A review on Miscible CO_2 Flooding Technique for the application of Enhanced Oil Recovery

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ABSTRACT

The oil production rate is declining rapidly since the wells are getting older and there aren't many new oil discoveries. So, instead of searching for new oil reserves, it is more reasonable and justified to focus on improving production from existing wells using enhanced oil recovery (EOR) techniques.

In this paper, we consider CO_2 flooding, which is a type of miscible gas flooding and one of the best EOR techniques. CO_2 flooding enhances production by dissolving in the remaining oil, reducing its viscosity, interfacial tension, density, and capillary pressure. This process causes the oil to expand and improves the recovery by releasing trapped oil in inaccessible pore spaces. Most miscible flooding projects use economically viable and readily available solvents such as CO_2 or N_2.

The screening criteria for CO_2 flooding include factors such as reservoir depth, pressure, temperature, minimum miscibility pressure (MMP), residual oil saturation, net pay thickness, crude oil gravity, viscosity, permeability, porosity, and reservoir heterogeneity [1]. While CO_2 flooding can greatly enhance oil recovery, it also involves using carbon emissions to increase crude oil production from older oilfields. However, it is important to note that CO_2 flooding carries potential environmental risks, such as subsea CO_2 leakage, CO_2 impurities, and the presence of potentially toxic trace elements in produced water. [2]

This paper is an extensive review of miscible CO_2 flooding, its benefits and drawbacks, its effects, methods of injection of CO_2, hazards, injection facilities and process design consideration.

Keywords: Miscible Gas Flooding; CO_2 Injection; Minimum Miscibility Pressure (MMP); Residual Oil Saturation; Enhanced Oil Recovery

1. Introduction

Typically, primary production refers to the initial extraction of about 20% of the Total Original Oil in Place from an oil reservoir. An additional 20% of the remaining oil is produced through secondary enhanced oil recovery (EOR) strategies, while the remaining 30% is extracted using tertiary EOR methods. One commonly employed tertiary EOR method is Miscible Gas Flooding, which includes various types of gas flooding techniques such as Nitrogen, Carbon Dioxide, Nitrogen and Sulphur compound, and LPG (Liquefied Petroleum Gas).

CO_2 flooding is a widely used tertiary EOR method due to the abundance of CO_2 on our planet, despite its classification as a greenhouse gas. CO_2 miscible flooding has demonstrated commercial success in reservoirs with low permeability and light oil. It has the potential to increase oil recovery by 10%-20% [Moritis, 2004]. The application of carbon dioxide for enhanced oil recovery has a long history spanning several decades. Typically, at least 30% of the hydrocarbon pore volume is injected into the reservoir to achieve CO_2 miscible displacement [Taber, 1997]. When properly designed, CO_2 flooding proves to be one of the most promising EOR methods. The availability of low-cost CO_2 from natural sources, coupled with the development of CO_2 transportation pipeline systems, has made CO_2 projects economically attractive. CO_2 miscible flooding projects have been implemented in various reservoirs in the Permian Basin and Rangely Field since 1984. As more EOR methods are developed, reservoirs often have multiple options to choose from. In addition to oil and injection fluid prices, there are other considerations when selecting an EOR method. Technical criteria are used to eliminate less viable options, and these screening criteria significantly influence the decision-making process. If only reservoir depth and oil gravity are taken into account, approximately 80% of the world's reservoirs are eligible for some form of CO_2 injection [Taber, 1997]. Before deciding on CO_2 injection, several reservoir and fluid characteristics should be considered, including reservoir depth, temperature, net pay thickness, permeability, porosity, heterogeneity, crude oil viscosity and gravity, reservoir parting pressure, and reservoir oil saturation. This review paper aims to provide insightful guidance on the significance of the Miscible CO_2 Flooding Method and explains the mechanisms of both CO_2 miscible and immiscible flooding.

In order to have a better understanding of the CO_2 displacement process we need to have the background knowledge of a basic EOR technology, CO_2 properties, miscible and immiscible displacement mechanisms, MMP, and MMP determination methods. In addition, different CO_2 injection strategies such as WAG and surfactant foams are also discussed in the paper.

