The Potential of CO2 Injection on Enhanced Oil Recovery Method for Oil Fields in Indonesia

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Abstract

Indonesia is one of the countries that have large oil and gas reserves. So far, primary and secondary oil recovery can only produce around 20%-40% of reservoir reserves in Indonesia, so there is a large amount of oil potentially remaining in reservoirs. One of the Enhanced Oil Recovery (EOR) methods is CO2 injection because there are many sources of CO2 gas in oil fields in Indonesia. The purpose of this study was to determine the performance of the CO2 injection mechanism method, which can make hydrocarbon fluid miscibility and increase the recovery factor of oil wells. The methodology in this study is a literature review that discusses oil field data in Indonesia. Screening criteria use several parameters, including reservoir pressure and minimum miscibility pressure. Field data is then calculated and predicted using simulations. From the results of the simulation, calculations carried out there are six oil field areas that have the potential for CO2 injection in an effort to improve oil recovery, namely in the East Kalimantan, West Java, and South Sumatra areas, with recovery factors ranging from 50% - 90% of the original oil in place (OOIP).). CO2 flooding has a good potential to be implemented in oil fields in Indonesia because there are many sources of CO2, easy to obtain, very good for increasing production rates in reservoirs with heavy and light oil content, and can reduce the results of environmental pollution from gas emissions.

Keywords: CO2 flooding, enhanced oil recovery, environmental pollution, minimum miscibility pressure, recovery factor

I. INTRODUCTION

The level of primary and secondary oil acquisition at the present time is at 20-40% of total OOIP, which indicates that there is a large potential of oil leftovers in the reservoir. Enhanced Oil Recovery is a well-known technology in the oil industry, which is utilized to increase oil production acquisition by transforming fluid and reservoir rock characteristics. This EOR technology is conducted by injecting a fluid or gas into the production well. To improve oil and gas production in Indonesia, there are two commonly known steps, which are extensification and intensification. The Extensification step is an effort to improve oil recovery by conduction exploration or opening new refineries. Meanwhile, intensification is a means to improve oil and gas production by increasing the

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recovery factor by utilizing advanced technology to recover oil or what is known as Enhanced Oil Recovery (EOR).
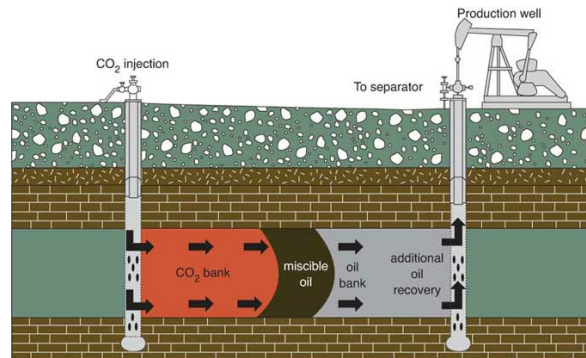

Figure 1. Carbon dioxide miscible flooding (Annual Report 2005)

The objective of this research is to acknowledge the performance of the CO_2 injection mechanism method that can create hydrocarbon fluid miscibility and improve recovery factors on oil refineries. Oil acquisition reduction cases are frequently happening because of the depleting number of oil due to continuous exploitations, even though oil is still available on the spot. However, it becomes more difficult to produce oil in the refinery because its oil containment and reservoir pressure are decreasing. Naturally, the production level of oil acquisition will get lower along the time. That is why technology to maintain a high level of production is required. If the situation is maintained, oil production will get lower and accelerate the end of production. Before it happens, a measured step is required to recovery production to the expected level. The selection of the applied method should be adapted to the presented condition in the field. One of the known EOR methods is CO_2 injection. By the existence of this method, the operating period of refineries can be improved, and in the end, it will also increase the profitability of oil refineries. The production level of oil refineries eventually will experience a decrease after its peak period. There are several efforts that can be conducted to maintain or to improve production rate when secondary recovery is no longer effective. However, the procedure mentioned above is aimed to improve short-term production. Meanwhile, for long-term improvement, it is possible to apply tertiary recovery by gas injection.

II. LITERATURE REVIEW

The physical element of CO_2 injection operational can be utilized to illustrate how the process works. First, the pipe channel CO_2 into the field with high pressure and density according to the requirement of the reservoir. CO_2 is then channeled into the injection well that is strategically placed in the good pattern to optimize the sweeping reservoir area. The injected CO_2 enters the reservoir and move through rocks' pore and contacting crude leftover droplets and miscible with the oil to form new oil accumulation, which is swept into the production wells.

