International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Enhanced Oil Recovery (EOR)

Igboko Nguevese Rosemary[1], Abba Yusuf[2], Junior Ishaya Ishaya[3]

[1]France Institute of Petroleum
[2]Kuban state Technological University, Krasnodar, Russia
[3]Kuban state Technological University, Krasnodar, Russia

ABSTRACT

Enhanced oil recovery, also known as tertiary recovery, is the process of extracting crude oil from an oil field that cannot be produced otherwise. EOR can extract 30 to 60 percent or more of a reservoir's oil, compared to 20 to 40 percent utilizing primary and secondary recovery methods. [2] Carbon dioxide and water are injected together with one of three EOR techniques: heat injection, gas injection, or chemical injection, according to the US Department of Energy. [1] Quaternary recovery refers to more advanced, speculative EOR procedures. [4] Enhanced oil recovery (EOR) and the use of specific chemicals for this purpose. Conventional technologies are unable to produce around 60-70 percent of the oil in place. EOR techniques are gaining traction, especially in light of the world's finite crude oil resources. Chemical and gas floods, steam, combustion, and electric heating are all used in EOR. Injected fluids are typically used to characterize gas floods, which include both immiscible and miscible processes (carbon dioxide, flue gas, nitrogen, or hydrocarbon). Cyclic steam (huff and puff) or steam drive are used in steam projects. Chemical enhanced oil recovery (CER) is one of the most common EOR techniques that lowers the water-oil interfacial tension (surfactant/alkaline) and boosts volumetric sweep efficiency by lowering the water-oil mobility ratio (polymer). The basic mechanics of various chemical approaches, as well as the interactions of various chemicals with reservoir rocks and fluids, have been covered in this chapter. A current status of chemical flooding at the laboratory scale, as well as pilot projects and field applications, has also been presented.

Keywords: Enhanced Oil Recovery, EOR, CO_2, and chemical flooding.

1.Introduction

Primary, secondary, and tertiary (or improved) recovery are the three phases of crude oil development and production in oil reservoirs. During primary recovery, the reservoir's natural pressure or gravity force oil into the wellbore, which is then brought to the surface using artificial lift techniques (such as pumps). During primary recovery, however, only approximately 10% of a reservoir's initial oil in place is normally generated. Secondary recovery procedures mainly include pumping water or gas into a field to displace oil and drive it to a production wellbore, resulting in the recovery of 20 to 40% of the original oil in place.

Gas injection, heat injection, and chemical injection are the three main EOR procedures. Gas injection, which employs natural gas, nitrogen, or carbon dioxide (CO2), accounts for roughly 60% of EOR production in the US. [1] In the United States, thermal injection, which involves the input of heat, accounts for 40% of EOR production, with the majority of it taking place in California. [1] In the United States, chemical injection, which can involve the use of long-chained molecules called polymers to boost the efficiency of water floods, accounts for around 1% of EOR production. [1] In 2013, Russia introduced a technique known as Plasma-Pulse technology to the United States. This approach has the potential to boost existing well production by another 50%. [8]

The majority of today's global oil output comes from older fields. Oil corporations and governments are both concerned in increasing oil recovery from aged resources. Furthermore, in recent decades, the pace of replacement of produced reserves by new finds has been progressively dropping. To satisfy the increased energy demand in the coming years, increasing the recovery factors from mature fields under primary and secondary production would be crucial. Enhanced Oil Recovery (EOR) methods, as well as new drilling and well technologies, intelligent reservoir management and control, advanced reservoir monitoring techniques, and the application of various enhancements to primary and secondary recovery processes, are all included in Improved Oil Recovery (IOR) methods.

The current article, on the other hand, provides a thorough examination of EOR status and prospects to boost oil recoveries and ultimate recovery factors in reservoirs ranging from extra heavy oil to gas condensate. (See Figure 1) It's worth noting that statistics on EOR activity are frequently concealed because it's not recorded. All figures and reports in this page are based on data from published journals, conference proceedings, and other sources. After the mid-1908s, EOR gas injection project data have been stable, with a growth tendency since 2000, especially with the increase in CO2 projects. Indeed, for the first time in three decades, EOR gas injection projects have outnumbered thermal projects since 2002.

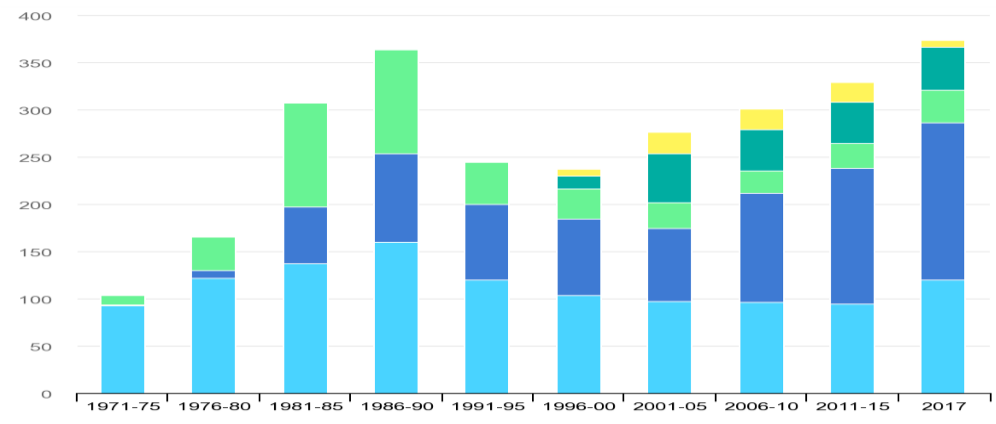

Figure 1 Number of EOR projects in operation globally, 1971-2017

Gas injection, heat injection, and chemical injection are the three main EOR procedures. Gas injection, which employs natural gas, nitrogen, or carbon dioxide (CO2), accounts for roughly 60% of EOR production in the US. [1] In the United States, thermal injection, which involves the input of heat, accounts for 40% of EOR production, with the majority of it taking place in California. [1] Chemical injection, which uses long-chained chemicals called polymers to improve the efficacy of water floods, accounts for around 1% of EOR production in the US. [1] In 2013, Russia introduced a technique known as Plasma-Pulse technology to the United States. This approach has the potential to boost existing well production by another 50%.