2. Background of the study

Oil development and production can be divided into three phases: primary recovery, secondary recovery, and tertiary, also known as enhanced oil recovery (EOR). In the primary recovery phase, oil is naturally extracted from the reservoir using its inherent energy. This energy can come from factors such as rock and liquid expansion, water drive, dissolved gas expansion, gravity drainage, or a combination of these effects. The natural energy propels the oil into the wellbore, where it is further aided by artificial lift. This process continues until the reservoir pressure becomes too low or the proportion of gas or water in the produced fluid becomes too high, indicating the limit of primary recovery.

To extract more oil from the reservoir, it is necessary to maintain reservoir pressure by injecting additional fluids, which marks the start of the secondary recovery phase. This technique typically involves injecting water and/or gas into the reservoir. The injection of fluids serves two main purposes: to sustain reservoir pressure and to drive the reservoir oil towards the production wellbore. Over the course of several years of secondary recovery, the injected fluid gradually reaches the production well and constitutes a significant portion of the produced fluids. Secondary recovery reaches its limit when the cost of production outweighs the benefits, indicating that further extraction is no longer economically viable. Primary and secondary recovery together could recover about 1/3 of the original oil in place.

3. EOR Process

Enhanced oil recovery (EOR) is a process that refers to the displacement of the remaining oil in the reservoir. Particularly, EOR refers to oil recovery by the injection of materials not normally present in reservoir. There is another term “IOR” that needs to be distinguished from EOR. Generally, IOR (improved oil recovery) often refers to the oil recovery by any process. Oil production from EOR projects continues to supply an increasing percentage of the world oil production. About 3% of the worldwide oil production comes from EOR.

The injected fluids must improve the natural energy in the reservoir and interact with the reservoir rock or oil system to provide a favourable condition for residual oil recovery.

Effects that injected fluids have on the reservoir oil system include increasing capillary number and decreasing mobility ratio by:

a) Reduction of interfacial tension between oil and displacing fluid
b) Reduction of capillary forces
c) Oil viscosity reduction
d) Increase of drive water viscosity
e) Reservoir rock wettability alteration

The ultimate goal of EOR processes is to increase overall oil displacement efficiency, E which is a combination of microscopic displacement efficiency, Ev and macroscopic or volumetric displacement efficiency, Ed.:

$$E = E_v \cdot E_d$$

4.0 Fundamentals and Mechanisms of CO_2 Flooding

As a secondary or tertiary technique, carbon dioxide flooding can be used in the field and often entails the sequential or alter national injection of CO_2 and other fluids. In order to try to control the mobility of the fluids in reservoirs where the displacement is horizontal or nearly so, the CO_2 flooding method typically involves alternating injection of CO_2 and water, whereas in vertical floods the various fluids would be injected sequentially. For instance, in vertical downward displacement, the CO_2 might be followed by a lighter gas to maximise the benefit of gravity segregation and reduce viscosity and gravity" fingering; in vertical upward displacement, the CO_2 might be followed by water to once again take use of the gravity segregation.[1]

No matter how CO_2 flooding is used in the field, the following elements may help to improve oil recovery:

a) crude oil's swelling,
b) miscibility effects,
c) increase in injectivity, and

d) internal solution gas drive causes the crude oil's viscosity to decrease.[1]

The amount of crude oil will rise from 10% to 60% as a result of CO_2 dissolving into it[2]. Lower residual oil saturation results from these phenomena, which is more pronounced for light oil. Oil swelling increases the recovery factor for a given residual oil saturation, and under normal conditions, the mass of the remaining oil in the reservoir is lower than the amount of residual oil that has not come into contact with CO_2.

Oil viscosity is decreased as a result of CO_2 dissolving in crude. Calculations revealed that the primary cause for EOR is this viscosity lowering.