In production wells, the well manifold allows testing on each well to see how many oil, gas, and water can be produced in each location. The produced liquid is then separated with produced gas that includes CO_2. When the injected gas is starting to break through the production well location, it needs to be further processed. Every CO_2 produced needs to be separated from the natural gas and recompressed for reinjection process with additional CO_2. In some situations, and the produced

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formation water is separated and processed to be re-injected consecutively with CO_2 injection. This technique is conducted to improve swiping efficiency (WAG process) (NETL, 2010).
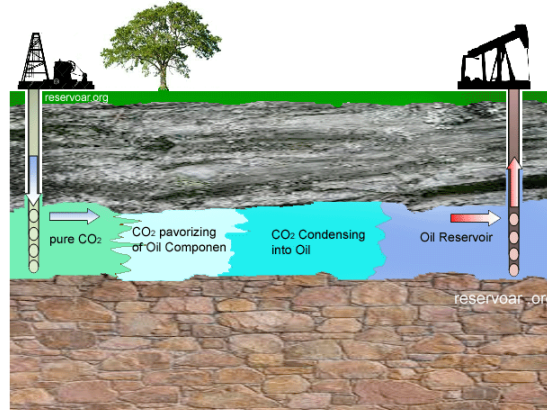

Figure 2. A Scheme of EOR Carbon Dioxide Injection Process (Khalil & Biyanto, 2018)

In a mixed CO_2 gas injection method, there are two types of miscibility contacts, which are First Contact Miscibility, where CO_2 injection is conducted with a single test by determining pressure at a higher level, and Multi-Contact Miscibility which is a CO_2 injection conducted on several times until it reaches mixing point. There are several methods to determine TTM pressure, which are by using laboratory slim tube test, correlation calculation, and slim tube simulation. There are many correlations that can be utilized based on the critical point calculation of a simplified multi-component system on a pseudo component. Generally, a correlation can only predict a decent minimum mixing pressure on a certain range of a crude oil composition where the correlation itself is developed. There are several correlation methods mentioned by a number of experts, for example, Hlm Josendal correlation, Yellig Metcalfe correlation (1980), Cronquist et al. correlation (1981), National Petroleum Council correlation (2001), and Ellisa M. EIM Shokkir correlation (2006). These correlation methods possess different factors on each correlation. For example, Cronquist et al. only utilizes temperature in the TTM calculation factor. In 2006, M. El-M Shokkir managed to discover a correlation that can calculate TTM value, which is influenced by CO_2 purity. The factors utilized in this correlation are oil composition and temperature (Setiati, 2016).

Oil recovery improvement concurs with different techniques, one of which is by injecting CO_2 in permeable and light-oil reservoirs. This CO_2 injection can improve 10% to 20% of recovery factors (Huang, Yang, Liao, & Zeng, 2015). Besides that, this CO_2 injection can also lower atmosphere gas emission by conserving CO_2 inside the reservoir. The miscible gas injection also indicates that the moving gas can be mixed with oil on reservoir, whether on the first contact or on the next several contacts, which in turn will improve sweeping and volumetric displacement efficiencies (Ev and Ed). A transitional zone will develop between the oil reservoir and the displaced gas, where the injection ability of gas will depend on reservoir pressure, temperature, and oil formation factor natures. CO_2 injection contains two mechanisms:

CO_2 Miscible Mechanism
The miscible process happens when the reservoir pressure is higher than Minimum Miscibility Pressure (MMP), which causes the injected CO_2 to be highly mixed with crude oil (CO_2 and oil in the reservoir form a single-phase). When reservoir pressure is above MMP, miscibility between CO_2 and oil is achieved through multiple-contact or dynamic miscibility, where the hydrocarbon with molecule at a medium and higher level than oil vaporize into CO_2 (gas drive process), and a part of

