April 2023

OIL RECOVERY PRINCIPLES & PRACTICES

EDITED BY
Dr. Barasha Deka

CIIR Scientific Publications

Oil Recovery
Principles & Practices

EDITED BY

Dr. Barasha Deka

CIIR Scientific Publications
Noida, India.

CIIR Scientific Publications

Oil Recovery Principles & Practices

First published April 2023 by CIIR Scientific Publications, Noida, India.

April 30, 2023

ISBN 978-81-962237-1-7

Edited and Compiled by
Dr. Barasha Deka

Publisher Address
Council for Industrial Innovation and Research
B-17, Sector-6, Noida,
Uttar Pradesh, India.
201301
Email: info@ciir.in
www.ciir.in

Contents

	Title of Chapters	Page (s)
Chapter 1	INTRODUCTION TO ENHANCED OIL RECOVERY Dr. Suman Paul	1
Chapter 2	CLASSIFICATIONS FOR THERMALLY ENHANCED OIL RECOVERY Dr. Abhinav Kumar	4
Chapter 3	MISCIBLE ENHANCED OIL RECOVERY Dr. Kalpajit Hazarika	7
Chapter 4	MICROBIAL FLOODING PROCESSES Dr. Deepjyoti Mech	10
Chapter 5	SURFACTANT FLOODING MECHANISM Dr. Kalpajit Hazarika	12
Chapter 6	THE IMPACT OF ANIONIC SURFACTANTS Dr. Barasha Deka	15
Chapter 7	INTRODUCTION TO CHEMICAL ENHANCED OIL RECOVERY (ALKALI-SURFACTANT) Dr. Deepjyoti Mech	18
Chapter 8	CLASSIFICATION OF EOR TECHNOLOGIES Dr. Kalpajit Hazarika	21
Chapter 9	TRADITIONAL CHEMICAL EOR TECHNIQUES Dr. Kalpajit Hazarika	24
Chapter 10	EOR POLYMER TYPES Dr. Barasha Deka	27
Chapter 11	CHEMICAL EOR TECHNIQUES Dr. Barasha Deka	30
Chapter 12	CHALLENGES WITH CHEMICAL EOR Dr. Kalpajit Hazarika	32

Preface

Petroleum engineers have also played a significant part in the effective remediation of aquifers contaminated with harmful substances by expanding oil recovery technology. The use of surfactants to clean up aquifers contaminated with nonaqueous phase liquids like trichloroethane is an illustration of such an expansion. Where traditional cleanup techniques have fallen short, surfactant aided aquifer remediation has proven to be quite successful.

Additional environmental advantages come from using sound engineering techniques to achieve high oil recovery. The requirement for new field developments is reduced, for instance, by the adoption of enhanced oil recovery (EOR) techniques, which prolong the field's life beyond its initial recovery period. EOR also lowers greenhouse gas (GHG) emissions by injecting hydrocarbon gases that would otherwise be flared and sequestering carbon dioxide. An enhanced oil recovery (EOR) project needs specialists with knowledge from many fields. Realistically, it's possible that an organization won't always have a group of experts on hand. Despite the fact that such a collection of experts is available, they might not have much experience dealing with unique issues in a specific project. Every EOR project is quite expensive. In project design, we cannot afford to make mistakes. And textbooks cannot provide the necessary experience. It must be drawn jointly from numerous real field studies. This inspired us to write and publish this book.

The book compiles knowledge from all available sources. Here, in addition to their collection from books and other sources, the specialists in various EOR domains summarize their considerable research knowledge and personal field experience. This book describes the most modern EOR approaches based on recent advances. Additionally, the principles of EOR techniques are briefly discussed. A single book cannot, however, contain all of the field cases. There have been attempts to talk about the key insights and knowledge gained from significant field projects. The writers' personal research or published studies are used to summarize the authors' overall field experience and practices.

Professionals working on real-world EOR projects are the target audience for the book. The foundational information is also beneficial for learners of EOR technology and for students. Which EOR techniques are effective in shale and tight oil reservoirs is clarified in this book. This book assists readers in understanding the physical and chemical mechanisms for the injected EOR fluids to boost oil recovery in shale and tight oil reservoirs as well as the primary fluid and rock features of shale and tight reservoirs, which are the major target for EOR approaches. Additionally, this book offers proxies that connect the functionality of enhanced oil recovery by combining several EOR techniques with various operational parameters, rock, and fluid features. The book helps academics and students understand the fundamentals and principles that make the performance of EOR methods so different in conventional reservoirs and unconventional formations. It also gives professionals working in the petroleum industry the know-how to conduct a successful project for various EOR methods in shale plays.

Dr. Barasha Deka
Editor

CHAPTER - 1

INTRODUCTION TO ENHANCED OIL RECOVERY

Dr. Suman Paul
Assistant Professor, Department of Petroleum Engineering,
Presidency University, Bengaluru, India,
Email Id: - sumanpaul@presidencyuniversity.in

Oil and gas continue to be the major energy sources in the globe despite the advancements achieved in renewable energy. After using conventional oil recovery techniques, significant volumes of oil reserves are still not recovered. To recover bypassed oil and residual oil retained in the reservoir, chemically enhanced oil recovery (CEOR) has been determined to be an effective oil recovery approach. Chemical injections are used in this EOR technique to increase oil recovery. This review includes a current summary of chemical EOR along with a thorough discussion of the chemicals utilized and the mechanism guiding their use for oil recovery [1]–[3]. The difficulties in using the numerous standard chemical EOR procedures were emphasized, and it was recommended to find ways to solve them. Additionally, the contemporary trend of adding nanotechnology or their synergistic effects on the effectiveness and stability of traditional chemicals for EOR was also investigated and analyzed [4], [5].

Enhanced Oil Recovery

The process of creating liquid hydrocarbons using strategies other than the traditional ones, such as using gas or water to pressurize reservoirs and using reservoir energy. About 30% of the first oil in situ will typically be produced from a reservoir using traditional production techniques. The leftover oil, which makes up around 70% of the original resource, is a sizable and desirable target for improved oil recovery techniques.

Enhanced oil recovery processes can be classified into four categories:

1. Chemical flooding processes
2. Thermal flooding processes
3. Miscible flooding processes
4. Microbial flooding processes

Chemical Flooding

Chemical flooding depends on adding one or more chemical compounds to an injected fluid to either lower the interfacial tension between the reservoir oil and the injected fluid or to increase the injected fluid's sweep efficiency. Chemical flooding technology uses three standard techniques. The first is polymer flooding when a sizable macromolecule is utilized to raise the viscosity of the fluid being displaced. As a result, the reservoir's sweep efficiency is increased. Chemicals that lower the interfacial tension between an oil and a displacing fluid is used in the second and third approaches, micelle-polymer and alkaline flooding, respectively [6], [7].

Flooding Of Polymers

When reservoir brines and high temperatures are present, polymers lose surface viscosity, which increases injection viscosity and, as a result, mobility.

Surfactant flooding:

Surfactant flooding is a tried-and-true EOR method for releasing trapped residual oil from reservoirs. The purpose of surfactant injection into a reservoir is to improve the oil recovery factor by changing the wettability of the porous medium to change the fluid/fluid interaction by lowering IFT between the oil and brine as well as fluid/rock characteristics. Alkali flooding is an EOR approach that boosts the oil recovery factor by using an alkali (a basic chemical, ionic salt of an alkali metal, or alkaline earth metal). The approach differs from previous EOR methods in that during the EOR process, a saponification reaction generates the compounds that help in oil recovery on-site [8].

Surfactant Flooding

A tried-and-true EOR method called surfactant flooding is utilized to release trapped residual oil. The purpose of surfactant injection into a reservoir is to change the fluid/fluid interaction by lowering IFT between the characteristics of the oil and brine and fluid/rock via altering the wettability of the porous media. An amphiphilic substance is a surfactant, sometimes referred to as a surface-active agent molecule. This indicates that surfactants have two functional groups inside their organic shell. These are the non-polar hydrophobic group, which is often oil-soluble, and the hydrophilic group, which is typically water-soluble. The long-chain hydrocarbon, fluorocarbon, chain, or short polymer chain that is the lipophilic hydrophobic group is often branched or unbranched. The lip-phobic hydrophilic group, on the other hand, is made up of moieties whose categorization depends on the underlying chemical component.

Bibliography

[1] C. Zhang, X. Long, X. Tang, A. Lekomtsev, and G. Y. Korobov, “Implementation of water treatment processes to optimize the water saving in chemically enhanced oil recovery and hydraulic fracturing methods,” *Energy Reports*, 2021, doi: 10.1016/j.egyr.2021.03.027.

[2] C. Watkins, “Chemically enhanced oil recovery stages a comeback,” *Int. News Fats, Oils Relat. Mater.*, 2009.

[3] M. H. Ahmadi, S. M. Alizadeh, D. Tananykhin, S. K. Hadi, P. Iliushin, and A. Lekomtsev, “Laboratory evaluation of hybrid chemical enhanced oil recovery methods coupled with carbon dioxide,” *Energy Reports*, 2021, doi: 10.1016/j.egyr.2021.02.005.

[4] H. Bahraminejad, A. K. Manshad, and A. Keshavarz, “Characterization, Micellization Behavior, and Performance of a Novel Surfactant Derived from Gundelia tournefortii Plant during Chemical Enhanced Oil Recovery,” *Energy and Fuels*, 2021, doi: 10.1021/acs.energyfuels.0c03272.

[5] A. Mohsenatabar Firozjaii, M. Akbari, and G. Zargar, “Sensitivity analysis and optimization on effective parameters during chemical enhanced oil recovery (CEOR) using experimental design and numerical simulation,” *Energy Sources, Part A Recover. Util. Environ. Eff.*, 2019, doi: 10.1080/15567036.2018.1549164.

[6] A. Gbadamosi, A. Yusuff, A. Agi, P. Muruga, R. Junin, and O. Jeffrey, “Mechanistic study of nanoparticles-assisted xanthan gum polymer flooding for enhanced oil recovery: a comparative study,” *J. Pet. Explor. Prod. Technol.*, 2022, doi: 10.1007/s13202-021-01334-8.

[7] C. Nikolova and T. Gutierrez, “Use of Microorganisms in the Recovery of Oil From Recalcitrant Oil Reservoirs: Current State of Knowledge, Technological Advances and Future Perspectives,” *Frontiers in Microbiology*. 2020. doi: 10.3389/fmicb.2019.02996.

[8] S. H. Shafiai and A. Gohari, “Conventional and electrical EOR review: the development trend of ultrasonic application in EOR,” *Journal of Petroleum Exploration and Production Technology*. 2020. doi: 10.1007/s13202-020-00929-x.