The term miscibility can be defined as the capacity of two or more substances to combine in all necessary amounts to produce a single homogenous phase [2]. Miscibility is the property of two or more fluids that allows them to mix in all proportions without the presence of an interface, and it pertains to petroleum reservoirs. The fluids are regarded as immiscible if two fluid phases develop after a small amount of one fluid is added to another.

A miscible gas drive involves two procedures. The two procedures are known as the numerous contact miscibility processes and the first contact miscibility process, respectively. When both fluids are entirely miscible in all amounts without exhibiting any numerous behaviours, first contact miscibility is attained [3]. Reservoir oil and other solvents are not immediately miscible, but under specific circumstances, miscibility can be created through in-situ mass transfer between the oil and solvent through repeated interactions. Multiple contact or dynamic miscibility are two names for this type of miscibility [3]. When a lot of CO_2 is combined with oil, there is a lot of mass transfer between the phases. Condensing gas drive and vaporising gas drive are the two processes that multiple contact miscibility may be broken down into.

4.1 Vaporizing Gas Drive

The ability of CO_2 to extract or vaporise hydrocarbons from crude oil is its most significant function. A lean injection gas that is used in a vaporising gas drive mechanism flows over reservoir oil that is rich in intermediate components, extracting those fractions from the oil, and concentrates them at the displacement front where miscibility is attained [2].

4.2 Condensing Gas Drive

The term "condensing" describes a process whereby intermediate components are transferred from a rich solvent to an intermediate lean reservoir oil by condensation [2]. When fresh oil is encountered downstream in a CO_2 miscible flooding process, the intermediates that were stripped from the oil and are now present in the gas condense

5. Miscible Gas Injections

Introducing miscible gases into the reservoir through injection operations is known as "miscible flooding." Because the interfacial tension between oil and water is lowered, a miscible displacement technique keeps reservoir pressure constant while enhancing oil displacement. [3]

Today, most effective and popular way of oil production is to inject gas that is miscible with the oil at the target reservoir temperature and pressure. Oil recovery for miscible gas floods can be substantially higher than primary recovery methods because the interfacial tension between the remaining oil and the injected gas is reduced to zero. As the fluids' interfacial tension decreases, capillary pressure decreases, and the remaining oil is only saturating to a level of 1–2%.[1]

It also helps to improve the sweep efficiency of the reservoir. As the gas mixes with the oil, it moves through the reservoir, pushing and displacing the oil from the microscopic pore spaces. This ensures a more thorough sweep of the reservoir and helps to extract a higher proportion of the original oil in place.

One of the miscible fluids used today is carbon dioxide, which is injected as a supercritical fluid at temperatures and pressures above its critical point. Two other gases, methane and nitrogen, can mix with oil, but doing so requires much higher reservoir pressures. The price and availability of the gas on the field also affect the kind of gas that is used.[4]

5.1 Screening factors of CO_2 flooding

Theoretically, miscible gas flooding increases oil production as compared to other EOR techniques. Not all reservoirs, however, may be eligible for a miscible gas flooding process. Miscible flooding procedures often call for a deep depth of injection because formation fracture and miscibility pressure cannot be reached at shallow depths. For the purpose of assessing the effectiveness of miscible flooding, an additional screening criterion exists. When these conditions are satisfied, a fast performance assessment can show how effective a miscible process might be. For a successful miscible flooding, reservoirs with an API gravity of 30 and higher are more suitable as a major screening criterion. This is due to the fact that crude oils with a high API have a lower viscosity and require richer crude oils in intermediate components to achieve miscibility through the VGD or CGD process. Additionally, less viscosity offers a better mobility ratio. Additionally, it has been stated that for CO_2 breakthrough to be delayed, viscosity needs to be lower than 12 cP, residual oil saturation needs to be higher than 300 STB/acre-ft, and reservoir heterogeneity needs to be very low.[1]

5.2. Gas Flooding Research of CO_2 flooding

5.2.1. Mobility Control

Three mobility control techniques have been researched: in situ deposition of chemical precipitates, mobile "foam-like dispersions" of CO_2 and aqueous surfactant, and the use of polymers for direct thickening of high-density CO_2.[6]