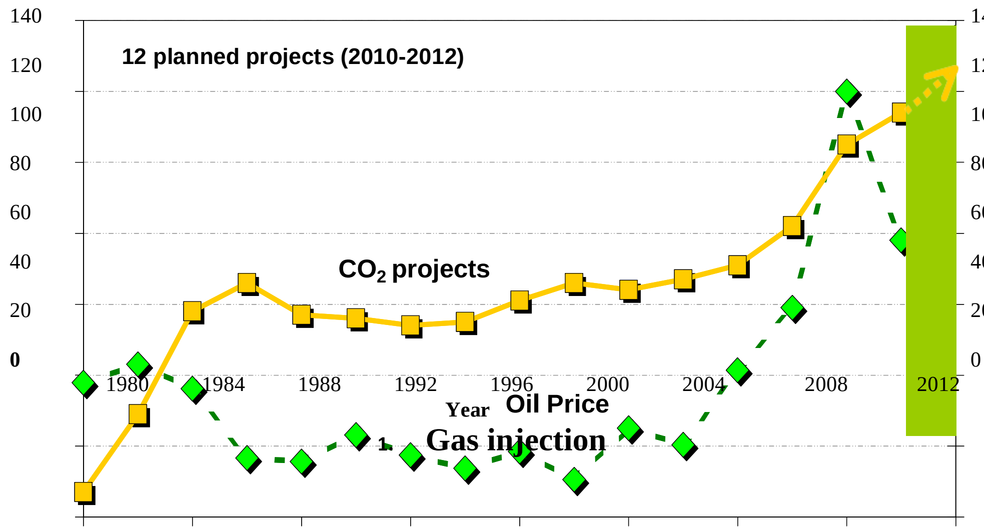

Figure 2. Evolution of CO2 projects and oil prices in the U.S. (From Oil & Gas Journal EOR Surveys 1980–2010 and U.S. EIA 2010).

The most widely utilized method for increased oil recovery is gas injection, often known as miscible flooding. Injection procedures that introduce miscible gases into the reservoir are referred to as miscible flooding. Because the interfacial tension between oil and gas is lowered, a miscible displacement technique maintains reservoir pressure while improving oil displacement. This refers to the removal of the interface between the two fluids that are interacting. This results in maximum displacement efficiency. [9] CO2, natural gas, and nitrogen are among the gases used. Carbon dioxide is the most widely utilized fluid for miscible displacement because it lowers oil viscosity and is less expensive than liquefied petroleum gas. [9] The phase behavior of mixtures of that gas and the crude, which is heavily dependent on reservoir temperature, pressure, and crude oil composition, is used to displace oil by carbon dioxide injection.

EOR methods entail injecting fluids into a reservoir to supplement natural energy and displace oil to producing wells. More crucially, the injected fluids interact with the reservoir rock-fluids system to create favorable conditions for improved oil recovery. Oil swelling, interfacial tension decrease, oil viscosity reduction, rock wettability modification, and phase behavior impacts are all examples of beneficial interactions (1). As a result, simple water flooding and dry gas injection for pressure maintenance aren't EOR processes because none of these interactions are present.

As an oil field develops and production rates fall, there is a rising motivation to intervene and use tertiary recovery techniques to try to boost oil output (also termed improved or enhanced oil recovery). The fall in efficacy of primary or secondary procedures could be caused by a variety of variables, including poor management, internal pressure drop owing to diminishing oil levels, or reservoir heterogeneity. Fractures or faults in the rock, as well as obstacles created by strongly cemented sections or shale, can induce reservoir heterogeneity. [1] Around 60 to 70 percent of oil cannot be obtained normally, necessitating the employment of secondary or tertiary recovery techniques. [1] It is also true that the transition from secondary to tertiary recovery techniques takes place well before the reservoir becomes fully unproductive. [1]

Method

The initial step in CO_2 flooding is to inject water into the reservoir, which will allow the reservoir's pressure to restore to productive levels. After the reservoir has reached the desired pressure, the CO_2 is pumped down through the same injection well. CO_2 gas is injected into the reservoir in order to make contact with the oil. CO_2 and low-boiling hydrocarbon derivatives form a miscible front as a result. [1] In front of the miscible zone, an oil bank forms, making it easier to transfer oil out of the reservoir via the production well. Furthermore, the viscosity of the oil with CO_2 dissolved in it reduces as the gas dissolves into it. [1] The CO_2 injection is normally alternated with water injection, with the water acting to sweep the oil into the production zone, a process known as the water alternating gas process (WAG).

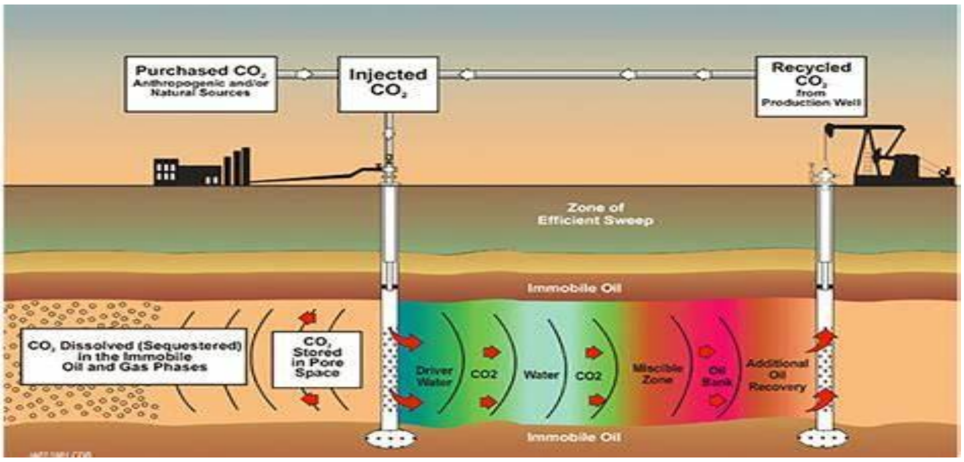

Figure 3 diagram showing Gas Enhanced Oil Recovery

2. Thermal injection

The steam flooding technique - Various methods are used to heat the crude oil in the formation in order to reduce viscosity and/or evaporate part of the oil, lowering the mobility ratio. The increased heat lowers the surface tension of the oil and enhances its permeability. The heated oil may also evaporate before condensing, resulting in better oil. Cyclic steam injection, steam flooding, and combustion are some of the methods used. These techniques increase the sweep and displacement efficiency. Since the 1960s, steam injection has been utilized commercially in California fields. [10] Solar thermal enhanced oil recovery initiatives began in California and Oman in 2011. This approach is similar to thermal EOR, but the steam is generated by a solar array.