CHAPTER - 2

CLASSIFICATIONS FOR THERMALLY ENHANCED OIL RECOVERY

Dr. Abhinav Kumar
Assistant Professor, Department of Petroleum Engineering,
Presidency University, Bengaluru, India,
Email Id: - abhinav@presidencyuniversity.in

The literature has shown the significance and widespread applicability of thermal EOR techniques. Over the last several decades, many different aqueous approaches that include water and its derivatives have been employed extensively. The most well-known thermal EOR procedures are cyclic steam stimulation (CSS), ISC, hot water and steam flooding, hot water injection, or steam-assisted gravity drainage (SAGD). The use of nonaqueous technologies, which provide thermal energy to the reservoir without injecting water or its byproducts, is one of the other thermal EOR strategies. Electric and electromagnetic heating are two examples of such techniques. Due to technical limitations and environmental concerns, nonaqueous technologies are seldom used; thus, more research is needed to make them more competitive. Combining nonaqueous technologies with water or solvent injection is a recent advancement in this direction. Later in this work, further information regarding thermal EOR techniques will be offered [1]–[3].

Heating Using Electrical and Magnetic Fields

This EOR method heats the heavy oil in its reservoir using an electrical current. The establishment of a vapour chamber in the reservoir as a result of the oil heating process will result in the oil's easy mobility. Three basic categories of electrical EOR techniques exist: low-frequency Ohmic heating is sometimes referred to as inductive heating, high-frequency heating, and radiofrequency/microwave heating. A potential difference is placed between two electrodes, one of which serves as an anode and the other as a cathode, in the process of ohmic heating. Two oil wells may be used in the field to do this, with one acting as the cathode while the other serves as the anode. This method has been found to have benefits and enhance oil recovery, but it also has some drawbacks. For example, it produces steam during heating, which reduces the quantity of water present and, as a consequence, the thermal energy that water can transmit. It has been proposed to combine this approach with water injection.

This is anticipated to improve the heating process, particularly in low-permeability zones. It had been shown via numerical modelling utilising the CMG-STARS thermal reservoir simulator that down-hole electric heating methods may be combined with the injection of a working fluid to improve heat transmission. Water, pure solvents (butane, hexane, and natural gas condensate), or mixtures of water and solvents were utilised as working fluids in the investigation. The research demonstrates that utilising a solvent and water mixture as the working fluid is more efficient than using a solvent alone. This is because the solvent's dilution impact enhances the solvent and water's heat transfer properties, speeding up the process. As a result, it was stated that the surface water-oil ratio was reduced to be 3–10 times lower than that of SAGD and that the quantity of steam required was also reduced. Recently, electromagnetic heating (EM), a relatively new EOR technology, has attracted a lot of interest. This technique uses electromagnetic waves to create electrical energy that is then transported to dielectric and resistive materials where it is converted to thermal energy for use in EOR (Figure 1). To be used in EOR, EM technology transforms EM energy into thermal energy. High-frequency (radio or microwave) or low-frequency waves may also induce electromagnetic heating in the reservoir. When combined with solvent injection, the EM approach for EOR provides several benefits, including a decrease in carbon emissions, a reduction in excessive water consumption, and comparatively greater performance.

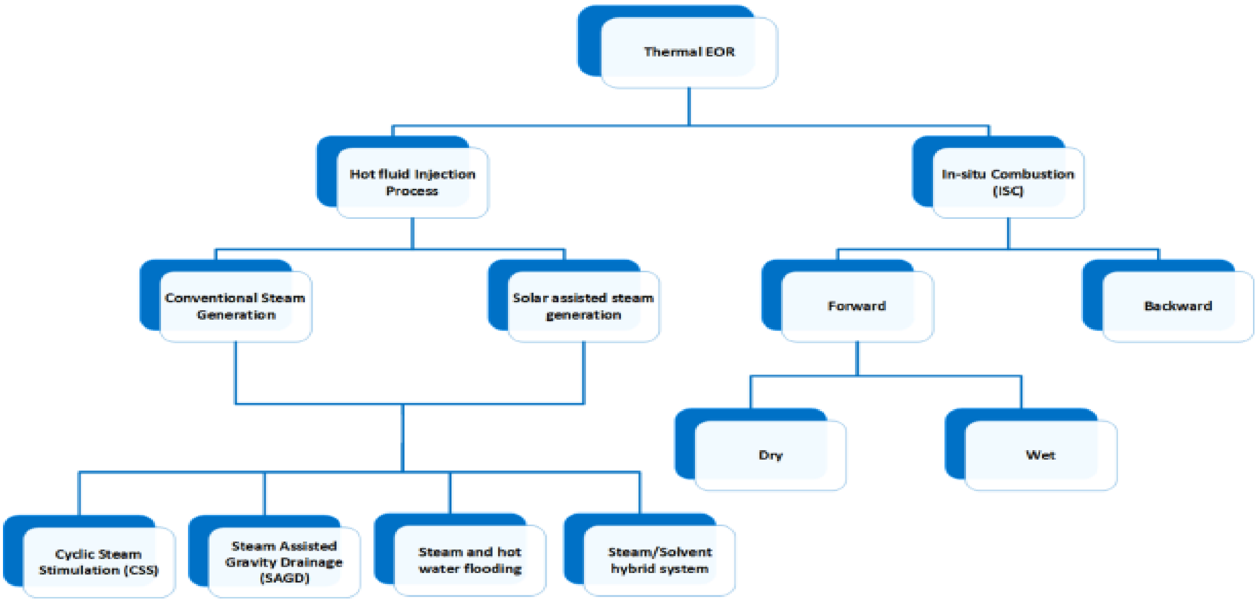

Figure 1: Illustrate the Thermal EOR processes

The impacts of EM heating power, initial water saturation, solvent kinds, and EM heating and solvent injection combination tactics in simultaneous or alternative ways were noted. Results showed that using solvent-assisted gravity drainage in addition to EM heating might improve oil recovery over using EM heating alone. Additionally, the performance of the system is impacted by the kind of solvent used. In comparison to EM heating and solvent injection occurring simultaneously, n-octane injection followed by EM heating results in greater performance. Additionally, it has been claimed that a modest initial water saturation improves the heating speed, which raises oil recovery. Electrically conductive materials were arranged in a field to perform EM induction heating with a changeable magnetic field produced by an inductor. To set up the flux in an electric machine, an electromotive force had been produced, and eddy current was produced using a device. The needed thermal energy is produced by this current, which depends on the material's heat capacity, the frequency of the induced current, the material's permeability, and the material's resistance to the passage of current through it [4]–[6].

For energy savings and process acceleration, preheating is crucial in EOR. To shorten the preheating period while conserving energy, down-hole electrical heaters (EH) and electromagnetic heating (EMH) have been proposed. The heating process for certain EOR techniques, such as SAGD, takes three to six months to complete. A model with a new analytical solution, having three different preheating processes, electrical heaters in both horizontal wells EH, electromagnetic antenna in the injector, steam circulation, and electrical heater in the producer EMH-EH was proposed. However, with high-frequency electromagnetic waves, this period could be reduced by the polarization of electrically conductive molecules inside the oil sands. The three approaches were contrasted in terms of energy savings and mobilization time. Electromagnetic heating (EMH) boosts energy savings, it was determined in the end. However, the literature is still developing in that area. Investigations carried out to examine this EOR technology led to crucial findings concerning its potential in oil recovery. An overview of the experimental, numerical, and field applications of EM heating for heavy oil recovery is one of them.

Bibliography

[1] A. R. Kovscek, “Emerging challenges and potential futures for thermally enhanced oil recovery,” *Journal of Petroleum Science and Engineering*. 2012. doi: 10.1016/j.petrol. 2012.08.004.

[2] P. D. Jordan and S. M. Benson, “Well blowout rates and consequences in California Oil and Gas District 4 from 1991 to 2005: Implications for geological storage of carbon dioxide,” *Environ. Geol.*, 2009, doi: 10.1007/s00254-008-1403-0.

[3] K. Ushijima, H. Mizunaga, and T. Tanaka, “Reservoir monitoring by a 4-D electrical technique,” *Lead. Edge*, 1999, doi: 10.1190/1.1438242.

[4] Y. Xu, C. Ayala-Orozco, P. T. Chiang, M. Shammai, and M. S. Wong, “Understanding the role of iron (III) tosylate on heavy oil viscosity reduction,” *Fuel*, 2020, doi: 10.1016/j.fuel.2020.117808.

[5] A. Ali, R. J. Chalaturnyk, and S. Movaghati, “Real-time reservoir model updating in thermal recovery: Application of analytical proxies and Kalman filtering,” *J. Pet. Sci. Eng.*, 2015, doi: 10.1016/j.petrol.2015.01.022.

[6] C. Tsingas and E. R. Kanasewich, “Seismic reflection amplitude versus angle variations over a thermally enhanced oil recovery site,” *Geophysics*, 1991, doi: 10.1190/1.1443043.

CHAPTER - 3

MISCIBLE ENHANCED OIL RECOVERY

Dr. Kalpajit Hazarika
Assistant Professor, Department of Petroleum Engineering,
Presidency University, Bengaluru, India,
Email Id: - kalpajithazarika@presidencyuniversity.in

Supercritical CO_2 is used in miscible EOR to remove oil from a depleted oil reservoir. By dissolving in the oil, making it swell, and lowering viscosity, CO_2 enhances oil recovery. CO_2 is an inexpensive injection source that may raise the recovery factor by 1-2$/Mscf. The majority of CO_2 flooding procedures take place in the US. Compressed nitrogen and hydrocarbon gases (natural gas and flue gas) are also utilised to replace miscible oil in high-depth reservoirs. These displacements in the reservoir may be just pressured maintenance [1]–[3].

Biological EOR

Up until the 2000s, chemical flooding was a less popular EOR technique than thermal or gas flooding, but now, enormous projects are recovered. Alkaline, surfactant, and polymer (soluble or cross-linked polymers) as well as additional chemicals including foaming agents, acids, and solvents, as well as combinations of alkaline-surfactant-polymer flooding, are injected during the chemical flooding operations (ASP). In the polymer flooding technique, water-soluble polymers were used to block off the reservoir's high-permeability zones and raise the viscosity of the water injected to expand the reservoir's swept area, which improved the efficiency of the displacement of moderately viscous oils. Under extremely particular conditions, adding a surfactant to the polymer formulation may lower the oil-water interfacial tension (IFT), remobilize stored oil, alter surface wettability, and therefore increase oil output. Some naphthenic acids in some oils may be converted by alkaline into surfactants that improve oil recovery. Additionally, the alkaline may help lower surfactant retention in the rock.