There hasn't been much success in the search for CO_2 -soluble polymers. There are polymers that dissolve into high-density CO_2, but the rise in viscosity is much smaller than what is needed to control mobility. To find out if suitable polymers can be synthesized for the successful direct thickening of CO_2, more research is required.[2]

Investigations are also being conducted on mobile foam-like CO_2 dispersions. In this idea, the gas's flowing viscosity is changed to inhibit viscous fingers and sustain displacement in a piston-like way. Contact should be made with previously un-swept areas as well as the reservoir's drained areas.[6]

5.2.2. Flooding performance

Field experiments and mechanism studies conducted domestically and abroad demonstrate that CO_2 flooding can greatly increase the recovery efficacy of low permeability reservoirs. However, miscible flooding is the most common field practise, while immiscible flooding projects are uncommon and of low output. According to statistical data, there are 327[1] active enhanced oil recovery projects worldwide, of which 135 involve CO_2 flooding and provide a daily oil output of 6.02 x 10^4 t[1]. The other 10 projects involve immiscible flooding and produce a daily oil output of 0.35 x 10^4 t[1]. According to the China Resource Review[2], there are many tight and light oil (API > 31.1) reserves in China, with an estimated 53.7 billion tonnes of original oil in situ (OOIP).

Jilin Oilfield, which can be found in Northeast China's Songliao basin, is made up of more than 20 distinct reservoirs that are primarily separated by faults. Most of the reservoirs are buried between 1800 and 2500 metres deep, with net pays between 2 and 20 metres[2]. They appear to be ideal for CO_2 EOR and storage based on the geological and petrophysical characteristics analysed from core analysis, well logging, well testing, and research/fluid sampling.

Injection of CO_2 was primarily intended to occur in a miscible flooding mode with producers' BHP exceeding the MMP (22.3 MPa)[2]. Since April 2008, a positive production response has been noted following CO_2 injection.

With the minor decrease in water cut, oil output in the pilot region has quickly increased from 20 t/d to 100 t/d[2]. It should be emphasised, though, that considerable CO_2 breakthrough happened roughly a year after injecting about 8.4% of the hydrocarbon pore volume (HCPV) of CO_2, around the same time that oil production peaked and rapidly decreased[2].

Since it improves oil production and sequesters CO_2 in the depleted reservoirs, CO_2 flooding is a promising and efficient method used to enhance oil recovery (CO_2-EOR). Immiscible and miscible CO_2 flooding has different methods that typically include oil viscosity reduction, oil swelling, and dissolved gas driving. Oil recovery can be significantly increased when miscibility is used to lower the interfacial tension during supercritical CO_2 injection into the deposit. Field applications, for instance, demonstrate that miscible CO_2 flooding can increase oil recovery by 8%–15% [3].

As it boosts oil production and sequesters CO_2 in oil reservoirs with limited permeability, CO_2 flooding is a promising technology used to improve oil recovery. However, the efficiency of CO_2 flooding can be significantly impacted by a reservoir's areal heterogeneity [3]. Thus, it is suggested that real-time producing regulation, differential production pressure control, and sweeping area regulation be used to improve the effectiveness of CO_2 flooding in spatial heterogeneous reservoirs.

5.3 Miscible flooding in fields

Worldwide, miscible CO_2 flooding has been applied in a variety of outdoor settings. The majority of them yielded positive results. The outcomes of Brock and Bryan's field experiment in 1989, which used CO_2 flooding as an EOR candidate, were collected. They grouped the projects into three categories: field cases, producing pilots, and nonproducing pilots. Field instances are emphasised here.[13]

Both continuous CO_2 flooding and water alternative gas (WAG) were used in a few of these projects. For instance, the CO_2 breakthrough in the Dollar hide field took place after 17 months. A WAG method was then put into place for a better mobility control approach.[13]