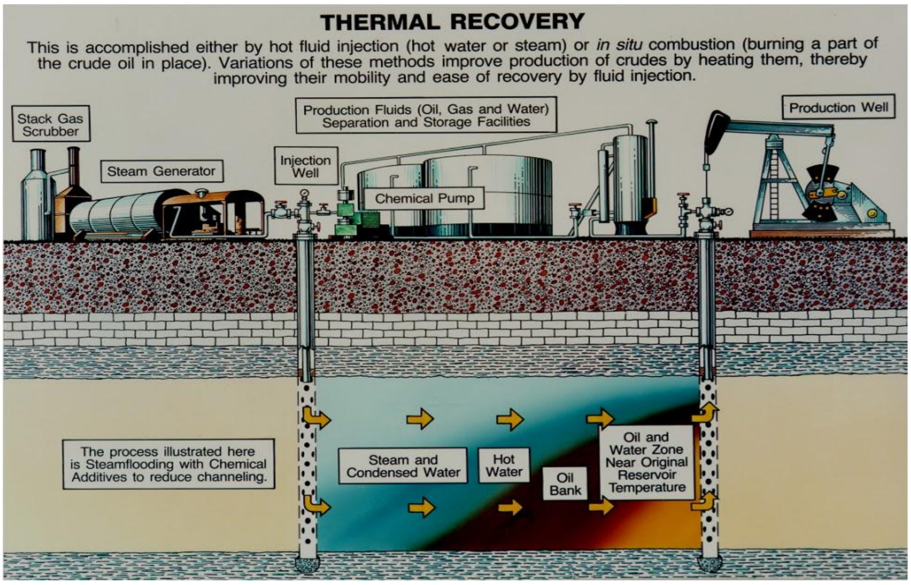

Figure 4 diagram showing thermal Enhanced Oil Recovery

Petroleum Development Oman and glass Point Solar announced in July 2015 that they had agreed to build a 1 GWth solar field on the Amal oilfield for $600 million. The Miraah project will be the largest solar field in the world in terms of peak thermal capacity. Glass Point and Petroleum Development

Oman (PDO) finished the first block of the Miraah solar plant on time and on budget in November 2017, and successfully delivered steam to the Amal West oilfield.
In November 2017, Glass Point and Aera Energy launched a cooperative project at the South Belridge Oil Field near Bakersfield, California, to build California's largest solar EOR field. A 850MW thermal solar steam generator is expected to produce roughly 12 million barrels of steam per year at the site. It will also reduce the facility's carbon emissions by 376,000 metric tons per year.

2.1 Steam flooding

Steam flooding is a technique for adding heat to a reservoir by injecting steam into a well in a pattern similar to water injection. [13] The steam eventually condenses into hot water; the oil evaporates in the steam zone and expands in the hot water zone. The oil expands, the viscosity decreases, and the permeability rises as a result. The procedure must be circular in order to be successful. This is the most often used improved oil recovery method today.

.

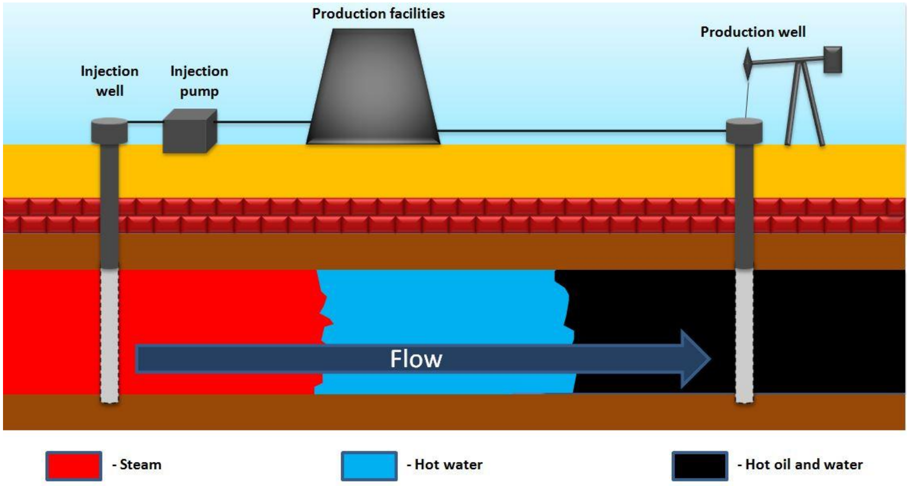

Figure 5 diagram showing Steam Enhanced Oil Recovery

2.2 Solar EOR

Solar EOR is a type of steam flooding that involves concentrating the sun's energy to heat water and generate steam using solar arrays. For the oil industry, solar EOR is proven to be a viable alternative to gas-fired steam production. Originally intended for electricity generation, central tower, or power tower technology, employs a field of huge tracking mirrors known as heliostats to focus sunlight on a boiler filled with water that sits atop a central tower.
The sun's energy is reflected on the boiler, which produces steam, which is utilized to power a typical turbine. The process of EOR comes to a conclusion when steam is produced. A heat exchanger converts high-temperature steam from demineralized water in the tower receiver to lower-temperature steam from high-contamination oilfield feedwater. The steam is then distributed through headers to injection wells, where it is injected into the oil-bearing deposit.

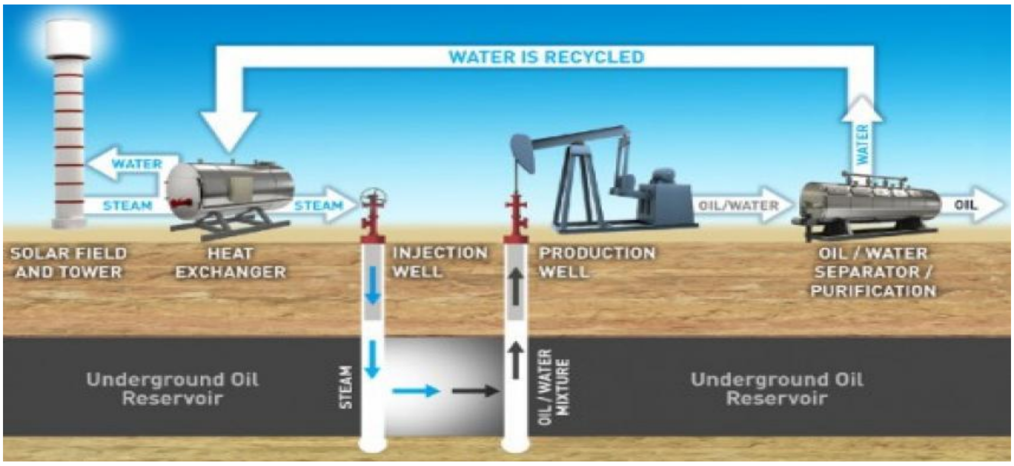

Figure 6 diagram showing Solar Enhanced Oil Recovery

2.3 Fire flooding

When the oil saturation and porosity are high, fire flooding works best. The heat is generated by combustion within the reservoir. The flame front will be maintained by injecting air or another gas mixture with a high oxygen concentration on a regular basis. The fire spreads across the reservoir and toward the production wells as it burns. The heat from the fire reduces the viscosity of the oil and aids in the conversion of reservoir water to steam. Steam, hot water, combustion gas, and a bank of distilled solvent all work together to push oil toward producing wells in front of the fire.

Dry forward, reverse, and moist combustion are the three types of combustion. To light the oil, a dry forward employs an igniter. The oil is forced away from the fire and toward the producing well as the fire continues. The air injection and ignition occur in the opposite directions in reverse. Water is introduced directly behind the front in wet combustion, and the hot rock converts it to steam. This puts out the fire and helps to distribute the heat more evenly

3.Chemical injection

Various chemicals, usually in the form of weak solutions, have been injected to enhance motility and reduce surface tension.[15] Injecting alkaline or caustic solutions into reservoirs with oil that contains organic acids will result in the creation of soap, which will lower the interfacial tension and boost production.[16] [17] In some formations, injecting a dilute solution of a water-soluble polymer to raise the viscosity of the injected water can help improve the amount of oil recovered.