Fundamentals and Co_2 Flooding Mechanism

CO_2 flooding in low permeability and light-oil reservoirs is one method for improving oil recovery, and it can raise the recovery factor from 10% to 20%. Additionally, it lowers greenhouse gas emissions by storing CO_2. Gas miscible flooding refers to the idea that the displacing gas and reservoir oil are miscible at initial contact or after many contacts, which enhances the volumetric sweeping or displacement efficiencies (Ev or Ed), respectively. Between the reservoir oil as well as the displacing gas, a transition zone will form, where the miscibility of the injected gas depends on the pressure, temperature, or oil characteristics of the reservoir. Two processes are involved in CO_2 miscible flooding [4]–[6].

Simulation and Performance of CO_2-Miscible Floods

MMP measurement is used to ascertain the reservoir's miscibility before a CO_2 flooding. The CO_2-EOR process is then tested on a modest scale in the field in a pilot test that follows. If all tests are successful, reservoir modelling is done to (a) scale up the EOR process to a complete oil field and (b) determine the best WAG ratio and hydrocarbon pore volume injection volumes for maximum oil recovery. The effectiveness of a flooding process is assessed by investigating the CO_2 and water slug, the performance of oil-production wells, the gas-to-oil ratio and water cut, and the injection wells for fluid distribution among various reservoir layers because these variables have a significant impact on the recovery factor.

Miscible Flooding

Miscible flooding is dependent on the oil's light components being mobilised, the oil's viscosity being reduced, the oil vaporising and expanding, and the interfacial tension is reduced. At the minimum miscibility pressure (MMP), which is determined experimentally through slim-tube tests or by mathematical correlations and is defined as the pressure at which more than 80% of the original oil-in-place (OOIP) is recovered at CO_2 breakthrough, the injected CO_2 completely dissolves through crude oil. On an industrial scale, however, a general rule-of-thumb for calculating MMP is an oil recovery of at least 90% per 1.2 pore volume of CO_2 injected. When the reservoir pressure is over the MMP, the intermediate and higher molecular weight hydrocarbons from the reservoir oil evaporate into the CO_2 (vaporised gas-drive process), and some of the injected CO_2 dissolves into the oil. This process is known as multiple-contact or dynamic miscibility (condensed gas-drive process). This mass transfer between the oil and CO_2 enables total interface-free miscibility between the two phases and aids in the formation of an oil- and CO_2-miscible transition zone. One initial contact, a vaporising gas drive, and a condensing gas drive make up CO_2 miscible flooding.

IMMISCIBLE FLOODING

Oil viscosity decrease, oil phase swelling, the removal of lighter components, and the fluid drive are all necessary for immiscible flooding. The CO_2 and oil will not combine into a single phase when the reservoir pressure is below the MMP or the reservoir oil composition is unfavourable (i.e., immiscible). However, when CO_2 dissolves in the oil, the viscosity of the oil is reduced, it swells, and solution gas is produced. These effects enhance sweeping effectiveness and permit more oil recovery. Like hydrocarbon gases, the miscibility of CO_2 through crude oil changes with temperature and pressure.

Approximately 20–40% of the OOIP is produced via primary and secondary oil recovery. As a result, the reservoir contains a significant volume of potentially unrecovered oil that may be the focus of effective EOR procedures. One of the extensively used EOR techniques is CO_2-miscible flooding, which recovers large quantities of crude oil while minimising the environmental damage caused by gas emissions. CO_2 may be injected as a water-alternating gas or a continuous stream (WAG). Successful CO_2 miscible flooding implementation requires a thorough analysis of the reservoir screening criteria, which include the reservoir's permeability and porosity API gravity, temperature, oil viscosity, depth, or net pay thickness.

Bibliography

[1] D. Alfarge, M. Wei, and B. Bai, “Numerical simulation study on miscible EOR techniques for improving oil recovery in shale oil reservoirs,” *J. Pet. Explor. Prod. Technol.*, 2018, doi: 10.1007/s13202-017-0382-7.

[2] H. R. Lashgari, A. Sun, T. Zhang, G. A. Pope, and L. W. Lake, “Evaluation of carbon dioxide storage and miscible gas EOR in shale oil reservoirs,” *Fuel*, 2019, doi: 10.1016/j.fuel.2018.11.076.

[3] M. Khan, A. Raza, M. K. Zahoor, and R. Gholami, “Feasibility of miscible CO_2 flooding

in hydrocarbon reservoirs with different crude oil compositions," *J. Pet. Explor. Prod. Technol.*, 2020, doi: 10.1007/s13202-020-00899-0.

[4] J. Zhang, H. X. Zhang, L. Y. Ma, Y. Liu, and L. Zhang, "Performance evaluation and mechanism with different CO2 flooding modes in tight oil reservoir with fractures," *J. Pet. Sci. Eng.*, 2020, doi: 10.1016/j.petrol.2020.106950.

[5] X. Su and X. an Yue, "Mechanism study of the relation between the performance of CO2 immiscible flooding and rock permeability," *J. Pet. Sci. Eng.*, 2020, doi: 10.1016/j.petrol.2020.107891.

[6] J. Qin, K. Zhang, and X. Chen, "Mechanism of the CO2 flooding as reservoirs containing high water," *Shiyou Xuebao/Acta Pet. Sin.*, 2010.

CHAPTER - 4

MICROBIAL FLOODING PROCESSES

Dr. Deepjyoti Mech
Assistant Professor, Department of Petroleum Engineering,
Presidency University, Bengaluru, India,
Email Id: - deepjyotimech@presidencyuniversity.in

Researchers and oil field operators have focused on the need to develop and/or advance the present enhanced oil recovery (EOR) technologies to make them more effective. This ongoing focus on the issue over the last several decades has led to a sluggish but steady increase in the average oil recovery factors. For instance, the average oil recovery factor in the USA is 39%, but the global average recovery rate is now about 30%. However, many experts predict that the recovery factor might reach 50–60%, or even 70–80%, shortly [1]–[3].

The process of shifting the accumulated gas and liquid hydrocarbons in the reservoir in the direction of producing wells is referred to as the development of an oilfield. Oil is generated first by exploiting the reservoir's inherent driving energy (i.e., primary recovery operations), or after the reservoir's inherent driving energy has been exhausted, by adding energy during secondary oil recovery (i.e., waterflooding or gas flooding).

The majority of the hydrocarbon reserves, particularly in Kazakhstan, have already been found and economically exploited. These mature reservoirs now have a decreasing number of drilling locations that are of economic interest. This presents an opportunity for the deployment of EOR techniques, such as the use of microbial enhanced oil recovery (MEOR) technology, due to the residual oil remaining in these mature hydrocarbon resources after secondary and primary oil recovery.

MEOR: Opportunities and Challenges

On a global scale, both primary and secondary oil recovery methods recover 33% of the original oil in place (OOIP); the remaining 67% of the oil may be kept in the reservoir by viscous or capillary forces. Chemical EOR applications use conventional chemicals like surfactants and solvents, which are surface-active substances. Surfactants lower the interfacial tension between oil and rock or oil and water by overcoming capillary forces, whilst solvents decrease the oil viscosity to facilitate the oil mobility. These chemicals are mixed with the injection water and moved throughout the reservoir during water flooding, but they only reach the areas where the water has already replaced the oil. In addition, the chemicals may be partially consumed and/or trapped within the rock formation before they reach the intended target area [2], [4], [5].

Due to the chemicals' failure to remain in touch with the residual oil for the necessary amount of time, which is necessary to provide a long-lasting effect, the injection of solvents or surfactants into certain reservoirs has produced disappointing results. Another issue is the reservoirs' inherent heterogeneity, which forces injected chemicals to flow where there is least resistance (e.g., high permeability zones, natural fissures, etc.), where residual oil saturation is often lowest. Since many years ago, it has been known that some kinds of microbes may break down hydrocarbons into organic solvents including alcohols, surface-active fatty acids, aldehydes, as well as other metabolites that can interact with crude oil to increase its fluidity. Microorganisms may also be used to manage other difficulties with oil production, such as the presence of paraffin, emulsions, or corrosion concerns. For instance, a lot of studies have been done on the utilisation of biosurfactants (BS) for applications related to increased oil recovery. The projects are evaluated to see whether the crude oil and reservoir qualities are compatible with MEOR before using MEOR technologies, taking into consideration the physicochemical characteristics of the crude oil, reservoir production performance, and reservoir attributes (i.e., temperature). In the first phase, samples of the reservoir fluid are gathered and examined for MEOR system compatibility. The first step is to identify the native bacterium that consumes hydrocarbons and is already suited to the circumstances of the in situ reservoir. Following this, the optimal action plan for each project is created.

Mechanisms for Recovering MEOR Oil

The components are combined at facilities on the surface before being pumped into the oil reservoir during the MEOR process. The injected water moves MEOR bacteria across the reservoir, where they gather in porous areas at the oil/rock or oil/water interfaces. Very little quantities of oil are consumed by bacteria, which then release metabolites such as carbon dioxide, surfactants, solvents, and acids. By eliminating paraffin, dirt, and other debris that clog the porous medium, these bioproducts increase rock permeability by interacting with the oil in the reservoir to lower oil viscosity, interface tension at the oil/rock and oil/water interfaces, and interface tension at the oil/water interface. Microbial cells and metabolites are produced in situ constantly. Long-term interactions between metabolites and the oil in the reservoir alter the oil's characteristics in such a manner that immobile, unrecoverable oil is transformed into moveable oil that may flow to the production wells, boosting oil output in line with this shift. The metabolism of microorganisms leads to the microbial breakdown of oil, a complex chemical molecule, where the hydrocarbon-oxidizing bacteria's metabolic byproducts serve as the substrate for other physiological groups in the reservoir. Fatty acids are created when hydrocarbons break down and may be used by other bacteria.

Bibliography

[1] M. G. J. Plata, M. A. E. Hernández, and R. G. T. Sáez, “Experimental Design for Evaluation of Formation Damage by Microbial Contamination in Water Flooding Processes. A Colombian Study Case,” *Fuentes el Revent. Energ.*, 2019, doi: 10.18273/REVFUE.V17N2-2019002.

[2] H. She, D. Kong, Y. Li, Z. Hu, and H. Guo, “Recent Advance of Microbial Enhanced Oil Recovery (MEOR) in China,” *Geofluids*. 2019. doi: 10.1155/2019/1871392.

[3] D. A. Hutchins, J. K. Jansson, J. V. Remais, V. I. Rich, B. K. Singh, and P. Trivedi, “Climate change microbiology — problems and perspectives,” *Nature Reviews Microbiology*. 2019. doi: 10.1038/s41579-019-0178-5.