The field has shown good recovery using gas flooding technique, which is well developed. Recovery rates from both immiscible and miscible gas flooding range from around 5% to 20% OOIP, with a miscible gas flood recovery rate average of about 10% incremental OOIP. In general, immiscible gas flooding recoveries are lower, at about 6% OOIP. Even though gas flooding recovery is highly profitable at these levels, 55% OOIP often persists after miscible gas flooding, assuming 65% OOIP beforehand. Due to the great gas mobility, the huge amount of oil that is still there is mostly the product of gas channelling through the formation. Gas breakthrough during miscible flooding often coincides with the production of oil and can lead to channeling. In contrast, in surfactant/polymer flooding, the formation of oil banks typically occurs before surfactant breakthrough. In water or surfactant-polymer floods, which have better mobility ratios, poor volumetric sweep is less of a concern. However, miscible flooding is generally more cost-effective and straightforward compared to chemical flooding, especially in deeper reservoirs where surfactant/polymer floods pose greater technical challenges. Surfactant floods have not yet proven to be economically profitable due to the high cost of chemicals [14].

Reservoir management is one of the key components of using gas floods. Field reservoir management is a life-cycle procedure that calls for accurate data collection and monitoring. To understand how to best apply a gas flood process, extensive core data, geology descriptions, and good reservoir simulation models are required.[13]

6. Methodology of CO_2 flooding

It's not a novel concept to use CO_2 to improve oil recovery. Whorton and Brownscombel were granted a patent in 1952 for a CO_2-based oil recovery technique [1].Through the 1950s and 1960s, laboratory research was published. Today, research is still being done in this area. For miscible displacement, carbon dioxide has been studied, as has for immiscible displacement, for creating well stimulation, and for carbonated waterflooding. There have been a few field tests in the past, and commercial oil recovery is currently possible [1].

Carbon dioxide is a gas that is inert, non-combustible, colourless, and odourless in its natural state. Its characteristics are as follows at standard settings (1.01 MPa, 0 °C) [2]:

a) Specific gravity in relation to air: 1.529
b) Molecular weight: 44.010 g/mol
c) Viscosity: 0.0135 mPa/s
d) Density: 1.95 kg/m^3

The rock in the reservoir and the hydrocarbon fluid already present are affected physically and chemically when CO_2 is pumped into the reservoir. These interactions serve as the fundamental explanation for why and how injected CO_2 recovers the remaining on-site oil. The majority of these mechanisms fall under the following categories [3]:

a) Oil volume growth
b) Reduction in oil and water density
c) lowering oil viscosity

d) Reducing the interfacial tension (IFT) that previously prevented oil from passing through the pores of reservoir rock and into the oil.
e) Vaporisation and extraction of trapped oil components, particularly light ones
Oil is highly soluble in carbon dioxide, which causes the oil to expand and subsequently lose viscosity and density [2]. Injecting CO_2, which is somewhat soluble in water, will result in decreased water density since there is almost always some water in the reservoir that is left over from a prior water flood [3]. When water and oil densities eventually approach parity, the effects of gravity segregation are reduced, override flow is less, and the fingering phenomenon is less frequent.
Both in the lab and on the ground, CO_2 miscible injection has been demonstrated as an effective method for increased oil recovery. The technique is now highly developed because there have been enough investigations. The need for a customised design for a single field persists due to the complexity of CO_2 flooding. The behaviour of the fluid during an injection serves as the foundation for the entire procedure [4]. The overall procedure entails reservoir screening, injection optimisation, precise laboratory design, reservoir modelling, economic evaluation, pilot testing, application re-evaluation, and commercialization [4]. The optimisation of the chemical formulation, reservoir setup, and injection tactics are all covered by specific designs.