Micro emulsions, which are special compositions of oil, water, and surfactant, can be very successful at reducing interfacial tension. The cost of the chemicals, as well as their adsorption and loss onto the rock of the oil-bearing deposit, limit the use of these technologies. Chemicals are pumped into many wells in each of these methods, and production happens in other neighboring wells.

.

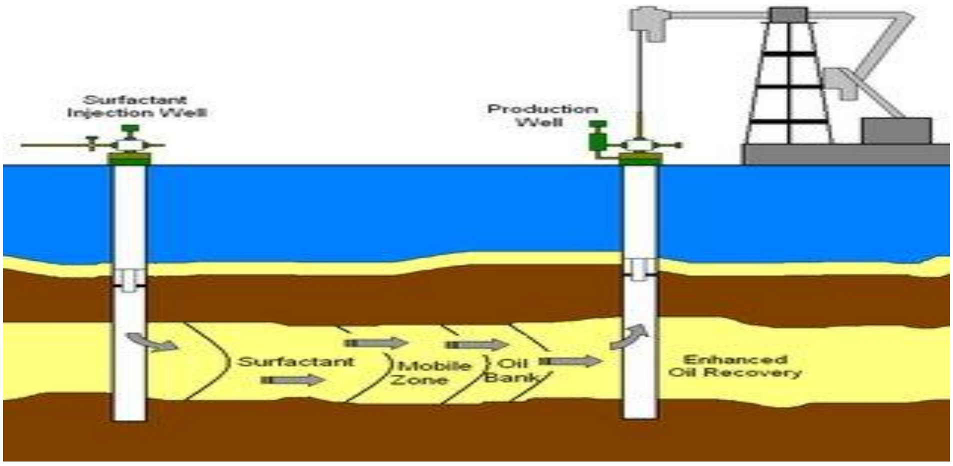

Figure 7 diagram showing Chemical Enhanced Oil Recovery

3.1 Polymer flooding

Polymer flooding is a technique for increasing the viscosity of water by mixing long chain polymer molecules with the injected water. As a result of boosting the water/oil mobility ratio, this approach improves vertical and areal sweep efficiency. Surfactants, when combined with polymers and hyperbranched polyglycerols, lower the interfacial tension between the oil and the water. [15] [18] This decreases residual oil saturation and enhances the process's macroscopic efficiency.

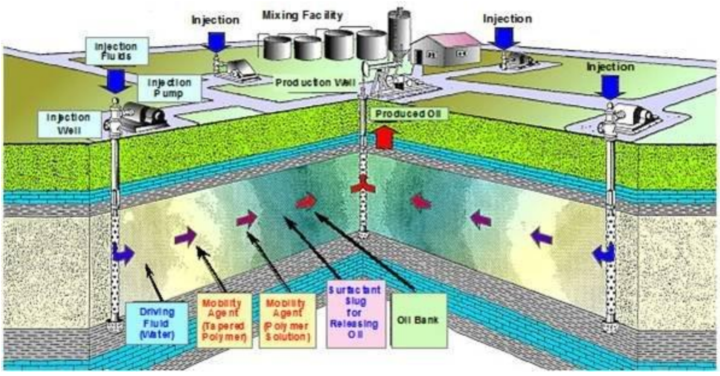

Figure 8 diagram showing Polymer Enhanced Oil Recovery

Co-surfactants, activity boosters, and co-solvents are commonly added to primary surfactants to improve formulation stability. The addition of sodium hydroxide to injection water is known as caustic flooding. It accomplishes this by lowering surface tension, reversing rock wettability, emulsifying the oil, mobilizing the oil, and assisting in the extraction of the oil from the rock.

3.2 Surfactant-polymer (SP) flooding

Injecting a chemical slug including water, surfactant, electrolyte (salt), and usually a co-surfactant (alcohol), followed by polymer-thickened water, is the surfactant-polymer flooding process. In this procedure, a surfactant with water and oil affinity is introduced to the polymer solution. The micellar solution is used to lower the interfacial tension of the water-oil system in the reservoir, allowing leftover oil to be displaced [15]. Gogarty and Tosch patented the SP flooding technology, known as Mara-flood, for Marathon Oil Company. The method's injection profile includes injecting a pre-flush (to establish the required salinity environment), micellar slug (surfactant, co-surfactant, and electrolyte), and polymer solution with driving water.
The following is the micellar solution composition that ensures a progressive transition from displacement water to displaced oil without an interface [13]:

- Surfactant at a concentration of 10% to 15%.
- Water is 20% of the total.
- Oil has a percentage of 25% to 70%.
- 34 percent co-surfactant

Alcohol is commonly used as a co-surfactant, which increases the chance of the micellar solution including oil or water. The surfactant portion of this surfactant-polymer flooding lowers the oil-water IFT, whereas the presence of polymer lowers the mobility ratio.

3.3 Microbial injection

Microbial injection is a component of microbial enhanced oil recovery, however it is rarely employed due to its greater cost and lack of widespread acceptance. These bacteria work by partially digesting long hydrocarbon molecules, producing biosurfactants, or expelling carbon dioxide (which then functions as described in Gas injection above). To achieve microbial injection, three methods have been used. In the first method, bacterial cultures are combined with a food supply (usually molasses) and injected into the oil field. The second method, which has been in use since 1985[20], involves injecting nutrients into the ground to feed existing microbial bodies; these nutrients encourage the bacteria to produce more natural surfactants, which they normally use to metabolize crude oil beneath. [21] [A better source is required].