[4] P. Mueller, D. Granse, S. Nolte, M. Weingartner, S. Hoth, and K. Jensen, “Unrecognized controls on microbial functioning in Blue Carbon ecosystems: The role of mineral enzyme stabilization and allochthonous substrate supply,” *Ecol. Evol.*, 2020, doi: 10.1002/ece3.5962.

[5] G. Wang, L. Duan, F. Han, R. Wang, S. Liu, X. Lei, J. Jing, Y. Gu, and Y. Lei, “Research on the change rule of microbial community in the microbial flooding process of Baolige oilfield,” 2020. doi: 10.1088/1757-899X/729/1/012040.

CHAPTER - 5

SURFACTANT FLOODING MECHANISM

Dr. Kalpajit Hazarika
Assistant Professor, Department of Petroleum Engineering,
Presidency University, Bengaluru, India,
Email Id: - kalpajithazarika@presidencyuniversity.in

Through the processes of interfacial tension reduction, wettability modification, or a combination of the two mechanisms, surfactant flooding increases pore-scale displacement efficiency. It is very hard for water to completely dispense all the oil in the pore scale during secondary recovery by water flooding owing to oil being trapped by capillary pressures. A dimensionless Capillary number is used to calculate this capillary force (Nc) There are three methods to do this:

a. Increasing the displacing fluid viscosity
b. Increasing the injection fluid velocity
c. Reducing the IFT

By raising the injection pressure above the reservoir's fracture pressure, increasing the injection fluid velocity may fracture the reservoir rock. The capillary forces holding back the trapped oil are weakened by a reduction in IFT at the oil/water interface, allowing oil droplets to easily flow from the pore throats of the rock and create an oil bank downstream. By raising the injection pressure above the reservoir's fracture pressure, increasing the injection fluid velocity may fracture the reservoir rock. The capillary number rises by less than 100 times when the displacing fluid viscosity is increased using polymer solutions. The only practical way to raise NC by 1000 times is to reduce IFT [1]–[3].

When brine and surfactant solutions are injected into oil reservoirs, the hydrophobic tail interacts with the components of crude oil while the hydrophilic head interacts with water. The interaction between the oil and alkyl tail of the surfactant results in an adsorbed film, which lowers the IFT at the oil/water interface.

Alteration of wettability:

Wettability is the ability or tendency of a solid surface to hold a certain kind of fluid when other immiscible fluids are present. The position, distribution, and flow of fluids inside a given reservoir are determined and controlled by the wettability of the rock surface in the reservoir rock system. Physical characteristics have a significant role in oil recovery because they affect factors like relative permeability and capillary pressure. Most oil reservoirs are classified as being in an oil-wet, water-wet, or mixed-wet condition depending on their wettability. Any of the following techniques (surface imaging tests, zeta potential measurements, spontaneous imbibition’s, and contact angle measurements) may be used to gauge this characteristic of the reservoir rock system. The point where the interface of the oil and water contacts at the rock surface defines the contact angle, which is used in the majority of investigations of wettability alteration measures.

The adhesive force of capillarity is reduced and the oil permeability of the reservoir is increased when the wettability of a surface is changed from oil-wet to water-wet. Thus, it may be concluded that oil recovery is easier in a reservoir that is water-wet as opposed to oil-wet. Only conventional and unconventional reservoir rock systems have been explored for the application of surfactants to change wettability. A study found that adding surfactants to frac fluids at the right concentration improved the effectiveness of hydraulic fracture therapy for unconventional (shale and tight) reservoirs with low and/or ultra-low permeability by changing the matrix wettability and, in turn, the fluid flow behavior. As a consequence, spontaneous imbibition takes place, which allows the aqueous phase to enter into the matrix by defeating the capillary forces holding the oil in place and increasing oil recovery [4], [5]. Similar to this, active chemicals called surfactants are employed to extract oil from typical sandstone or carbonate reservoirs. The process by which a surfactant changes the wettability of typical rock pores is known as a cleaning mechanism because it desorbs the oil-wet layer. The surface becomes less water-wettable and more water-wet as a result of surfactant desorption of the oil-wet layer.

Types of Surfactants and Their Structure

Numerous surfactants have been evaluated and tested for their appropriateness in oil recovery via laboratory testing and field research of surfactant EOR. Depending on the makeup of the hydrophilic head group, they are primarily categorized as anionic surfactants, non-ionic surfactants, cationic surfactants, or zwitterionic surfactants. New sets of surfactants are now being created and evaluated for EOR applications owing to the lack of traditional surfactants in flooding operations. This comprises biosurfactants, geminin surfactants, viscoelastic surfactants, and polymeric surfactants. Additional information on the characteristics and effectiveness of this new family of surfactants [6], [7].

An Anionic Surfactant

Cationic surfactants are surfactants that have a halide group together with a hydrophilic head that is positively charged. In the presence of water, they separate into an anion and an amphiphilic cation. This family of surfactants is highly effective in modifying the wettability of reservoir rock because it is readily attracted to the negatively charged surfaces of clays. Due to the similarity of their surface charges, cationic surfactants have been discovered as the key to releasing the huge and plentiful hydrocarbons contained in carbonate deposits. However, due to the high-pressure hydrogenation process needed for their production, they are more costly than anionic surfactants [8].

The Non-Ionic Surfactant

Non-ionic surfactants do not ionize in an aqueous solution, in contrast to anionic and cationic surfactants. Non-dissociable functional groups like phenol, ester, ether, alcohol, or amide make up the hydrophilic group. The alkyl or alkyl benzene group makes up the lipophilic group. Despite having no ionic charge, the hydrophilic group is soluble in water due to its intrinsic polarity, which is brought on by the existence of hydrogen bonds and van der Waals interactions. Nonionic surfactants have a better salt tolerance than ionic surfactants but a lesser capacity to reduce IFT.

Bibliography

[1] W. Yang, J. Lu, B. Wei, H. Yu, and T. Liang, “Micromodel Studies of Surfactant Flooding for Enhanced Oil Recovery: A Review,” *ACS Omega*. 2021. doi: 10.1021/acsomega.0c05750.

[2] O. T. Isaac, H. Pu, B. A. Oni, and F. A. Samson, "Surfactants employed in conventional and unconventional reservoirs for enhanced oil recovery—A review," *Energy Reports*. 2022. doi: 10.1016/j.egyr.2022.01.187.

[3] J. Liu, L. Zhong, T. Hao, Y. Liu, and S. Zhang, "Pore-scale dynamic behavior and displacement mechanisms of surfactant flooding for heavy oil recovery," *J. Mol. Liq.*, 2022, doi: 10.1016/j.molliq.2021.118207.

[4] R. Vishnudas and A. Chaudhuri, "Effects of polymer dispersion and adsorption on immiscible and miscible viscous instabilities during chemical enhanced oil recovery," *J. Porous Media*, 2019, doi: 10.1615/JPorMedia.2019028849.

[5] A. Gbadamosi, A. Yusuff, A. Agi, P. Muruga, R. Junin, and O. Jeffrey, "Mechanistic study of nanoparticles-assisted xanthan gum polymer flooding for enhanced oil recovery: a comparative study," *J. Pet. Explor. Prod. Technol.*, 2022, doi: 10.1007/s13202-021-01334-8.

[6] M. Y. Rezk and N. K. Allam, "Impact of Nanotechnology on Enhanced Oil Recovery: A Mini-Review," *Industrial and Engineering Chemistry Research*. 2019. doi: 10.1021/acs.iecr.9b03693.

[7] C. Negin, S. Ali, and Q. Xie, "Most common surfactants employed in chemical enhanced oil recovery," *Petroleum*. 2017. doi: 10.1016/j.petlm.2016.11.007.

[8] P. Druetta, P. Raffa, and F. Picchioni, "Chemical enhanced oil recovery and the role of chemical product design," *Applied Energy*. 2019. doi: 10.1016/j.apenergy.2019.113480.

CHAPTER - 6

THE IMPACT OF ANIONIC SURFACTANTS

Dr. Barasha Deka
Assistant Professor, Department of Petroleum Engineering,
Presidency University, Bengaluru, India,
Email Id: - barasha.deka@presidencyuniversity.in

Chemical EOR (CEOR) has been in the spotlight for decades and has received academic research attention notably in the field of reservoir applications. In the past, several research have sought to solve the problems associated with chemical flooding by examining the chemical adsorption processes that maintain the concentration of effective groups during flooding. Therefore, the purpose of this work is to explore the fundamental ideas behind the aforementioned parameter in order to provide future guidelines for managing surfactant losses as a result of adsorption. The emphasis is on how various factors, such as pH, temperature, surfactant type, and minerology, affect the adsorption of anionic surfactants [1]–[3].

Hydrocarbon chains, functional groups, and the purity of anionic surfactants are all factors in surfactant adsorption. The oil and gas sector is not very concerned about anionic surfactant purity, but colloids are. According to many accounts, the arrangement of the molecules, which is dependent on their attraction to one another, determines how the functional groups affect the structure of the adsorbed layers. The comparison of adsorption behaviour for isomeric surfactants with the same functional group stays the same and greatly relies on the charge of the functional group. It follows that anionic surfactants with longer chains have a direct interaction with aggregate on the rock surface. As a consequence, surfactants with longer hydrocarbon chains have a significantly stronger driving power for aggregation.

Mineralogy’s Impact

Sand-quartz, feldspar, or clay minerals are the most common minerals in sandstone reservoirs. Depending on the sandstone's depositional environment, different clay minerals, such as kaolinite, illite, montmorillonite, and chlorite, are present. The impact of clay minerals on the adsorption of anionic surfactant with a single adsorbent or clay fraction effect has been addressed by a number of writers. They said that the mineral kaolinite has the maximum adsorption, but that even negative ions and the effect of mineral surface area may alter adsorption. Few scholars have looked at how the structure of clay minerals and the type of surfactants affect adsorption, especially when montmorillonite and illite are used as a single adsorbent on an anionic surfactant. All of the findings point to an anionic surfactant and the kaolinite mineral's electrostatic link as the primary adsorption mechanism, and to the other clay mineral's relatively weak hydrogen bond.

Salinity's Impact

One of the causes of enhanced adsorption is the presence of free salt ions. The adsorption of anionic surfactants on quartz and kaolin sample is influenced by the presence of sodium chloride (NaCl) or calcium chloride ($CaCl_2$) in the solutions of anionic surfactants (NP10S, NP4S, NP25S, oxyethylene). The quantity of anionic surfactants that are adsorbed on solid surfaces rises with the addition of salts. The 98% pure anionic surfactant sodium dodecyl sulphate (SDS) was found to be more readily adsorbed on the surface of the sand as the salinity of the solution was raised. This is because there was less electrostatic repulsion between the surfactant species that were being adsorbed. Additionally, when the concentration of surfactants increased, more adsorption occurred on the surface of the sand particles until it reached the saturation point. The surface tension methodology and two-phase titration method were used to study the adsorption of sodium dodecyl sulphate (SDS) on kaolinite at varied surfactant concentrations and with additional electrolytes ($CaCl_2$, NaCl, or $AlCl_3$). They concluded that as the concentration of NaCl or $CaCl_2$ rises, so does the adsorption of SDS by kaolinite. Demonstrating that monovalent ions have an increased adsorption impact. However, the presence of trivalent and divalent ions reduces the solubilization of the surfactant and results in surfactant precipitation [4]–[6].