6.1. Injection Strategies of CO_2 flooding

Three solvent injection techniques are frequently used in industrial miscible flooding applications are slug injection, water-alternating-gas (WAG) injection, and gravity-stable injection. The slug process typically involves a continuous injection of 0.2 to 0.4 hydrocarbon pore volumes (HCPV) of solvent, which is then replaced by water or dry solvent. Tiny amounts of solvent (0.01-0.04 HCPV) and water are alternatively injected during the WAG process. The total amount of solvent injected ranges in most cases from 0.2 to 0.6 HCPV. Similar to the slug process, the final driving fluid is typically water or a dry solvent. It is well known that alternating tiny injections of water diminish solvent mobility and increase solvent sweep effectiveness. [5]

And for CO2 flooding depending on the reservoir geology, fluid and rock properties, the CO2 flooding involves the following-

1) Continuous infusion of CO_2 is needed for this procedure; no other fluid is allowed. To maximize gravity segregation, a lighter gas, like nitrogen, may occasionally be added after CO_2 injection.[6]
2) CO_2 is continuously injected, and then water is added. This procedure is the same as the continuous CO_2 injection procedure, except for the chase water that comes after the total volume of injected CO_2 slugs.[7]
3) Water is added after conventional water-alternating-gas (WAG). In this procedure, equal amounts of water and a specific volume of CO_2 are injected in cycles. Water injections are alternated with CO_2 injections to help overcome gas override and reduce CO_2 channeling, which increases the total CO_2 sweep efficiency.[5]
4) Tapered WAG- Conceptually, this design is comparable to the standard WAG, but it gradually reduces the volume of injected CO_2 in comparison to the volume of water.[8]

5) WAG followed with Gas- This procedure uses a standard WAG method that is then followed by a chase of a less expensive gas (such air or nitrogen), which is added after the entire amount of CO_2 slug has been injected.[9]

7. Operational aspects of CO_2 flooding

One of the most prevalent and beneficial substances on and in our environment is carbon dioxide. It is not shocking that early in the history of oil production, the concept of employing CO_2 to extract oil from subsurface reserves first emerged [1]. The development of CO_2 oil-recovery techniques made great strides in the years immediately following World War II. The 1950s saw the publication of articles and patents by Whorton et al., Saxon et al. [2]. Beeson and Ortloff [3], Holm, and Martin, which provided the groundwork for modern oil recovery methods[1].

The following developments in CO_2 flooding technology occurred in the 1960s [1]–[3]:

a) definition of the amount of CO_2 needed for oil recovery;
b) development of the use of CO_2 as a well stimulant additive in fracturing and acidizing;
c) field tests of CO_2 flooding.

The Mead Strawn field hosted the first successful field test of CO_2 with waterflooding, which proved that severe CO_2 gravity override and channelling are not always present in the reservoir and that more oil was produced by a CO_2 slug followed by waterflooding than by waterflooding alone.

The displacing CO_2 gas gets sufficiently enriched in C_5 through C_{20} hydrocarbons when specific pressures are reached that a more effective unit displacement of oil is found, and oil recovery exceeds the quantity predicted by solubility effects. When oil is displaced virtually completely in the areas contacted by CO_2 at and above this pressure, this is known as real miscible displacement.

For calculating the flooding pressure required for miscible displacement to work at its most effective level for oil displacement, a variety of correlations have been put up[2].

Temperature is a factor in any association because it influences the volume and density of CO_2 and, consequently, its liquid-type solubility. The number and, to a lesser extent, the kind (paraffin, aromatic) of hydrocarbons present in the crude oil dictate the level of CO_2 solvency necessary, making the oil composition an equally significant variable[1], [2], [4]. The composition (purity) of the injected CO_2, where C_1 through C_4 and other gases like nitrogen have a significant impact on the pressure necessary for miscible displacement, must also be taken into account in correlations.

Continually fed contaminants either boost or diminish the CO_2's ability to dissolve depending on how well they dissolve in oils. For instance, N_2 would make the injected gas less solvent while C_3 would make it more subsequently [1].

To further understand the displacement mechanism, researchers have been examining the intricate phase correlations between injected CO_2 or CO_2-rich gas and oil components [3]. But at this moment, the outcomes of slim-tube flow experiments core floods, and reservoir simulation studies can be used to establish whether a reservoir is suitable for CO_2 flooding.