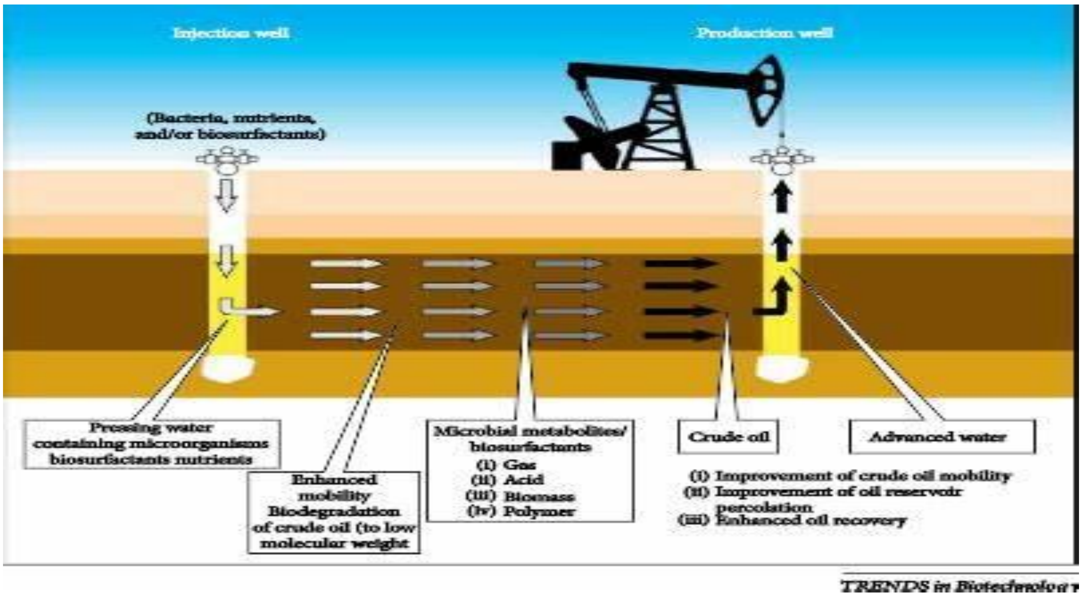

Figure 9 diagram showing Microbial Enhanced Oil Recovery

The bacteria go into near-shutdown mode once the injected nutrients are consumed, their exteriors become hydrophilic, and they migrate to the oil-water interface area, where they cause oil droplets to develop from the larger oil mass, making the droplets more likely to flow to the wellhead. The Beverly Hills Oil Field in Beverly Hills, California, and oilfields around the Four Corners have both used this method. Because the Earth's surface is substantially cooler than the petroleum deposits (a temperature decrease of 9-10-14 °C per thousand feet of depth is typical), the third option is employed to handle the problem of paraffin wax components of crude oil precipitating as the crude flows to the surface.

4. Economic costs and benefits

Adding oil recovery methods raises the price of oil, which in the case of CO_2 is typically between 0.5 and 8.0 US dollars per tonne. Increased oil extraction, on the other hand, is a financial gain, with revenue dependent on current oil prices. [31] For oil prices of 15-20 US$/barrel, onshore EOR has paid a net 10-16 US$ each tonne of CO_2 injected. Prevailing costs are influenced by a variety of factors, but they can help determine the economic viability of any surgery, with more procedures and more expensive procedures being financially viable at higher prices. [32] For example, at roughly 90 US$/barrel, the economic advantage per tonne CO_2 is around 70 US$. According to the US Department of Energy, 20 billion tons of CO_2 extracted may yield 67 billion barrels of economically recoverable oil.

The oil and gas industry claims that using captured, anthropogenic carbon dioxide derived from the exploitation of lignite coal reserves to power electric generation and support EOR from existing and future oil and gas wells provides a multifaceted solution to the country's energy, environmental, and economic problems.

[33] Coal and oil resources are unquestionably limited. While additional energy sources are being studied and developed, the United States is in a solid position to use traditional energy sources to meet future power needs. [33] CO_2 EOR establishes a market for coal gasification byproducts and lowers the price of carbon sequestration and storage for the coal sector.

Due to increased oil consumption and a reduction in oil supply, quote oil output derived from EOR climbed from 0.3 percent to 5% between 1986 and 2008.[34]

4.1. Boundary Dam Power Station, Canada

In 2014, Sask Power's Boundary Dam Power Station project installed carbon capture and sequestration (CCS) equipment at its coal-fired power plant. Prior to the sale of Cenovus' Saskatchewan holdings to Whitecap Resources in 2017, the plant will capture 1 million tonnes of CO_2 per year, which it sold to Cenovus Energy for increased oil recovery at its Weyburn Oil Field[35]. [36] The project is expected to inject a total of 18 million tons of CO_2 and recover an additional 130 million barrels of oil (21,000,000 m3), prolonging the oil field's life by 25 years (Brown 2001). [37] Weyburn is expected to store 26 million tonnes of CO_2 (net of production), with another 8.5 million tonnes (net of production) at the Weyburn-Midale Carbon Dioxide Project, resulting in a net reduction in atmospheric CO_2 from CO_2 storage in the oilfield. For a year, that's the equivalent of taking nearly 7 million cars off the road. [38] The EOR project has worked much as expected since CO_2 injection began in late 2000. Currently, the field is producing 1600 m3 (10,063 barrels) of additional oil per day.

5. Environmental impacts

Large amounts of generated water are frequently pumped to the surface by enhanced oil recovery wells. This water may contain dangerous heavy metals and radioactive compounds, as well as brine. [53] If not adequately controlled, this can be exceedingly harmful to drinking water supplies and the ecosystem in general. Disposal wells are used to inject produced water deep underground, preventing surface contamination of soil and water. The US Environmental Protection Agency (EPA) and state governments regulate injection well operations under the Safe Drinking Water Act in the United States. [56] In order to preserve drinking water sources, the EPA has issued Underground Injection Control (UIC) regulations. [57] The EPA classifies enhanced oil recovery wells as "Class II" wells. Well operators must re-inject the brine used for recovery deep underground in Class II disposal wells, according to the regulations.

Some potentially important environmental impacts associated with EOR including

- Pollution of land and surface waters from spills or leaks of oil, brine, or other chemicals,
- loss of biota,
- excessive erosion and sedimentation (mostly in hilly terrain) and subsequent deterioration of surface-water quality,
- contamination of groundwater, and
- excessive air emissions from thermal operations

Potential groundwater impacts includes:

- production of toxic and carcinogenic substances from synergistic interactions among chemicals used primarily in the micellar-polymer flooding technique,
- formation of acid waters with small amounts of oil and metal residues and oxides from *in situ* combustion, and
- Corrosion of well casings and potential leaks of hydrogen sulfide primarily from injection of miscible carbon dioxide.

Environmental planning (including monitoring, protective measures, and reclamation schemes) must be an intrinsic element of the initial project development for EOR techniques to expand in an environmentally acceptable manner. For most of the highlighted environmental concerns, acceptable monitoring, prevention, mitigation, and reclamation processes are available, although the optimal solutions may not be known by operators or mandated by law. Most states have strict regulations for plugging abandoned wells and disposing of waste, but due to a lack of staff and funds, these regulations may not be enforced. Other environmental factors, such as reclamation plans, water quality and other monitoring programs, and abandonment plans, are frequently overlooked.

It is underlined that the oil-producing industry requires additional environmental planning and monitoring standards. To protect the environment, states

are encouraged to continue strengthening and modernizing their oil-regulatory systems.
More research is needed on

- toxicity and carcinogenicity of chemicals used in injection processes,
- evaluation of groundwater monitoring technologies and the
- Reclamation procedures for soils contaminated by oil and brine.