Temperature Effect

Early studies on the temperature relation of solution adsorption revealed that as temperature rises, adsorption decreases. The greater the adsorption, which is an exothermic reaction, the lower the temperature. To successfully interpret the impact of temperature on adsorption, however, surfactant thermal breakdown interference must be removed. Sulfonate precipitation has been created by the mineral dissolution at high temperatures. To increase surfactant solubility when using sulfonates as additions, cosurfactants or sequestering agents may be needed.

Result of PH

Adsorption is significantly influenced by pH, which also affects how charged the rock surface is. The adsorption of protons from the solution onto charged sites causes the solid surface to become more positive when the Ph of an aqueous solution is lower than 6. The adsorption of anionic surfactants, which is carrying a negative sign, will tend to increase due to the low pH. Given the wide range of surfactant types, anionic surfactant continues to be advantageous for CEOR, particularly for sandstone reservoirs. The stability and adsorption of surfactants in the real world may be impacted by the stated formation water total dissolved ions, reservoir temperature, and soil mineralogical composition. To prevent surfactant losses and make the project economically viable, the stated consideration has to be understood under various physicochemical circumstances. Eliminating these losses will make it possible to create effective anionic surfactant and processing methods for oil recovery.

Bibliography

[1] T. Cserháti, E. Forgács, and G. Oros, “Biological activity and environmental impact of anionic surfactants,” *Environ. Int.*, 2002, doi: 10.1016/S0160-4120(02)00032-6.

[2] Y. R. Bazel, I. P. Antal, V. M. Lavra, and Z. A. Kormosh, “Methods for the determination of anionic surfactants,” *Journal of Analytical Chemistry*. 2014. doi: 10.1134/S1061934814010043.

[3] G. Kume, M. Gallotti, and G. Nunes, “Review on anionic/cationic surfactant mixtures,” *J. Surfactants Deterg.*, 2008, doi: 10.1007/s11743-007-1047-1.

[4] A. M. Al-Sabagh, N. M. El Basiony, S. A. Sadeek, and M. A. Migahed, “Scale and corrosion inhibition performance of the newly synthesized anionic surfactant in desalination plants: Experimental, and theoretical investigations,” *Desalination*, 2018, doi: 10.1016/j.desal.2018.01.036.

[5] B. Wyrwas and A. Zgoła-Grześkowiak, “Continuous flow methylene blue active substances method for the determination of anionic surfactants in river water and biodegradation test samples,” *J. Surfactants Deterg.*, 2014, doi: 10.1007/s11743-013-1469-x.

[6] T. Zhu, Z. Zhou, F. Qu, B. Liu, and B. Van der Bruggen, “Separation performance of ultrafiltration during the treatment of algae-laden water in the presence of an anionic surfactant,” *Sep. Purif. Technol.*, 2022, doi: 10.1016/j.seppur.2021.119894.

CHAPTER - 7

INTRODUCTION TO CHEMICAL ENHANCED OIL RECOVERY (ALKALI-SURFACTANT)

Dr. Deepjyoti Mech
Assistant Professor, Department of Petroleum Engineering,
Presidency University, Bengaluru, India,
Email Id: - deepjyotimech@presidencyuniversity.in

EOR is a technique for increasing the value of already-existing assets. Increasing oil recovery from a deposit includes injecting a chemical into the formation. The most popular EOR method in recent years has been chemical, and the chemicals employed are polymer, alkali, and surfactant. These substances can be used singly or in combination. Chemical EOR, a technology that recovers between 30 and 60% of the oil in a reservoir, is used to manage the majority of the depleting reservoirs in India's Upper Assam basin [1], [2]. In core flooding investigations carried out in reservoir settings with few slugs, the improved performance of chemical water was proven. Clay minerals like kaolinite and smectite predominate in the reservoir under investigation. Due to the anionic nature of the reservoir, the anionic surfactant will be appropriate for this investigation. Smart water containing alkali will lessen the adsorption of surfactant and lower IFT since the reservoir is water-wet. The oil recovery factor was twice as high after alkali-surfactant flooding as it was after water flooding.

Oil and gas resources continue to provide a significant contribution to the world's energy supply, notwithstanding recent energy output from renewable sources. It becomes more important to maximize oil recovery from previously under-exploited reservoirs to fulfil the rising global energy demand in the face of declining energy resources. The three stages of oil recovery include primary, secondary, and tertiary enhanced oil recovery (EOR) phases. The two most often utilized forms of EOR technologies are thermal and chemical EOR techniques. However, in reservoirs with a deep pay zone and a limited pay zone, thermal EOR methods are beneficial. Due to its higher efficiency, technological and economic viability, and low capital cost, chemical EOR has been deemed the most practicable of all EOR techniques. Three chemical EOR techniques are polymer flooding, surfactant flooding, and alkaline flooding. The Upper Assam Basin is an excellent reservoir to use for chemical EOR. By examining various samples of crude oil, rock formation samples, or formation water samples, this experimental investigation on the Upper Assam Basin resulted in the development of chemical water with alkali or surfactant [3], [4].

Oil and gas resources continue to provide a significant contribution to the world's energy supply, notwithstanding recent energy output from renewable sources. It becomes more important to maximize oil recovery from previously underutilized reserves to fulfill the rising global energy demand close to decreasing energy resources. By analyzing various crude oil samples, rock formation samples, or formation water samples, the basin led to the development of chemical water with alkali and surfactant to increase rock wettability and oil recovery. The formulation of chemicals and chemical slugs was based on investigations of the reservoir clay, surface tension, wettability, and IFT. In the reservoir being studied, kaolinite and smectite are the dominant clay minerals. It will be reasonable to utilize an anionic surfactant for this investigation because the reservoir is anionic. In reservoirs with restricted slugs, core flooding tests using chemical water showed enhanced performance [5], [6].

The discovery of crude oil at Naharpung, Assam, in 1866 marks the beginning of the history of oil and gas in the Upper Assam Basin. Oil was first discovered in the area in the late 1960s, and commercial production only started in 1974. Since then, the Upper Assam Basin has been producing crude oil from the oil reservoirs, and as a result of primary and secondary recovery techniques, it is currently in the late stage of depletion. EOR is becoming more and more in demand as a result. In this study, different samples of crude oil, rocks, and formation water are tested to determine their properties, and then the identification of chemical slug is done following those results. The chemical slug is then created, and core flooding is used to calculate the recovery factor.

Large volumes of oil are left in the reservoir by traditional oil recovery techniques. An approach for improved oil recovery is thought to be the ASP process. Using phase behavior, interfacial tension, surfactant usage, and numerical modelling approaches, this dissertation shows the ASP features. My flooding trials show that my ASP procedures successfully retrieve the oil trapped after water flooding. When the Water Oil Ratio (WOR) or synthetic surfactant concentration in the ASP system changes, the ideal salinity changes as well. The ideal salinity in this thesis depends solely on the molar ratio of a natural soap to a synthetic surfactant, or soap fraction of total soap plus surfactant. These results might be condensed into a single curve for each synthetic surfactant/crude oil combination.

In comparison to the system without alkali, the ASP system under study has a substantially broader low IFT area (0.01 mN/m). A second phase including surfactants was shown to exist in colloidal solution in most of the Winsor I area where an oil-in-water microemulsion coexists with excess oil. The achievement of the ultra-low tension is significantly aided by this colloidal dispersion. To ensure that there is initially enough of the dispersed material to create low tensions but not enough to cover the oil drop during IFT measurements, a novel methodology is designed that considerably shortens the time needed to attain equilibrium. One of the biggest obstacles to the commercial use of ASP is surfactant retention. It was shown that, especially at low salinities, Na_2CO_3, but not NaOH or Na_2SO_4, may significantly inhibit the adsorption of anionic surfactants on carbonate formations. To simulate the ASP process, a one-dimensional numerical simulator was created.

Bibliography

[1] N. Lashari and T. Ganat, “Emerging applications of nanomaterials in chemical enhanced oil recovery: Progress and perspective,” *Chinese Journal of Chemical Engineering*. 2020. doi: 10.1016/j.cjche.2020.05.019.

[2] A. O. Gbadamosi, R. Junin, M. A. Manan, A. Agi, and A. S. Yusuff, “An overview of chemical enhanced oil recovery: recent advances and prospects,” *Int. Nano Lett.*, 2019, doi: 10.1007/s40089-019-0272-8.

[3] Z. Liu, G. Zhao, M. Brewer, Q. Lv, and E. J. R. Sudhölter, “Comprehensive review on surfactant adsorption on mineral surfaces in chemical enhanced oil recovery,” *Advances in Colloid and Interface Science*. 2021. doi: 10.1016/j.cis.2021.102467.

[4] P. Druetta, P. Raffa, and F. Picchioni, “Chemical enhanced oil recovery and the role of chemical product design,” *Applied Energy*. 2019. doi: 10.1016/j.apenergy.2019.113480.

[5] M. Chemil, Z. Zizi, N. Drouiche, M. Khodja, and M. Hadji, “Water treatment technology performance for chemical enhanced oil recovery: modeling, simulation and optimization,” *Appl. Water Sci.*, 2021, doi: 10.1007/s13201-021-01476-4.

[6] C. S. Loaiza, J. F. Patiño, and J. M. Mejía, “Numerical evaluation of a combined chemical enhanced oil recovery process with polymer and nanoparticles based on experimental observations,” *J. Pet. Sci. Eng.*, 2020, doi: 10.1016/j.petrol.2020.107166.

CHAPTER - 8

CLASSIFICATION OF EOR TECHNOLOGIES

Dr. Kalpajit Hazarika
Assistant Professor, Department of Petroleum Engineering,
Presidency University, Bengaluru, India,
Email Id: - kalpajithazarika@presidencyuniversity.in

Oil and gas reserves remain the primary source of the world's energy supply, notwithstanding the recent rise in energy output from renewable sources. In contrast to the depletion of energy resources, it becomes more crucial to optimize oil recovery from previously under-exploited reservoirs to meet the world's expanding energy demand. Most oil recovery procedures consist of the primary, secondary, and tertiary (EOR) phases. Following the application of both primary and secondary oil recovery techniques, the reservoir still contains two-thirds of the original oil in place (OOIP) [1], [2]. This is a result of capillary forces either avoiding or retaining the oil (residual oil). Skipped oil forms as a result of reservoir heterogeneities or an unfavourable mobility ratio between the aqueous or oleic phases. Contrarily, the remaining oil is made up of discrete ganglia that arise when an oleic mass protrusion that resembles a finger narrows down due to the interplay of interfacial tension and a local pressure gradient (IFT).

