. Dimensionless numbers groups of material and force parameters involved in seismic stimulation were defined carefully so that numerical simulations could be applied to field-scale conditions. Using defined analytical criteria, there is a significant range of reservoir conditions over which seismic stimulation can be expected to enhance oil production. This study is supported strongly by numerical simulations: Seismic stimulation will mobilize trapped oil, thus increasing oil production, when two dimensionless criteria are met. The first condition is the static-force requirement that when a seismic wave pushes on a trapped oil bubble, the radius of curvature of the downstream meniscus of the bubble is reduced sufficiently to get through the pore-throat constriction that is blocking its downstream progress. The second condition is the dynamic requirement that in a cycle of the time-harmonic stimulation, the meniscus has enough time to advance through the constriction before the seismic force changes direction and begins to push the meniscus upstream. These two conditions can be achieved by using sufficiently large stimulation amplitudes and sufficiently small stimulation frequencies. Numerical results pertained to lower oil-volume fractions for which the stimulation-induced coalescence of bubbles did not result in a continuous stream of oil spanning the flow cell under study. At slightly larger oil-volume fractions, stimulation can form connected streams of oil that span the flow cell, thus creating an even larger oil-production effect [15].

[J. J DOOLEY, R. T DAHOWSKI, C. L DAVIDSON, 2010] In this paper author have examines the historical evolution of CO2-EOR in the United States and concludes that estimates of the cost of CO2-EOR production or the extent of CO2 pipeline networks based upon this energy security-driven promotion of CO2-EOR do not provide a robust platform for spurring the commercial deployment of carbon dioxide capture and storage technologies (CCS) as a means of reducing greenhouse gas emissions. The paper notes that the evolving regulatory framework for CCS makes a clear distinction between CO2-EOR and CCS and the authors examine arguments in the technical literature about the ability for CO2-EOR to generate offsetting revenue to accelerate the commercial deployment of CCS systems in the electric power and industrial sectors of the economy. The authors conclude that the past 35 years of CO2-EOR in the U.S. have been important for boosting domestic oil production and delivering proven system components for future CCS systems. However, though there is no reason to suggest that CO2-EOR will cease to deliver these benefits, there is also little to suggest that CO2-EOR is a necessary or significantly beneficial step towards the commercial deployment of CCS as a means of addressing climate change [16].
[SCOTT C. JACKSON, DUPONT, ALBERT W. ALSOP, DUPONT, ROBERT FALLON, 2010] In this paper author observed the demonstrated two mechanisms that exceeded, in the lab, the targeted increase in the recovery factor. 1. Improved sweep efficiency by plugging of high permeable zones thereby forcing water to produce oil from previously unswept parts of the reservoir. 2. Reduced oil / rock surface tension resulting in a change in the wettabilty of the rock and lower residual oil saturation. This paper describes the field data used to demonstrate the effectiveness of the improved sweep efficiency by using a microbe to plug high permeable zones in a target reservoir – called bioplugging.
The microbe and the nutrients are tailored to the conditions of each reservoir thus giving MEOR the greatest chance for success. We have tested the efficacy of the microbial treatment with a series of slim tube tests and interwell tests. Oil production has increased in the field by 15 to 20% with a corresponding reduction in water cut. Our ongoing research has provided many insights into the appropriate application of microbial EOR. The unique aspects of each production area, the nature of the oil, the water, the formation matrix, and the background microbial population and their complex interactions must all be assessed when considering the potential application of microbial EOR. The amount of work described for assessing potential MEOR mechanisms is extensive. However, this process has been

streamlined and we have been able to assess new target reservoirs for potential MEOR treatments quickly [17].

[ALEKSANDR VALERYEVICH MAKSYUTIN, RADMIR RASIMOVICH KHUSAINOV, 2014] In this paper author study Provides information on the current high-viscosity oil in Russia and the world, as well as the main challenges for their development and possible potential ways of this crude hydrocarbon stimulation from the depths. The experimental researches technique and results of studying the influence of the plasma-pulse action technology on the rheological properties of highly viscous oil is analysed. Plasma-pulse action technology enables to reduce the effective oil viscosity up to 30% and thixotropic properties appearance up to 48% depending on the processed oil type [18].

3. CONCLUSION

MEOR is well-proven technology to enhance oil recovery from oil wells with high water cuts and also to improve it in mature oil wells, but still in order for MEOR processes to be well accepted and successful, extensive laboratory tests are required prior to field implementation to select the suitable microbes, to understand their growth requirements and production conditions. Also, optimization of nutrients and testing the microbes and their bioproducts compatible with reservoir conditions are required. During field tests, design of the microbial system and oil production response has to be well documented and results have to be monitored and followed up.

4. FUTURE SCOPE

Improvements of the operational performance and the economical optimization of EOR projects in the future would require the application of a synergistic approach among EOR processes, improved reservoir characterization, formation evaluation, reservoir modelling and simulation, reservoir management, well technology, new and advanced surveillance methods, production methods, and surface facilities as stated by Pope. This synergistic approach is in line with the Smart Fields Concept, also known as Intelligent Field, Digital Field, i-Field or e-Field, developed by Shell International Exploration and Production that involves an integrated approach, which consists of data acquisition, modelling, integrated decision making, and operational field management, each with a high level of integration and automation.

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