6. Worldwide EOR application

The injection of fluids into a reservoir to reduce oil saturation and increase the oil recovery factor is classified as an EOR process. The injection of thermal fluids such as steam into reservoirs to reduce the viscosity of heavy oils, as well as the injection of water soluble chemicals such as polymer, surfactant, and alkali to improve the recovery factor primarily in medium and light oil reservoirs, are the most common EOR recovery processes. In medium and light oil reservoirs, miscible and immiscible gas injections, such as hydrocarbon (HC) gas, CO2, N2, and air, are also common. Figure 1 depicts global daily EOR production, as well as the locations and rates of the major EOR projects.
The majority of significant EOR applications are carried out in onshore areas, with the exception of thermal projects in Venezuela's Zulia state and hydrocarbon injection operations in the North Sea. Repsol has previously investigated the recovery procedures used on offshore reservoirs with similar characteristics to Repsol's mature reservoirs in Trinidad and Tobago, such as Teak, Saaman, and Pui.

7. Current applications

A number of real-world instances demonstrate the growing importance of offshore EOR. Since 1976, offshore EOR initiatives have been used in North Sea fields (Awan, Teigland, Kleppe 2006). In this region, EOR off-shore processes have been focused on five technologies and 19 field application projects, including hydrocarbon gas injection (six miscible field applications), water-alternate-gas (WAG) injection (three miscible and six immiscible field applications), simultaneous water and gas (SWAG) injection (one field application), and microbial enhanced oil recovery (MEOR) (one field application). In the North Sea, WAG appears to be the most successful EOR technology.
China National Offshore Oil Corp. (CNOOC) has been using EOR chemical flooding in offshore heavy oil reservoirs in China's Bohai Bay since 2003. (Xiaodong, et. al. 2011). With three existing polymer EOR projects on heavy oil fields, polymer flooding is an important technology for the strategic development of these types of fields. The projects were performed to reduce the amount of mature water floods. By the end of 2010, total oil production had increased by more than 6 MMstb. In 2011, Petrobras completed the first CO_2 and natural gas injection pilot project in pre-salt Brazil, in miscible circumstances, using the WAG method (Santnna Pizarro, Moreira Branco 2012).The pilot is being conducted in the Santos Basin at Lula Field (28-300API), deepwater (1800-2400m).The associated natural gas produced with the oil in the field is the source of CO_2.
Early data indicate that the EOR procedure being tested has the potential to be successful.Additionally, Repsol and Petrobras have explored various chemical EOR technologies (such as polymers, surfactants, and low-salinity water flooding) for the Albacora-Leste field in deep water (about 2300 meters) off the coast of Brazil (Abdelmawla 2013)
Albacora-Leste is a turbidity reservoir with formation brine of extremely high salinity (80,000-90,000ppm).Repsol and Petrobras are currently collaborating to do a chemical EOR pilot test.Di Pietro et al. (2014) assessed recoverable crude oil resources associated with CO2-EOR at 531 offshore oil fields in the Gulf of Mexico.
According to the study, there is a tremendous chance to use CO2 -EOR in key offshore reservoirs in the GOM at a reasonable cost.The study also suggests including CO2 -EOR in the conceptualization stage of future deepwater offshore projects' development plans, which might save money and time.

8. Drivers and challenges

The continued rise in oil prices over the last seven years; the decline in secondary oil recovery of large reservoirs in the North Sea; the discovery of large offshore reservoirs in presalt Brazil; and major advances in the development of EOR chemicals are all driving factors for offshore EOR applications (surfactants and polymers).
Applying EOR procedures to offshore projects is more difficult than applying them to onshore field settings. Sweep efficiency, for example, is substantially lower due to the distance between huge wells and the fact that there are far fewer wells. Reservoirs take longer to respond to the EOR process when it is used. Furthermore, off-shore facilities have limitations in terms of space, weight, and power supply. Furthermore, because many off-shore structures are old, safety restrictions for implementing new processes are greater than onshore.
As a result, offshore EOR applications have greater capital and operating costs than onshore EOR applications, limiting the number of feasible offshore EOR technologies. Air injection procedures, for example, are regarded too dangerous from an operational standpoint to be used in offshore settings. The commercial development of heavy oil resources in deepwater offshore reservoirs still faces many unsolved technological challenges when compared to shallow water conditions.
Due to the increased market value of these fluids and the ease with which they may be transported from the reservoir to their eventual destination, the majority of new offshore EOR projects are targeting light and medium oil fields. The low temperature of the sea water (about 4oC at the sea floor) affects the production of deepwater, offshore heavy oil fields in numerous ways, making it difficult to pump the oil to the top since its viscosity is

enhanced owing to heat loss along the production well to the surface. Transporting steam into the reservoir for the steam injection process is also very expensive and inefficient due to high heat loss and fuel costs.
The situation is different for developing heavy oil fields in shallow water close to shore, such as those on the eastern shore of Maracaibo Lake (60m water depth) in Venezuela, where more than 40 years of successful offshore, cyclic steam stimulation (CSS) in fields like Bachaquero [11.7OAPI, 6621million stock tank bbl (MMstb) OOIP] have been achieved (Escobar et. al. 1997).

9. Regional Insights on EOR

North America led the global industry in 2019, accounting for over 38% of total market share, with the United States being the largest contributor. The country's growth can be ascribed to the presence of various unconventional oil and gas resources as well as matured fields, which necessitate sophisticated extraction procedures to boost output from existing wells. EOR technology is also being used by leading oil and gas exploration companies in Canada to efficiently recover oil from fields.
CO2 EOR has been used in the United States for decades. CO2 EOR has been used in the Permian Basin for over 30 years, using CO2 generated naturally from New Mexico and Colorado. [44] According to the Department of Energy (DOE), fully utilizing 'next generation' CO2-EOR in the United States might result in an additional 240 billion barrels (38 km3) of recoverable oil resources. The availability of commercial CO2 in huge levels, which may be made possible by widespread use of carbon capture and storage, would be required to realize this promise. To put things in perspective, the total untapped domestic oil resources in the United States are more than 1 trillion barrels (160 km3), with the majority of it being unrecoverable. Apart from other economic benefits, the DOE estimates that if the EOR potential were fully realized, state and local treasuries would gain $280 billion in revenue from future royalties, severance taxes, and state income taxes on oil production.
In the United States, the greatest impediment to taking full use of CO2 EOR has been a lack of affordable CO2. Because there is currently a cost differential between what an oilfield operator can afford to pay for CO2 under normal market conditions and the expense of capturing and transporting CO2 from power plants and industrial sources, the majority of CO2 is currently sourced from natural sources. Using CO2 from power plants or industrial sources, on the other hand, could help to reduce carbon emissions (if the CO2 is stored underground). The cost gap is small for some industrial sources, such as natural gas processing or fertilizer and ethanol production (potentially $1020/tonne CO2). Capture costs are higher for other man-made CO2 sources, such as power generation and a variety of industrial processes, and the cost gap is much larger (potentially $30-50/tonne CO2). [45] To advance CO2 EOR in the United States and close the price gap, the Enhanced Oil Recovery Initiative has brought together leaders from industry, the environmental community, labor, and state governments.
Increased government support for EOR initiatives is expected to help the technology gain traction. For example, in 2019, the US Department of Energy announced USD 40 million in funding for research and development activities aimed at lowering the technical risk of enhanced oil recovery while also broadening EOR's applicability to both conventional and unconventional reservoirs.
Over the projection period, Asia Pacific is expected to develop at the highest rate, with China holding the greatest market share in the region. The Asia Pacific market is expected to rise because to rising oil and gas demand from major markets such as China and India, as well as greater deployment of EOR in older wells to fulfill production requirements.
Oman led the enhanced oil recovery market in the Middle East and Africa in 2019 and is likely to continue to do so during the forecast period. New EOR projects are scheduled to come online in countries including Saudi Arabia, the United Arab Emirates, Qatar, and Kuwait, resulting in increased market growth in the region.