To improve the overall oil displacement efficiency, many EOR approaches have been created and are now being applied. A combination of microscopic (pore scale) or macroscopic (volumetric sweep) oil displacement efficiency occurs during oil recovery. Macroscopic displacement efficiency measures how effectively the injected fluids contact the oil zone volumetrically concerning the total reservoir volume, whereas microscopic displacement efficiency refers to the ability of the displacing fluid(s) to mobilize oil trapped at the pore scale when it contacts the oil. In conclusion, EOR benefits from any mechanism that increases oil recovery efficiency at the macro, micro, or both scales. Thermal and non-thermal EOR approaches make up the majority of the developed and in-use EOR techniques [3], [4]. Unfortunately, thermal EOR methods are not appropriate for reservoirs having a deep pay zone or shallow pay zone. Non-thermal EOR has garnered a lot of attention as a way to recover oil that has been overlooked or stuck in the reservoir.

Due to its higher efficiency, economic and technological feasibility, and low capital cost, chemical EOR, a non-thermal EOR method, has been rated the most promising of all EOR technologies. The application of this EOR technology became more widespread in the 1980s as a result of increased oil prices and technological developments that make it feasible to understand their function. Oil recovery is increased by chemical EOR technologies because they increase the effectiveness of the water pushed into the reservoir to distribute the oil. Depending on the kind of chemical EOR method employed, the chemicals injected with the water slug alter the fluid-fluid and/or fluid-rock interactions in the reservoir. This can entail lowering the IFT between the imbibing fluid and oil or raising the injectant's viscosity for improved mobility and conformance control. Chemicals are also injected to alter the rock's wettability and increase oil permeability [5], [6].

Alkaline, surfactant, and polymer flooding are three well-known conventional chemical EOR techniques. The traditional chemical EOR techniques do, however, have certain drawbacks. Polymers lose viscosity in the presence of reservoir brines and high-temperature circumstances because their primary recovery mechanism is to improve the viscosity of injections and, as a result, mobility. Due to adsorption processes, surfactants and alkalis lose their effectiveness while flowing through porous media. Different methods of chemical flood injections were later developed, researched, and used for EOR operations. These include the polymer/polymer (SP), alkali/polymer (AP), and surfactant/alkaline/polymer (ASP) slug binary mixtures as shown in Figure 1. When used in oil wells, the synergy of the combined conventional chemicals showed higher efficiency. Foam boosted by surfactants or polymers has recently been examined for increased stability & mobility control but has also been found to improve oil recovery.

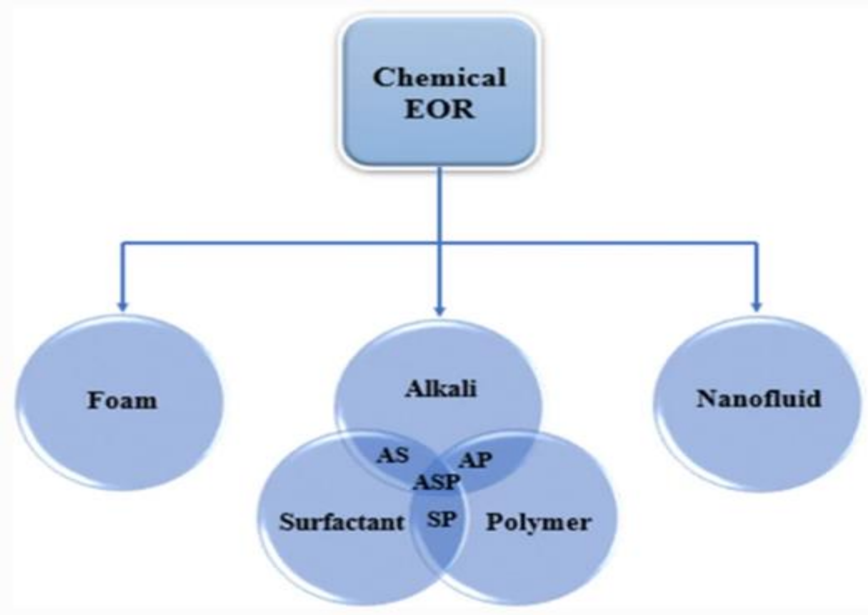

Figure 1: Illustrate the Classification of EOR.

Its usage and use in the oil and gas business have only lately been motivated by the development of nanotechnology and its applications to increase the effectiveness of different processes in the domains of metallurgy, catalysis, aeronautics, electronics, medicine, and fuel cells. The synthesis and use of materials with structural characteristics having at least one dimension in the nanometer range is referred to as nanoscience and nanotechnology (1–100 nm). The nanoparticle is the name given to the designed nano-material. The scalable or quantum effects of nanoparticles are responsible for the subsequent enhancement of a process's functional characteristics. They are referred to as nanofluids because the application of these functional materials requires a base fluid, such as oil, water, gas, or any other appropriate liquid component. The use of nanotechnology has provided answers to a variety of oil and gas issues, including hydraulic fracturing work, petroleum exploration, preventing asphaltene depositions or gas hydrate formations, as well as EOR.

Bibliography

[1] H. Panchal, H. Patel, J. Patel, and M. Shah, “A systematic review on nanotechnology in enhanced oil recovery,” *Petroleum Research*. 2021. doi: 10.1016/j.ptlrs.2021.03.003.

[2] O. Massarweh and A. S. Abushaikha, “The use of surfactants in enhanced oil recovery: A review of recent advances,” *Energy Reports*. 2020. doi: 10.1016/j.egyr.2020.11.009.

[3] Y. Zhou, D. Yin, W. Chen, B. Liu, and X. Zhang, “A comprehensive review of emulsion

and its field application for enhanced oil recovery," *Energy Science and Engineering*. 2019. doi: 10.1002/ese3.354.

[4] A. Bera and A. Mandal, "Microemulsions: a novel approach to enhanced oil recovery: a review," *Journal of Petroleum Exploration and Production Technology*. 2015. doi: 10.1007/s13202-014-0139-5.

[5] P. Raffa, A. A. Broekhuis, and F. Picchioni, "Polymeric surfactants for enhanced oil recovery: A review," *Journal of Petroleum Science and Engineering*. 2016. doi: 10.1016/j.petrol.2016.07.007.

[6] M. I. Youssif, R. M. El-Maghraby, S. M. Saleh, and A. Elgibaly, "Silica nanofluid flooding for enhanced oil recovery in sandstone rocks," *Egypt. J. Pet.*, 2018, doi: 10.1016/j.ejpe.2017.01.006.

CHAPTER - 9

TRADITIONAL CHEMICAL EOR TECHNIQUES

Dr. Kalpajit Hazarika
Assistant Professor, Department of Petroleum Engineering,
Presidency University, Bengaluru, India,
Email Id: - kalpajithazarika@presidencyuniversity.in

The three compounds that stand out in typical EOR are polymers, alkalis, and surfactants. The viscosity of the aqueous phase is increased by the injection of polymers using waterfloods, which also enhances their mobility as they migrate from the injection well toward the producer. The polymer solution also improves oil recovery by decreasing the reservoir's permeability to water. Surfactant solutions work by interacting with certain components in crude oil, solubilizing interfacial coatings, and inducing emulsification to lower the IFT between water and crude oil. The capillary forces of trapped or leftover oil are reduced as a result of the IFT decrease. Additionally, surfactant adsorption on reservoir rocks alters the wettability of the rocks, increasing oil recovery [1], [2]. While using a different injectant, alkali flooding works by a similar mechanism as surfactant solutions. Foam flooding guarantees that injected fluid is diverted away from thieving zones and towards the reservoir's low-permeable areas. To increase the pore size and sweep efficiency of the OOIP, AS, AP and ASP floods are based on the idea of using the various strengths and efficiencies of surfactant, alkali, or polymer solutions.

Plastic Flooding

Polymer flooding may be used when waterflooding an oil reservoir proves ineffective owing to viscous fingering processes that result in early water breakout. To improve the viscosity of the injectant, polymer flooding entails injecting large molecular-weight water-soluble polymers alongside the water slug. The injectant's increased viscosity enhances the injected slug's mobility and conformity control and eliminates the phenomenon of viscous fingering. By suppressing early water breakout, which is often seen during the water flooding process, an additional oil recovery factor is attained. For several decades, polymer flooding has been effectively used in numerous oilfields, whether on a pilot or commercial basis. This includes, among others, the Tambaredjo oilfield in Suriname, the Daqing oilfield in China, the East Bodo Reservoir and Pelican Lake fields in Canada, the Marmul field in Oman, and the Daqing oilfield in China. Polymer flooding has also continued to play a growing role in the contemporary energy market. The biggest contribution is the reportedly increased oil output of up to 300,000 barrels per day from China's Daqing oil field.

Nanofluid flooding, a chemical EOR process with documented field use in Colombia, has been assessed and investigated for EOR procedures. Increased injectant viscosity, wettability modification, structural disjoining pressure, IFT decrease, and structural disjoining pressure were identified as the mechanisms for the improved oil recovery. More recently, it has been discovered that mixing nanoparticles with traditional EOR compounds produces unique materials with exceptional and intriguing features [3], [4]. For instance, it was discovered that polymeric nanofluids, which combine nanoparticles with polymers in a synergistic way, have better rheological qualities and stability for use in high-temperature and high-salinity environments. Additionally, the combined use of nanoparticles and surfactants reduces their adsorption through a competitive adsorption process, whereas their use in foam produces stable foams with a longer half-life.

This foundational study provides an overview of the state-of-the-art in chemical EOR research at the moment. First, a review of traditional chemical EOR techniques was done. The typical EOR chemical types were defined, and their limits and the mechanisms behind their EOR applications were explored. The binary application of traditional chemical EOR techniques was then defined and examined. The latest development of using nanotechnology for chemical EOR was then investigated. The many kinds of nanofluids, how they work, and lab investigations were described. Finally, the difficulties with chemical EOR techniques were listed, and suggestions for further research were made.