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injected CO_2 will be dissolved into the oil (condensed gas drive process). Movement between oil and CO_2 allows both phases to dissolve completely without interface tension whatsoever and help develop a dissolved transitional zone (Drahansky et al., 2016).
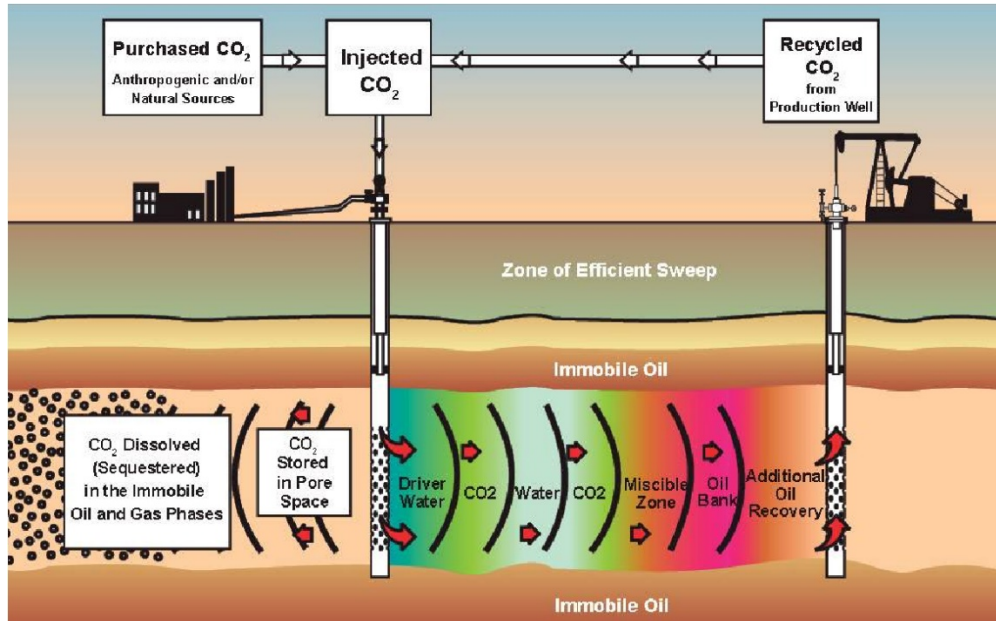

Figure 3. CO_2 Miscible Mechanism (Advanced Resources International, 2010)

CO_2 Immiscible Mechanism
This mechanism is utilized when the reservoir pressure level is below MMP, which inhibits CO_2 and oil in the reservoir to form a single-phase (unmixed). However, the CO_2 at this condition will be dissolved in oil and causes swelling or oil volume increase, which would lower viscosity and increase oil density (Drahansky et al., 2016).
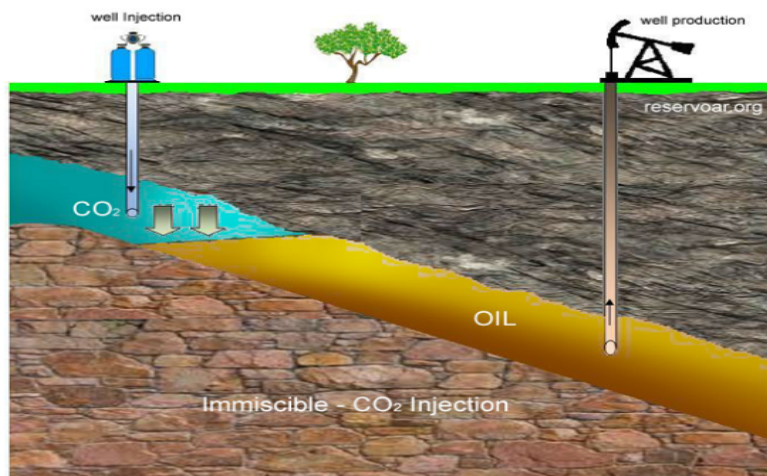

Figure 4. CO_2 Immisicible Mechanism (Merchant, 2015)

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III. RESEARCH METHODOLOGY

Based on reservoir geological condition, fluid, and rock formation, there are several CO_2 injection models, for example:

Continued CO_2 injection during EOR process

This process requires a periodically CO_2 injection without other fluid addition. Sometimes, nitrogen is also injected along with CO_2 gas to improve sweeping effectiveness (UKCS Oil and Gas Authority, 2017).
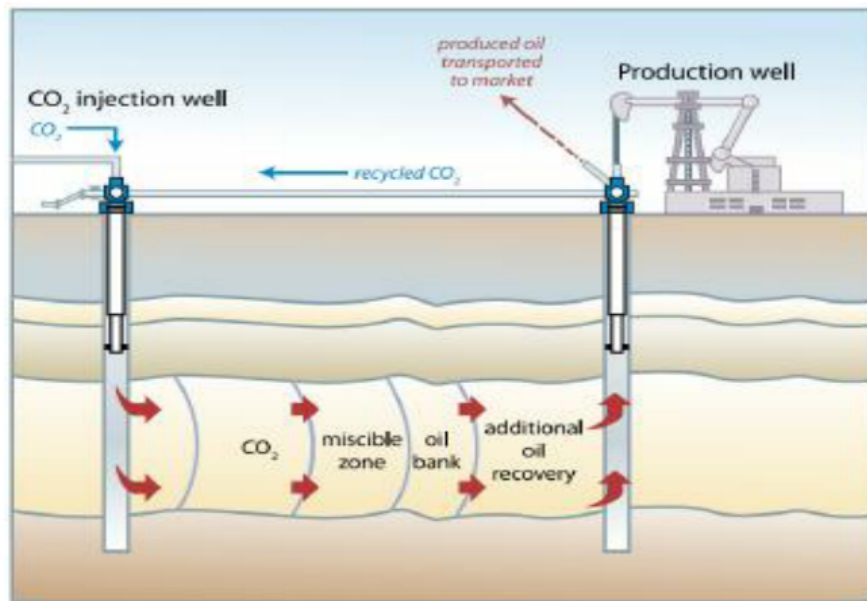

Figure 5. Continued CO_2 Injection (H. Hawez, 2014)

CO_2 Injection followed by water

This method is similar to CO_2 method, but water is injected to add CO_2 volume (UKCS Oil and Gas Authority, 2017). So after CO_2 injection is conducted, the process continued to water injection, as illustrated in the following figure.
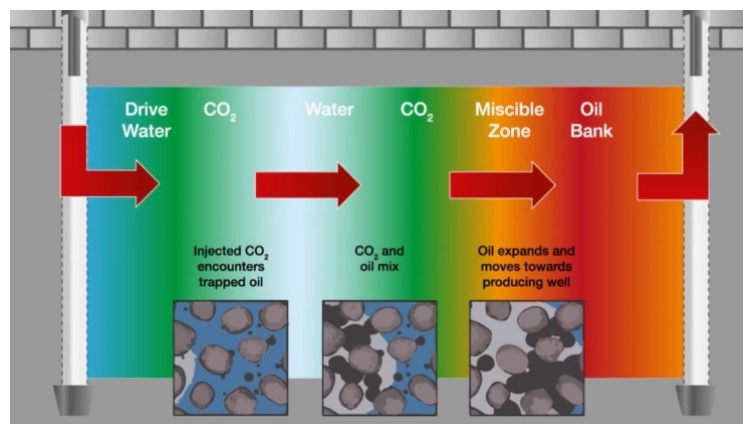

Figure 6. CO_2 injection, followed by water injection (Lee, 2014)

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CO_2 Injection periodically with water (conventional WAG)

In water-alternating-gas (WAG) process, a volume if CO_2 is injected with a periodic cycle with water on a predetermined similar volume. Water is periodically injected with CO_2 to help overcome gas override and lower excessive CO_2 channeling, while also improve CO_2 sweeping efficiency as a whole (Merchant, 2015).
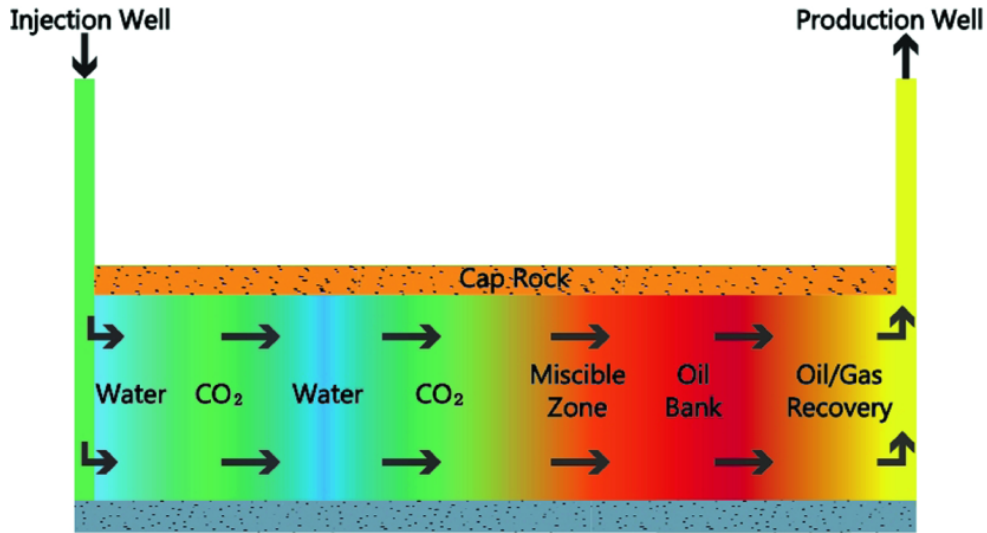