10. Technology Insights

In 2019, the thermal technology sector had the biggest market share of almost 39%. The procedure comprises applying heat to oil wells in order to reduce oil viscosity and increase mobility ratio. It's typically used in shallow wells with high viscosity, such as heavy oil and tar sand. Countries such as the United States, Canada, Oman, and Russia are using this technology.
During the projected period, CO2 injection technology is expected to grow at the quickest rate. To recover crude oil, it injects carbon dioxide into the rock pores. CO2 is a popular choice for EOR applications because it is miscible with crude oil and is less expensive than other similar miscible fluids utilized in these applications. Furthermore, this method has substantial environmental benefits, which is fuelling demand for this technology.
Furthermore, strict government rules requiring the oil industry to reduce emissions are leading to a greater adoption of CCS technology, which captures and injects carbon emitted from refineries into diminishing oilfields for the EOR process. The CO2 injection technology segment will grow as a result of these factors. Chemical EOR method includes injecting polymers and surfactants into an oil well, which reduces interfacial pressure and raises inundated viscosity, resulting in increased oil well productivity. China, Russia, Colombia, and Canada are among the countries that use chemical-based EOR technology.

11.Conclusions

For heavy oil reservoirs, thermal methods, notably steam injection, remain the primary EOR approach. SAGD appears to be a technology that is currently solely relevant to Canadian Oil Sands, notably the McMurray deposit. High-pressure air injection (HPAI) is one of the thermal recovery technologies that has sparked attention in both carbonate and sandstone formations in recent years. HPAI field efforts, on the other hand, are still centered on Montana's low-permeable dolomitic Red River formation, as well as North and South Dakota. Despite great success in ongoing projects, the restricted number of cases deployed as full-field projects is likely due to a lack of understanding and dissemination of information regarding HPAI designs and risk mitigation.

In offshore fields, gas condensate reservoirs, and fields in distant places without access to gas markets, hydrocarbon gas injection (continuous or in a WAG mode) remains the favored recovery method. Except in the Campeche Bay Area of Mexico, where there is a large amount of existing N2generation capacity, N2EOR projects appear to be on the decline. In recent years, CO2 injection has gained a lot of attention as an EOR method and maybe as a sequestration tactic. CO2-EOR projects in operation, on the other hand, are largely centered in the United States (particularly in the Permian Basin) and are linked to natural CO2 sources. CO2 -EOR/sequestration projects are unlikely to expand in the near future unless industrial sources of CO2 can be supplied at considerably lower costs and a solid regulatory framework can be put in place.

Chemical EOR technologies have contributed just a modest amount to global oil production in recent decades. China is the country that produces the most oil from chemical EOR developments. However, there are an increasing number of pilot-scale SP and ASP trials underway or planned, particularly in Canada and the United States. For heavy crude oil reservoirs (e.g., Canada) and offshore locations, polymer flooding is gaining popularity. Chemical EOR, on the other hand, is unlikely to have an impact on global oil output for at least two decades assuming it is ever implemented at commercial scales. Based on the success of the El Tordillo Field in Argentina, operators in South America and the United States are beginning to show interest in combining conformance technologies (gel treatments) to increase injection profile and sweep efficiency with chemical EOR floods such as CDG, SP, or ASP. Despite the growing interest in chemically assisted methods (such as spontaneous imbibition, wettability modifiers, and ITF reductions) and surfactant-polymer (SP) flooding to improve oil recoveries in carbonate formations, these projects are unlikely to have an immediate impact on global oil production.

References

1. Number of EOR projects in operation globally, 1971-2017 – Charts – Data & Statistics - IEA https://www.iea.org/data-and-statistics/charts/number-of-eor-projects-in-operation-globally-1971-2017
2. Chevron Could Employ Solar Energy for Enhanced Oil Recovery in Saudi Arabia | AIChE https://www.aiche.org/chenected/2012/06/chevron-could-employ-solar-energy-enhanced-oil-recovery-saudi-arabia
3. EOR evolution (oedigital.com) https://www.oedigital.com/news/455686-eor-evolution#:~:text=Worldwide%20EOR%20application%20EOR%20processes%20are%20defined%20as,oil%20saturation%20and%20increase%20the%20oil%20recovery%20factor.
4. "Enhanced Oil Recovery". www.doe.gov. U.S. Department of Energy.
5. Electric Power Research Institute, Palo Alto, CA (1999). "Enhanced Oil Recovery Scoping Study." Final Report, No. TR-113836.
6. Clean Air Task Force (2009). "About EOR" Archived March 13, 2012, at the Wayback Machine
7. Hobson, George Douglas; Eric Neshan Tiratsoo (1975). Introduction to petroleum geology. Scientific Press. ISBN 9780901360076.
8. Walsh, Mark; Larry W. Lake (2003). A generalized approach to primary hydrocarbon recovery. Elsevier.
9. Organization for Economic Co-operation and Development. 21st century technologies. 1998. OECD Publishing. pp. 39. ISBN 9789264160521.
10. Smith, Charles (1966). Mechanics of secondary oil recovery. Reinhold Pub. Corp.
11. "Novas Energy USA Open Offices in Houston, Texas to Introduce its Proprietary Enhanced Oil Recovery Technology in the United States".
12. "Search Results – Schlumberger Oilfield Glossary". www.glossary.oilfield.slb.com.
13. Elias, Ramon (2013). "Orcutt Oil Field Thermal DiatomiteCase Study: Cyclic Steam Injection in the Careaga Lease, Santa Barbara County, California". SPE Western Regional & AAPG Pacific Section Meeting 2013 Joint Technical Conference. Monterey, California: Society of Petroleum Engineers. doi:10.2118/165321-MS. ISBN 9781613992647.
14. "Petroleum Development Oman and GlassPoint Announce Commencement of Steam Delivery From Miraah Solar Plant". November 2017.
15. "GlassPoint Belridge Solar Announcement". 2017-11-30.
16. Temizel, Cenk; Canbaz, Celal Hakan; Tran, Minh; Abdelfatah, Elsayed; Jia, Bao; Putra, Dike; Irani, Mazda; Alkouh, Ahmad (10 December 2018). "A Comprehensive Review Heavy Oil Reservoirs, Latest Techniques, Discoveries, Technologies and Applications in the Oil and Gas Industry". SPE International Heavy Oil Conference and Exhibition. Society of Petroleum Engineers. doi:10.2118/193646-MS.
17. "Search Results – Schlumberger Oilfield Glossary". www.glossary.oilfield.slb.com.
18. Choudhary, Nilesh; Nair, Arun Kumar Narayanan; Sun, Shuyu (2021-12-01). "Interfacial behavior of the decane + brine + surfactant system in the presence of carbon dioxide, methane, and their mixture". Soft Matter. 17 (46): 10545–10554. doi:10.1039/D1SM01267C. ISSN 1744-6848.
19. Hakiki, F., Maharsi, D.A. and Marhaendrajana, T. (2016). Surfactant-Polymer Coreflood Simulation and Uncertainty Analysis Derived from Laboratory Study. Journal of Engineering and Technological Sciences. 47(6):706–725. doi: 10.5614/j.eng.technol.sci.2015.47.6.9
20. Hakiki, Farizal. A Critical Review of Microbial Enhanced Oil Recovery Using Artificial Sandstone Core: A Mathematical Model. Paper IPA14-SE-119. Proceeding of The 38th IPA Conference and Exhibition, Jakarta, Indonesia, May 2014.
21. Ferreira, da Silva; Francisco, Bandeira; Cunha, Coutinho-Neto; Homem-de-Mello, Moraes de Almeida; Orestes, Nascimento (2021-12-01). "Hyperbranched polyglycerol derivatives as cetyltrimethylammonium bromide nanocarriers on enhanced oil recorevery processes". Journal of Applied Polymer Science. 139 (9): e51725. doi:10.1002/app.51725.
22. "Tiny Prospectors", Chemical & Engineering News, 87, 6, p. 20
23. Nelson, S.J. and Launt, P.D., (March 18, 1991) "Stripper Well Production Increased with MEOR Treatment", Oil & Gas Journal, vol-89, issue-11, pgs 115–118
24. Titan Oil Recovery, Inc., Beverly Hills, CA. "Bringing New Life to Oil Fields." Accessed 2012-10-15.