Disproportionate Drop in Permeability (DPR)

Polymer floods increase sweep efficiency by disproportionate permeability decrease in addition to the idea of mobility ratio. Some reservoirs have an unequal distribution of permeability due to their heterogeneity. This causes a considerable proportion of moveable oil and gas to remain stuck in low permeability zones and channels excessive water production via those layers, which leads to poor recovery in the initial or secondary phases of production. While the heterogeneous reservoir is being flooded with polymer solutions, the water relative permeability (Krw) is reduced, ensuring that the oil relative permeability is not adversely impacted (Kro). This phenomenon is known as a disproportionate reduction in permeability (DPR). The higher resistance of the polymer to water diverts later injected water into unswept or inadequately swept (low permeability) sections of the reservoir, improving oil recovery through the segregation of flow routes and layer building on the pore wall by the adsorbed polymer.

Velocity of Molecules Made Of Polymers

The third proposed cause for increased macroscopic effectiveness during polymer flooding is polymer viscoelasticity. Contrary to Newtonian fluids, polymers expand and contract repeatedly (stretching and recoiling) when they move across porous environments. This enables the polymeric molecules to produce more elastic viscosity, which enhances the efficiency of displacement at the microscopic and macroscopic scales. The impact of a polymer's viscoelastic characteristics on sweep efficiency at the macroscopic level [4]. The polymer solution's elastic difference was produced using a polymer with a comparable average molecular weight but a distinct molecular weight distribution (MWD). Their respective experiments showed that high elastic polymer solutions had much higher flow resistance through porous media and propagation front stability, which reduced the number of fingers. This added up to enhanced oil recovery, decreased residual oil saturation, but also higher sweep efficiency.

Bibliography

[1] P. Raffa, A. A. Broekhuis, and F. Picchioni, “Polymeric surfactants for enhanced oil recovery: A review,” *Journal of Petroleum Science and Engineering*. 2016. doi: 10.1016/j.petrol.2016.07.007.

[2] M. I. Youssif, R. M. El-Maghraby, S. M. Saleh, and A. Elgibaly, “Silica nanofluid flooding for enhanced oil recovery in sandstone rocks,” *Egypt. J. Pet.*, 2018, doi: 10.1016/j.ejpe.2017.01.006.

[3] A. Muggeridge *et al.*, “Recovery rates, enhanced oil recovery and technological limits,” *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*. 2014. doi: 10.1098/rsta.2012.0320.

[4] A. N. El-hoshoudy, S. E. M. Desouky, M. Y. Elkady, A. M. Al-Sabagh, M. A. Betiha, and S. Mahmoud, “Hydrophobically associated polymers for wettability alteration and enhanced oil recovery – Article review,” *Egyptian Journal of Petroleum*. 2017. doi: 10.1016/j.ejpe.2016.10.008.

CHAPTER - 10

EOR POLYMER TYPES

Dr. Barasha Deka
Assistant Professor, Department of Petroleum Engineering,
Presidency University, Bengaluru, India,
Email Id: - barasha.deka@presidencyuniversity.in

The two primary types of polymers used in polymer flooding recovery operations are synthetic polymers and biopolymers. The most common types of synthetic polymers are polyacrylamides as well as their derivatives, such as partially hydrolyzed polyacrylamide (HPAM), hydrophobically associating polyacrylamide (HAPAM), or copolymers of acrylamide. Contrarily, biopolymers include substances like xanthan gum, hydroxy ethyl cellulose, carboxy methyl cellulose, mushroom polysaccharide, sclera glucan, guar gum, welan gum, cellulose, schizo phyllan, and lignin. It is intriguing that xanthan gum or HPAM, which will be discussed in greater detail, is used in the most often reported field applications.

Hydrolyzed Polyacrylamide in Part (HPAM)

Synthetic straight-chain polymers called hydrolyzed polyacrylamide (HPAM) are employed in EOR applications because they are water-soluble. It is a copolymer of polyacrylamide or polyacrylic acid made either by copolymerizing sodium acrylate with acrylamide or by partial hydrolysis of PAM. They are recognized as the polymer used for EOR the most frequently. Due to its inexpensive cost, superior water solubility, mobility control, and resistance to bacterial assault, HPAM is typically used for field applications [1], [2].

For this polymer, the typical degree of hydrolysis (DOH) is 15–35% of the acrylamide (AM) monomers. Consequently, they have a negative charge. Many of the rheological and physical characteristics of the polymer solution, including viscosity, adsorption, or water solubility, are explained by the DOH. However, HPAM is extremely susceptible to outside influences including pH, salinity, temperature, shear pressures, and hardness. Extreme variations of these parameters in reservoirs cause HPAM molecules to lose their ability to increase viscosity and, as a result, their effectiveness.

Gum Xanthan

A polysaccharide called xanthan gum polymer is produced when certain bacteria digest glucose as well as its isomer fructose. The most effective source of xanthan gum is generally considered to be the bacteria Xanthomonas campestris. Because of its stiff polysaccharide chains, which make it resistant to breakdown in the presence of salt, temperature, or shear pressures, the biopolymer exhibits these properties [3], [4]. The biopolymer is also referred to as a polyelectrolyte because it contains charged moieties on its side chain, specifically acetate or pyruvate groups. With a molecular weight range of 2 to 50 106 g/mol, xanthan gum possesses the substantial thickening capacity required for reservoir mobility control. In comparison to HPAM and other synthetic acrylamide polymers, xanthan gum has a sturdy structure. It can be observed by simulating the rheological behavior of xanthan gum using theoretical models (such Herschel-Bulkley and Ostwald's models) that the polymer shows shear thinning behavior, which correlates to adequate injectivity for field activities.

Difficulties with Polymer Flooding

The viscosification of the injected brine is the primary goal of adding polymers to displacement fluids. Furthermore, between the transferred polymer molecules as well as the rock surface in the reservoir, important interactions including electrostatic interactions or London dispersion forces take place. Depending on how much the transferred polymer molecules are retained, this leads to the creation of a bank of injection fluid that is either completely or partially devoid of polymer. As a result, the reservoir's ultimate injectant viscosity is less than the desired target viscosity, which reduces the efficiency and efficacy of the polymer flood [5], [6]. Polymer type, concentration, rock permeability, molecular weight, flow velocity, temperature, salinity, as well as the presence of clay minerals are all variables that affect how well polymers are retained in porous media. Overall, polymer retention plays a significant role in determining how economically viable a polymer flooding process will be since it affects the permeability of the rock, the viscosity of something like the injected polymer solution, or ultimately the oil recovery procedure. Hydrodynamic retention, mechanical entrapment, but also polymer adsorption are the three primary methods for polymer retention in porous media.

Surfactant Flooding

A tried-and-true EOR method called surfactant flooding is utilized to release trapped residual oil. The purpose of surfactant injection into a reservoir is to change the fluids/fluid interaction by lowering the IFT between the oil and brine and the fluid/rock characteristics by changing the wettability of the porous media. An amphiphilic substance is a surfactant, sometimes referred to as a surface-active agent molecule. This indicates that surfactants have two functional groups inside their organic shell. These are the non-polar hydrophobic group, which is frequently oil-soluble, and the hydrophilic group, which is typically water-soluble. The long-chain hydrocarbon, siloxane chain, fluorocarbon, or short-polymer chain which could or could not be branched is typically the lipophilic hydrophobic group. The lipophobic hydrophilic group, on the contrary hand, is made up of moieties whose categorization depends on the chemical component present. Quaternary ammonium salts, alcohols, polyoxyethylene chains, sulfonates, carboxylates, and sulphates are some of the moieties.

Bibliography

[1] P. Raffa, A. A. Broekhuis, and F. Picchioni, “Polymeric surfactants for enhanced oil recovery: A review,” *Journal of Petroleum Science and Engineering*. 2016. doi: 10.1016/j.petrol.2016.07.007.

[2] M. I. Youssif, R. M. El-Maghraby, S. M. Saleh, and A. Elgibaly, “Silica nanofluid flooding for enhanced oil recovery in sandstone rocks,” *Egypt. J. Pet.*, 2018, doi: 10.1016/j.ejpe.2017.01.006.

[3] B. Haq, “Green enhanced oil recovery for carbonate reservoirs,” *Polymers (Basel).*, 2021, doi: 10.3390/polym13193269.

[4] A. Jafari, M. Hasani, M. Hosseini, and R. Gharibshahi, “Application of CFD technique to simulate enhanced oil recovery processes: current status and future opportunities,” *Petroleum Science*. 2020. doi: 10.1007/s12182-019-00363-7.

[5] X. Sun, Y. Zhang, G. Chen, and Z. Gai, “Application of nanoparticles in enhanced oil recovery: A critical review of recent progress,” *Energies*, 2017, doi: 10.3390/en10030345.

[6] J. Niu, Q. Liu, J. Lv, and B. Peng, “Review on microbial enhanced oil recovery: Mechanisms, modeling and field trials,” *Journal of Petroleum Science and Engineering*. 2020. doi: 10.1016/j.petrol.2020.107350.

CHAPTER - 11

CHEMICAL EOR TECHNIQUES

Dr. Barasha Deka
Assistant Professor, Department of Petroleum Engineering,
Presidency University, Bengaluru, India,
Email Id: - barasha.deka@presidencyuniversity.in

Due to the ongoing depletion of conventional oil sources and the accelerating rise in the world's energy demand, there is now a great deal of interest in the many chemical-enhanced oil recovery (EOR) techniques. Chemical EOR with surfactant flooding is a tried-and-true technique. This approach has been effective because it maximizes oil recovery by using many different processes. This would include emulsification, foam production, wettability modification, and interfacial tension (IFT) decrease. Surfactant flooding remains problematic despite being widely used because of problems including instability in hard or typical reservoir conditions and high adsorption. These problems have an impact on anticipated oil recovery, which lowers the projects' economic returns. However, surfactants may be correctly chosen based on the characteristics of the reservoir and the kind of rock. Surfactant screening techniques are often used for this, and they place restrictions on the IFT, surfactant adsorption, as well as other parameters under certain temperature and salinity conditions [1], [2].

Absorption of Surfactants and their Effect on EOR

Surfactant retention in porous media happens throughout the flooding process according to three primary mechanisms: precipitation, adsorption, and phase trapping. By choosing a surfactant that can withstand changes in temperature or salinity, phase entrapment and surfactant precipitation may be avoided. Unfortunately, it is only possible to decrease the adsorption of a surfactant onto reservoir rock. The effectiveness of the surfactant to minimize the oil-water IFT is impacted by the adsorption process due to a drop in surfactant concentration in the injected solution. As a result, this adsorption process affects how well surfactant-based EOR mobilizes the trapped oil. This might harm the economy in a big way.