The highly high mobility of the CO_2 has been the main obstacle to lucrative CO_2 flooding applications, As a result, a large portion of the oil is not contacted, is not swollen, and does not have its viscosity decreased[2], [3]. Due to the extracted C0/hydrocarbon zone's dispersion, which prevents oil from being properly banked and mobilised, miscible displacement may only occur in small-volume channels and finger areas. Increased CO_2 injection causes an excessive flow via CO_2 already-swept zones.

To date, more than 30 field tests of CO_2 injection techniques have been conducted. Many were at least successful technically [5].

A proven EOR method, CO_2 flooding is applicable to many different reservoir rock and oil types. The cost and source of CO_2 are likely the most crucial aspects influencing a project's economic success. Depending on the source's characteristics, its location in relation to the oil field, and the mechanism used to deliver CO_2 to the field, it may be feasible to find a source for oilfield flooding [1]

7.1. CO_2 sources of CO_2 flooding

In miscible flooding, one of the commonly used methods is CO_2 source miscible flooding. This technique involves injecting CO_2 gas into the reservoir to enhance oil recovery. CO_2 is abundantly available in various sources, including natural deposits, industrial processes, and carbon capture and storage projects. The CO_2 gas is pressurized and injected into the reservoir, where it mixes and dissolves with the oil. This miscible mixture reduces the viscosity of the oil, lowers interfacial tension, and improves the displacement of trapped oil. CO_2 source miscible flooding has proven to be commercially successful, particularly in low-permeability reservoirs and those with light oil. The accessibility and availability of CO_2 as a solvent make it an attractive option for enhancing oil recovery and maximizing production from aging oilfields.

CO_2 can come from three places: (1) natural hydrocarbon gas reservoirs with CO_2 as an impurity (usually less than 25%), (2) industrial or anthropogenic sources with a wide range of CO_2 percentages in effluent, and (3) natural CO_2 reservoirs. The source gas might need to be processed, depending on its purity, to get the CO_2 concentration high enough (90–98%) for EOR, especially if it's a miscible process.[10]

7.2. Surface facilities of CO_2 flooding

The criteria for a CO_2-EOR facility are generally the same as those for a waterflood, with the exception of the CO_2 injection facility, which includes the following three key pieces.

1. Extraction - CO2 is taken out of separator gas, which, after breaking through in producing wells, starts to display rising CO_2 levels.
2. Processing - CO_2 is refined to specifications after being collected from the separator gas and is then dehydrated before compression.
3. Compression - To boost its injection pressure, CO_2 is compressed.[11]

Additional injection wells may be necessary as part of a field-wide application. On the basis of simulation findings and field experience, well specifics such as their count, locations to comply with well pattern (for example, regular five-spot, inverted five-spot, and so on), and appropriate injection rates are usually determined. Drilling new wells and recompleting older wells can meet injection-well criteria. Infill drilling may be effective in some cases to improve reservoir areaal coverage and expand pattern flood across the field, while step-out drilling may be a preferable alternative in others.[12]

7.3. Problems in CO_2 flooding

In tight reservoirs, gas injection offers numerous benefits over water floods. Low porosity and permeability will reduce the injectivity and viability of flooding with water. Gas injection, however, comes with some problems.

7.3.1. CO_2 Conformance Control Problems

By storing CO_2, the reservoirs can significantly lower the quantity of carbon dioxide that is emitted into the atmosphere. However, injected CO_2 frequently travels through fractures, channels with high permeability, and streaks seen in reservoirs, leading to poor hydrocarbon recovery and subpar CO_2 storage performance.[15]

Low viscosity, which causes an undesirable mobility differential between CO_2 and oil, is one of the main issues with CO_2 flooding in particular fields.[7]

Because of its great mobility, CO_2 bypasses the majority of the crude oil in the flood pattern and seeks out the widest throats or pores for the path of least resistance, travelling the shortest distance between the injection well and the production well. Due to the variability of the reservoir, CO_2 occasionally passes through highly permeable strata and fractures. As a result, a large amount of the oil is not touched and is not cleaned up. Early CO_2 breakthrough shows signs of inadequate sweep efficiency. These drawbacks are referred to as fingering and channelling issues. Due to CO_2's low gravity, a gravity overriding issue is also undesirable.[15]