25. Choudhary, Nilesh; Narayanan Nair, Arun Kumar; Che Ruslan, Mohd Fuad Anwari; Sun, Shuyu (2019-12-24). "Bulk and interfacial properties of decane in the presence of carbon dioxide, methane, and their mixture". Scientific Reports. 9 (1): 19784. Bibcode:2019NatSR...919784C. doi:10.1038/s41598-019-56378-y. ISSN 2045-2322. PMC 6930215. PMID 31875027.
26. "CO2 for use in enhanced oil recovery (EOR)". Global CCS Institute. Archived from the original on 2014-01-01. Retrieved 2012-02-25.
27. Choudhary, Nilesh; Che Ruslan, Mohd Fuad Anwari; Narayanan Nair, Arun Kumar; Sun, Shuyu (2021-01-13). "Bulk and Interfacial Properties of Alkanes in the Presence of Carbon Dioxide, Methane, and Their Mixture". Industrial & Engineering Chemistry Research. 60 (1): 729–738. doi:10.1021/acs.iecr.0c04843. ISSN 0888-5885.
28. "Error" (PDF). www.netl.doe.gov.
29. Zekri, Abdulrazag Yusef; Nasr, Mohamed Sanousi; AlShobakyh, Abdullah (2011-01-01). "Evaluation of Oil Recovery by Water Alternating Gas (WAG) Injection - Oil-Wet & Water-Wet Systems". SPE Enhanced Oil Recovery Conference, 19–21 July, Kuala Lumpur, Malaysia. Society of Petroleum Engineers. doi:10.2118/143438-MS. ISBN 9781613991350.
30. Bleakley,W.B.Production Report:JournalSurveyShowsRecoveryProjectsUp.*OilGasJ.*
31. 1974, *72*, 69–76, 78.
32. Noran, D. Enhanced Recovery Action is Worldwide. *Oil Gas J.* 1976, *74*, 107–108, 110–114, 119–122, 124–131.
33. Noran, D. Production Report: Growth Marks Enhanced Oil Recovery. *Oil Gas J.* 1978, *76*, 113–140.
34. Matheny, S.L. Production Report: EOR methods help ultimate recovery. *Oil Gas J.* 1980, *78*, 79–124.
35. Leonard, J. Annual Production Report: Steam dominates enhanced oil recovery. *Oil Gas J.*1982,
36. *80*, 139–146, 152–159.
37. Leonard, J.AnnualProductionReport:EORsettomakesignificantcontribution.OilGasJ.
38. 1984, *82*, 83–90, 92–95, 98–105.
39. Leonard, J. Production/Enhanced Oil Recovery Report: Increased rate of EOR brightensoutlook.
40. *Oil Gas J.* 1986, *84*, 71–89.
41. Aalund,L.R. Annua lProductionReport:EORprojectsdeclinebutCO2 pushesupproduction.
42. *Oil Gas J.* 1988, *86*, 33–74.
43. Moritis, G. CO2 and HC Injection Lead EOR Production Increase. *Oil Gas J.* 1990, *88*,49–82.
44. Moritis, G. EOR Production Report. *Oil Gas J*. 1992, *90*, 60–65, 68–73,76–78.
45. Moritis, G. EOR Production Report. *Oil Gas J*. 1994, *92*, 60–69,72–78.
46. Moritis, G. 1996 EOR Worldwide Survey. *Oil Gas J.* 1996, *94*,45–61.
47. Manrique, E.J.; Muci, V.E.; Gurfinkel, M.E. EOR Field Experiences in Carbonate Reservoirs in the United States. *SPE Reserv. Eval. Eng.* 2007, *10*,667–686.
48. Moritis, G. Future of EOR & IOR: New companies, infrastructure, projects reshape landscape for CO2 EOR in the US. *Oil Gas J.* 2001, *99*, 68–69,72–73.
49. Hustad, C.W. Capturing, Managing and Gathering CO2 for EOR Onshore and Offshore: Challenges and Opportunities. Presented at the ACI Optimising EOR Strategy, London, UK, 11–12 March2009.
50. Crude oil price: Refiner average domestic crude oil acquisition cost (April 2009). Available online: http://tonto.eia.doe.gov/dnav/pet/hist_xls/R12003m.xls. (accessed on 11 August2010).
51. Taber, J.J.; Martin, F.D.; Seright, R.S. EOR Screening Criteria Revisited—Part I: Introduction to Screening Criteria and Enhanced Oil Recovery Projects. *SPE Reserv. Eng.* 1997, *12*,189–198.
52. Taber, J.J.; Martin, F.D.; Seright, R.S. EOR Screening Criteria Revisited—Part II: Applications and Impact of Oil Price. *SPE Reserv. Eng.* 1997, *12*,199–205.