Figure 7. Water alternating gas (WAG) CO_2 Flooding (Lee, 2014)

Periodically CO_2 and water injection (WAG)

This method is similar to the conventional WAG method, but in this method, a gradual subtraction of CO_2 injection is conducted relative to water injection volume (Merchant, 2010).
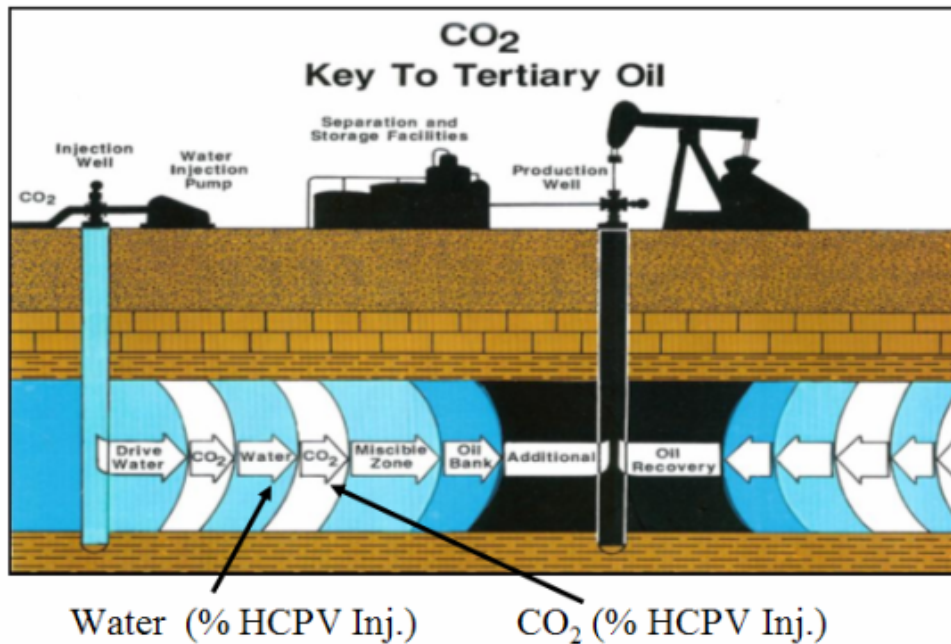

Figure 8. Periodically injection of CO_2 and water (WAG) (Merchant, 2010)

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In this research, the method utilized to improve the recovery factor or production capacity of a well is by conducting both secondary and tertiary gas injection recovery, especially CO_2 injection.

In the injection of CO_2 gas, a selection criterion that includes reservoir depth, pressure and temperature, minimum miscibility pressure (MMP), residual oil saturation, net pay density, crude oil gravity, viscosity, permeability, porosity, and reservoir heterogeneity (Huang et al., 2015). On initial screening, according to National Petroleum Board, the optimum criteria for CO_2 miscible is summarized in Table 1 (Drahansky et al., 2016). Every deviation of these criteria will depend on reservoir size and its hydrocarbon recovery potential. For example, when reservoir temperature is higher than 120°F, the additional pressure required in the process is between 200 to 500 psi to be able to reach miscibility. CO_2 density depends on the depth of the injection, which controls the temperature and pressure around 0.6-0.8 g/cc. At this point, CO_2 must be injected at 800m of depth, where CO_2 is at a solid phase (both liquid or supercritical). Reservoir with a high salinity level is more vulnerable to CO_2 reserve than a low salinity reservoir (Al-Aryani, Obeidi, Brahmakulam, & Ramamoorthy, 2011).

Table 1. Filter Criteria for CO2 Injection (Drahansky et al., 2016)

Criteria	Optimum condition
Depth, ft	2500-3000
Reservoir temperature, °F	<120
Total dissolved solids (TDS)	>3000
Oil gravity	<10,000 mg/l
Oil viscosity, cp	Medium to light oils (27-39 °API)
Reservoir type	Carbonate or Sandstone reservoar
Minimum miscibility pressure (MMP)	1300-2500 psi
Oil saturation	>20%
Net pay thickness, ft	75-137
Porosity	>7%
Permeability	>10mD

The requirements in Table 1 act as references on reservoir data selection for CO_2 injection to improve oil production capacity..