7.3.2 Asphaltene Deposition and Scale

CO_2 has a strong ability to cause the asphaltene molecules in crude oil to flocculate. This phenomena may occur in the vicinity of injection well bores where the mixture's CO_2 level is as high as 60–70%. Asphaltene often appears as a scattered phase within the oil when it is stabilised by resins and intermediate hydrocarbon components. Instability results from CO_2 extracting intermediate components from oil during the vaporising drives. Asphaltene will consequently flocculate and eventually precipitate as a result. Asphaltene may cause pore throats close to wellbores to clog, which could have an impact on permeability and potentially CO_2 injectivity.[16]

7.3.3 Formation Dissolution

In water, CO_2 dissolves to form an acidic gas and a weak acid that can react with formation, especially in carbonates. The reaction between the formation and the CO_2-formed acid may lead to rock disintegration and modifications to the heterogeneity of the reservoir.The primary components of increased oil recovery are produced by the solubility of CO_2 in crude oil.The amount of CO_2 that can be dissolved in oil depends on the temperature, pressure, and oil's properties. West Texas crude oil has a gravity of 39 °API compared to 30.3 °API for ADA crude. Solubility will increase with rising pressure and may occasionally reach a saturation state. The amount of crude oil will grow as a result of CO_2 dissolving into it.. This phenomenon is greater for light oil and leads to lower residual oil saturation.[17]

8. Improvement of CO_2 Flooding

a) Measure the mobility of CO_2-foam on diverse oil field rock types employing multiple surfactants over a wide variety of flow speeds, surfactant concentrations, and flowing volume ratios. Adsorption and thermal stability tests are among the procedures used to evaluate potential surfactants for CO_2 foams.[18]

b) In order to find suitable direct thickeners, synthesise and evaluate prospective forms of dense CO_2-soluble polymers.[19]

c) To evaluate the usefulness of specific mobility control approaches, look for additional reliable but less time-consuming methods.

d) Perform a series of unprotected and mobility-controlled CO_2 floods to evaluate the utility of available mobility control technologies in a direct comparison.[18]

9. New concepts of improving CO_2 flooding

a) Nanoparticle-assisted CO_2 Flooding: Oil recovery may be improved by adding nanoparticles to the CO_2 stream, such as silica or clay nanoparticles. Nanoparticles can improve sweep effectiveness, decrease capillary forces that prevent oil displacement, and change how wettable the reservoir rock is. Additionally, they have the ability to adhere to asphaltene surfaces and stop flocculation.[3]

b) Surfactant-Assisted CO_2 Flooding: To increase oil recovery, surfactants can be employed in conjunction with CO_2 flooding. Oil is better displaced and mobilised when surfactants are present because they lower the interfacial tension between CO_2 and oil. They may also change the reservoir rock's wettability, which would improve oil displacement.[7]

c) Foam-Assisted CO_2 Flooding: CO_2 and a foaming ingredient can be injected into the reservoir to produce foam. Foam has the advantage of decreasing CO_2 mobility, boosting sweep efficiency, and expanding the region in which CO_2 and oil come into contact. Better oil displacement is achieved as a result of the control it provides over fingering effects and channelling.[20]

10. Conclusion

This study summarized CO_2 miscible flooding field application information and demonstrated existing screening criteria. Although the choice of EOR method is never a result of simple factors, the summarized recommended range can still serve as a reference to benefit field engineers and researchers in the future.

Miscible flooding is a promising EOR technique that has been widely studied and used in the oil industry. Its effectiveness depends on several factors, including reservoir properties, fluid composition, injection rate and pressure, and economic considerations. Further research is needed to optimize the design and implementation of miscible flooding projects.

"Miscible flooding has the potential to significantly increase oil recovery from reservoirs that are not amenable to other EOR techniques. Therefore, continued research and development in this area are necessary to improve the effectiveness and economic viability of miscible flooding."[21]

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