Gas injection

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In the production of oil from subsurface reservoirs, 65% of the oil initially in place (OIIP), on average, is left in the reservoir after more oil as possible has been recovered by natural depletion and with the aid of water flooding. Residual oil and gas are enhanced oil recovery (EOR) methods.

EOR techniques are classified into thermal (such as steam or hot water injection) techniques and non-thermal techniques (including designer water flooding, gas injection and chemical flooding). The former is primarily intended for heavy oils, while the latter are normally applied in light oil reservoirs.

There are some of the non-thermal enhanced oil recovery methods, such as polymer flooding, alkaline-surfactant-polymer (ASP) and alkaline flooding are much expensive and are also subjected to some operational restrictions, such as temperature (reservoir) and formation permeability.

Gas injection techniques in various forms consisting of hydrocarbon gas injection (including natural gas, enriched natural gas and a liquefied petroleum slug driven by natural gas) and non-hydrocarbon gas injection (such as carbon dioxide, nitrogen and flue gas) are widely used to reduces the residual oil saturation.

In gas injection, a compressed gas such as carbon dioxide (CO_2), natural gas (consisting primarily of methane, CH_4), nitrogen (N_2), or flue gases are injected into the reservoir to displace oil toward the production wells. The injected gas either partially dissolves in the oil (immiscible gas flooding) or mixes completely with it (miscible flooding), leading mainly to swelling of the oil, viscosity reduction in the oil phase and also for miscible flooding, lowering of the interfacial tension (IFT) between the displacing phase and oil .

CO_2 injection is preferred because it applies for two different purposes; improving oil recovery and CO_2 sequestration for diminish the greenhouse gases emissions. Several problems such as corrosion in the production wells or injection and surface facilities as well , CO_2 separation from the saleable hydrocarbons, large requirement of CO_2 per increase in barrel and asphaltene precipitation which causes formation damage and wettability alteration have been reported for CO_2 injection process.

Injection of N_2 or nitrogen-contaminated lean hydrocarbon gases are appropriate EOR processes for deep reservoirs, high pressure reservoirs, with light or volatile oil that are rich in light and also intermediate hydrocarbon components (C_2–C_5) due to their miscible displacement potential. Low cost, abundance and availability of nitrogen are the most reported advantages for nitrogen injection.

Nitrogen is produced by cryogenic processes from air for a long period of time. CO_2 (carbon dioxide) flooding enhances oil recovery by the following main mechanisms: (1) oil swelling, (2) reduction of crude oil viscosity, and (3) reduction of interfacial tension (IFT), the latter pertains to miscible flooding .

The mechanism of swelling of oil by carbon dioxide injection which makes the volume of oil increase would help discontinuous oil droplets trapped in a porous medium to merge with the flowing oil phase. Reduction in the viscosity is another major mechanism which is significant at even moderate pressures. The amount of solution gas or oil ratio in case of nitrogen injection is lower than that of CO2.

The swelling factors of N2 were also lower than those of CO2 due to nitrogen lower solubility in the oil. If the pressure is low (lower than 3 MPa), solubility of nitrogen and flue gas is negligible. The viscosity reduction due to N2 injection is much lower than that of carbon dioxide injection. Addition of N2 to the injection gas implies that some mechanisms other than swelling and viscosity reduction are important.

One possibility is the buildup of free gas saturation with the N2 containing injectants that may decreases the relative permeability to water, thereby improving the mobility ratio. Moreover, nitrogen has a higher molar volume than CO2 which tells that one mole of nitrogen displaces a higher volume of gas than that of CO2. Therefore, N2 is more favorable in terms of displacement volume. So that our focus in this study is on N2. Literature review on N2 miscibility

Immiscible gas injection can potentially recover a large amount fraction of the remaining oil after primary depletion or water flooding (WF). However, such potential has hardly ever been realized because of the low vertical efficiency and areal sweep efficiency. Nitrogen injection process is also performed either by miscible or immiscible, depending on the injection pressure of N2, reservoir temperature and reservoir oil composition. Miscibility is theoretically defined as the conditions at which there is no interface between the reservoir oil and displacing phase .

In other words, it can be say that two phases are miscible when a single phase fluid is produced after intermingling of two fluids with each other at any ratio. The lowest operating pressure, at reservoir temperature, at which miscibility is achieved between reservoir fluid and injection gas is termed as the minimum miscibility pressure (MMP) . There has been a few correlations in the literature for N_2 MMP estimation producing different average absolute error values.

A study done by Fathinasab, Ayatollahi and Hemmati-Sarapardeh had resulted in a correlation for MMP which will be used for pure N_2, nitrogen mixtures and lean gases. The developed correlation yields the least error and is a function of average critical temperature of the injection gas, reservoir temperature, C_7 + fraction molecular weight of crude oil, volatile components (mole fraction) and intermediate components (mole fraction) of crude oil.

Since N_2 is not as good a solvent for oils as carbon dioxide (CO_2), or even methane (CH_4), the pressure required for nitrogen to become miscible with any oil should be greater than that for methane which, in turn, is higher than CO_2 . This especially makes nitrogen attractive for highly undersaturated reservoirs at immiscible conditions.

Literature review on challenges in gas flooding and a solution

The major technical challenge of immiscible gas injection is to maintain proper sweep efficiency of the injected gas, improve gas utilization and delay its breakthrough. These result from a combination of gravity override and gas channeling through high permeability streaks in the formation. Gas segregation, channeling and fingering through high permeability streaks are inherent in any gas injection; they are due to the excessively higher mobility and far lower density of gas (displacing phase) compared to oil or water (displaced phase).

Unfavorable mobility ratios lead to even more severe channeling in heterogeneous reservoirs and heavier oil reservoirs. Consequently, the drive fluid does not contact a large part of the reservoir and the volumetric sweep efficiency of the reservoir remains poor .

Furthermore, a displacement is adversely affected by capillary end effects, arising from the discontinuity of capillarity in the wetting phase at the outlet end of the core, that, for the gas/oil system, cannot be overcome by high gas throughput rates. WAG injection is implemented to improve mobility ratio and sweep efficiency.