Isotherms of Surfactant Adsorption

The use of surfactant adsorption isotherms may be used to explain the adsorption of ionic surfactants on oppositely charged reservoir rock. An adsorption isotherm typically consists of four areas. Due to electrostatic interactions between the surfactant monomers and the solid surface in the region I, adsorption occurs across low concentrations of the surfactant. According to Henry's rule, the adsorption in this area grows linearly as the surfactant concentration rises. In area II, lateral interactions between the hydrocarbon chains cause surfactant surface aggregates to begin to develop [3]. By reducing interfacial tension and boosting oil mobility, surfactant flooding increases oil output by enabling more effective displacement of the oil by injected water. The wettability of porous rocks is enhanced with surfactant EOR, enabling water to go through them more quickly and displacing more oil. Water injected into an oil reservoir becomes more viscous due to polymer displacement, increasing the pressure it may apply to the oil without simply running through it. This technique works less well on rock formations with limited permeability because it raises the viscosity of the water [3], [4]. Alkali, oil, and rock combine chemically to produce alkaline displacement. When an alkaline chemical is added to an oil field, the oil interacts with it to produce surfactants that lower interfacial tension. As a result, the oil may more easily travel through permeable rock. When particular microorganisms are introduced to an oil field, they metabolize a portion of the hydrocarbon and create byproducts that help with oil recovery. Solvents, alcohols, bio-polymers, acids, bio-surfactants, or gases are some of these bi-products.

Benefits of Surface Flooding for Enhanced Oil Recovery

The amount of surfactant needed for efficient oil recovery has significantly decreased because of recent advances in surfactant-enhanced oil recovery. When paired with the price of the surfactants themselves, the first research in the 1970s and 1980s employed surfactant concentrations ranging from 2–12%, which proved to be too expensive [5]. The quantity of chemicals needed has been considerably reduced by recent developments in research or surfactant product technology, which have reduced chemical concentrations within the range of 0.1-0.5%. More complex and secure EOR solutions are now available from surfactant manufacturers at lower prices than ever before. The greatest news is that these discoveries have improved both human health and the environment as a whole. Some of the most recent and efficient EOR surfactants are from plant sources including maize, soy, and sunflower oil. For instance, Envirofluid's Triple7 EOR is made up of free fatty acids, esters, fatty alcohols, or wax esters from soy, maize, or seed oil fractions that have undergone amine reactions. It is easily biodegradable, safe, and non-toxic. Both polymer displacement and alkaline displacement are often ineffectual. Polymer injection often only works on very porous rock because it makes the flooding medium more viscous. Polymer displacement in poor permeability rock rapidly reaches a point where it stops working.

Bibliography

[1] N. Lashari and T. Ganat, “Emerging applications of nanomaterials in chemically enhanced oil recovery: Progress and perspective,” *Chinese Journal of Chemical Engineering*. 2020. doi: 10.1016/j.cjche.2020.05.019.

[2] O. Massarweh and A. S. Abushaikha, “A review of recent developments in CO2 mobility control in enhanced oil recovery,” *Petroleum*. 2022. doi: 10.1016/j.petlm.2021.05.002.

[3] M. Vora, S. Sanni, and R. Flage, “An environmental risk assessment framework for enhanced oil recovery solutions from offshore oil and gas industry,” *Environ. Impact Assess. Rev.*, 2021, doi: 10.1016/j.eiar.2020.106512.

[4] O. E. Medina, C. Olmos, S. H. Lopera, F. B. Cortés, and C. A. Franco, “Nanotechnology applied to thermal enhanced oil recovery processes: A review,” *Energies*, 2019, doi: 10.3390/en12244671.

[5] B. Yuan and D. A. Wood, “A comprehensive review of formation damage during enhanced oil recovery,” *Journal of Petroleum Science and Engineering*. 2018. doi: 10.1016/j.petrol.2018.04.018.

CHAPTER - 12

CHALLENGES WITH CHEMICAL EOR

Dr. Kalpajit Hazarika
Assistant Professor, Department of Petroleum Engineering,
Presidency University, Bengaluru, India,
Email Id: - kalpajithazarika@presidencyuniversity.in

Other difficulties faced by the use of chemical EOR include the cost of the chemicals employed in oil recovery as well as formation damage caused by chemicals, in addition to the retention of chemical (surfactant or polymer) molecules, which presents a danger to the use of chemical EOR [1]–[3].

Formation Damage

The formation damage concerns brought on by the retention or reactivity of the chemicals in the reservoir rock system represent a major constraint of this EOR approach despite the highly desired oil recovery throughout different applications of chemical EOR technologies. Issues with formation damage in the reservoir tend to impair oil recovery performance and bring new technical and financial difficulties to oilfield operations and infrastructure. For instance, despite their potential to restrict mobility, oil-in-water or water-in-oil emulsions produced by the application of surfactant have been found to create significant pore blockage in low permeability reservoirs. Additionally, the usage of surfactant molecules in reservoirs with hard brines leads to the precipitation, phase entrapment, and adsorption of surfactant molecules on rock pores, which also blocks the pore throat system.

The polymer molecules also build up and clog the surface of rock grains in the circumstances of hydrodynamic retention, adsorption, mechanical entrapment, and inaccessible pore volume caused by the flocculation of polymers at high salinity. The particle filtration phenomenon describes these circumstances when they take place in tiny rock pores. Meanwhile, clays and other minerals may be dissolved by the alkali chemicals employed in alkaline flooding. Fines migrate and cause damage during the dissolving process, which might reduce reservoir permeability. Additionally, scale precipitation brought on by an incompatibility between alkali and formation water may gather on the reservoir rock's pore walls, reducing permeability or even causing the reservoir to permanently dry up.

Chemical EOR Process Cost

Typically, this EOR technique uses few chemicals. However, the widespread field use of chemical EOR causes a skyrocketing increase in the price of the chemicals needed for the procedure, which in turn raises the cost of the EOR procedure as a whole. The efficiency of extracting hydrocarbons and cost-effectiveness are factors that are taken into consideration when choosing an EOR procedure. The deployment of this EOR approach has the drawback that its selectivity and field execution is dependent on the oil price environment. Only when oil prices are higher are they viable and lucrative. For instance, most oil fields using chemical EOR were shut down to avert losses in 2015 when the price of oil collapsed to about $40 per barrel. Weak alkali was used in place of strong alkali in the Daqing oil field to keep the ASP flooding process affordable in certain of its fields and to reduce the expense of the chemical EOR process [4]–[6].

Chemical EOR adsorption inhibitor issues:

Chemical EOR Adsorption Inhibitor Issues: Adsorption inhibitors, also known as sacrificial agents, have received a lot of attention and have been advised for use during field applications of chemical EOR, particularly in high-temperature but also high-salinity reservoirs, to prevent the unceasing adsorption of chemicals on rock pores throughout their use in chemical EOR. Sacrificial agents are thought to be more effective when used in chemical EOR. After all, they interact less with cations in the formation fluids because they form complexes with the monovalent, divalent, and polyvalent cations found in the hardness brine. Second, the chemicals as well as the sacrificial agent compete for the adsorption sites in the rock pores. Due to the great surface coverage or limited desorption of the rocks, the sacrificial agent is preferentially adsorbed on their surface. Furthermore, the sacrificial agent prevents the injected chemicals from reaching further adsorption sites because of their great surface coverage. To successfully recover the leftover and bypassed oil, the whole process raises the number of chemicals present in the injected slug, leading to incremental oil recovery. The need that them to be very inexpensive is the most crucial aspect to take into account while choosing sacrificial agents. Polyacrylate and lignosulfonates are typical examples of sacrificial agents that have been studied and shown to be efficient. Because they are derived as byproducts of the pulp industry, lignosulfonates are especially economically appealing.

Preparation of the Reservoir

The functionality of the chemicals injected for the EOR process is attacked and reduced by the presence of component hardness brines. Preflushing, or injecting a slug of water with certain qualities and features, is a common part of the conditioning process. Before chemical EOR, the preflush targets the hardness brines and filters and removes them from the reservoir. To find the most appropriate and efficient preflush for conditioning the reservoir, however, a competent design approach is required. The TDS of the field, the composition of the field brine, the chemical concentration, the chemical slug size, the preflush concentration, as well as the preflush slug size are all important considerations throughout the design process.

Formulation of Cost-Effective EOR Chemicals

Due to the high cost of EOR chemicals, efforts for research and development should concentrate on developing less priced, more effective EOR chemicals from waste or by. Waste cooking oil wasted coconut oil, and palm fruit bunch have all been utilized to create new, effective biodegradable surfactants. Additionally, flash, a byproduct of coal-fired power stations, is utilized to produce nanoparticles for use as nanofluid EOR chemicals. For future study, it is suggested that palm kernel shell, a byproduct of the processing of palm oil, be used to create graphene and carbon nanotubes.

Bibliography

[1] X. Chen, Q. Feng, X. Wu, and G. Zhao, “A pilot numerical simulation case study for chemical EOR feasibility evaluation,” *J. Pet. Explor. Prod. Technol.*, 2016, doi: 10.1007/s13202-015-0183-9.

[2] M. Madani, G. Zargar, M. A. Takassi, A. Daryasafar, D. A. Wood, and Z. Zhang, “Fundamental investigation of an environmentally-friendly surfactant agent for chemical enhanced oil recovery,” *Fuel*, 2019, doi: 10.1016/j.fuel.2018.10.105.

[3] M. Shakeel, A. Samanova, P. Pourafshary, and M. R. Hashmet, “Experimental analysis

of oil displacement by hybrid engineered water / chemical EOR approach in carbonates," *J. Pet. Sci. Eng.*, 2021, doi: 10.1016/j.petrol.2021.109297.

[4] K. S. Lee and J. H. Lee, "Hybrid Chemical EOR Using Low-Salinity and Smart Waterflood," in *Hybrid Enhanced Oil Recovery using Smart Waterflooding*, 2019. doi: 10.1016/b978-0-12-816776-2.00004-0.

[5] T. A. Musa, A. F. Ibrahim, H. A. Nasr-El-Din, and A. M. Hassan, "New insights into guar gum as environmentally friendly polymer for enhanced oil recovery in high-salinity and high-temperature sandstone reservoirs," *J. Pet. Explor. Prod.*, 2021, doi: 10.1007/s13202-020-01080-3.

[6] Q. Wang, F. Liang, W. Al-Nasser, F. Al-Dawood, T. Al-Shafai, H. Al-Badairy, S. Shen, and H. Al-Ajwad, "Laboratory study on efficiency of three calcium carbonate scale inhibitors in the presence of EOR chemicals," *Petroleum*, 2018, doi: 10.1016/j.petlm.2018.03.003.

M/S CIIR Scientific Publications
B-17, Sector - 6, Noida,
Uttar Pradesh, India.
201301
Email: info@ciir.in

April 2023
ISBN 978-81-962237-1-7