IV. FINDING AND DISCUSSION

CO_2 injection is one of the well-known EOR methods frequently utilized to improve oil recovery because of its relatively low cost. Also, CO_2 possesses suitable characteristics for the EOR process. For example, it is easily dissolved in crude oil because of its light nature, and it has the ability to lower oil viscosity and also increase water viscosity, lower oil density, and form a fluid that mixed with oil because of the extraction process so it would be able to act as solution gas drive. CO_2 injection source comes from wells that produce relatively pure CO_2 or factories that process hydrocarbon gas that contains a vast amount of CO_2 as a contaminant. CO_2 injection also produces a positive impact on the environment because a part of CO_2 (pollutant) is re-injected on the ground (Khalil & Biyanto, 2018). CO_2 injection has also been practiced in a geological formation, such as on old refineries all over the world. Principally, CO_2 injection on the field is aimed to lower the surface tension between injection fluid and reservoir fluid, so that oil saturation can be produced (Stalkup, 1983).

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Indonesia, as one of the numerous countries that produce oil, possesses numerous old refineries that have been operated for a long time. Oil production on these old fields can be improved by conducting CO_2 injection as Enhanced Oil Recovery (EOR) process. There are many reservoirs in Indonesia that are profitable and suitable as CO_2 (either mixed or unmixed) injection candidates. The produced oil is ranged from medium to light oils. Oil saturation after waterflood is high, and most of these wells are filled with water. Almost 62% of OOIP or 48.2 billion barrel of oil is available at the reservoirs. This accumulation is based on 650 oil fields targeted as EOR points (Usman, 2011). CO_2 injection potential in Indonesian oil reservoirs is measured based on its available additional recovery capacity and CO_2 source availability. There are oil and gas fields in Indonesia with a high level of CO_2 content (for example, Natuna field), and sources of CO_2 produced by oil-based power plants or LNG/LPG refineries, for example, the one located in Bontang/Arun. A screening process, laboratory test, and reservoir simulation modeling on several oil fields in Indonesia have been conducted. Sangatta field is an old reservoir with a production capacity that can be improved by CO_2 injection. Besides that, the Sangatta field is very close to CO_2 source, which is the LNG Bontang refinery, which is a high source of CO_2. Figure 2 shows a map of the Sangatta field location, which is at 210 km north of Balikpapan City and 50 km of LNG Bontang refinery. Data utilized in this research are geological, reservoir, production, rock sample, and reservoir fluid data. Geologically, Sangatta possesses layered reservoirs with an anticline structure of 18 km^2. Laterally, this field also possesses a complex fault system. The productive zone is located at Balikpapan formation with a depth of 500-1300 meters and in a lithological manner formed of sandstone covered by clay and coal. The number of located reservoirs is 277 reservoirs (layers) with an initial oil content of 261.3 million Bbl. The amount of produced oil up until the conduction of this research is at 31.6 million Bbl or around 12% of its initial oil content. With a reserve of 88% from initial content, Sangatta production capacity possesses the high potential to be improved and also utilized as a permanent CO_2 reservation area. Based on the parameter screening, the Sangatta field possesses higher Minimum Miscibility Pressure than the initial reservoir pressure. MMP determination laboratory test was conducted on five injection pressure, which is at 2250, 2500, 2750, 3000, and 3250 Psi. as shown in the following figure, oil recovery factors on 2250, 2500, and 2750 Psi of injection pressures show a steep increase, meanwhile on 3000 and 3250 Psi injection pressures, the increase is relatively low. Based on the calculation, there are two tendencies of oil recovery factor improvement on two categories of injection pressures which are at 2250, 2500, and 2750 Psi injection pressures and for 3000 and 3250 Psi injection pressures. MMP is determined by the intersection of two tendency lines, which shows 2850 Psi of pressure, as illustrated in the following figure. MMP value is higher than the estimated MMP produced with the correlation method on the screening process. MMP is an important parameter that can be utilized as reservoir simulation modeling data input. In this case, an approximate of 1763 Psi additional pressure for each reservoir to reach MMP is required, as shown in the following figure. The selected injection pressure is at 3000 Psi or 150 Psi higher than the MMP test result that shows 2850 Psi, to make sure that mixed pressure is above the required minimum pressure.

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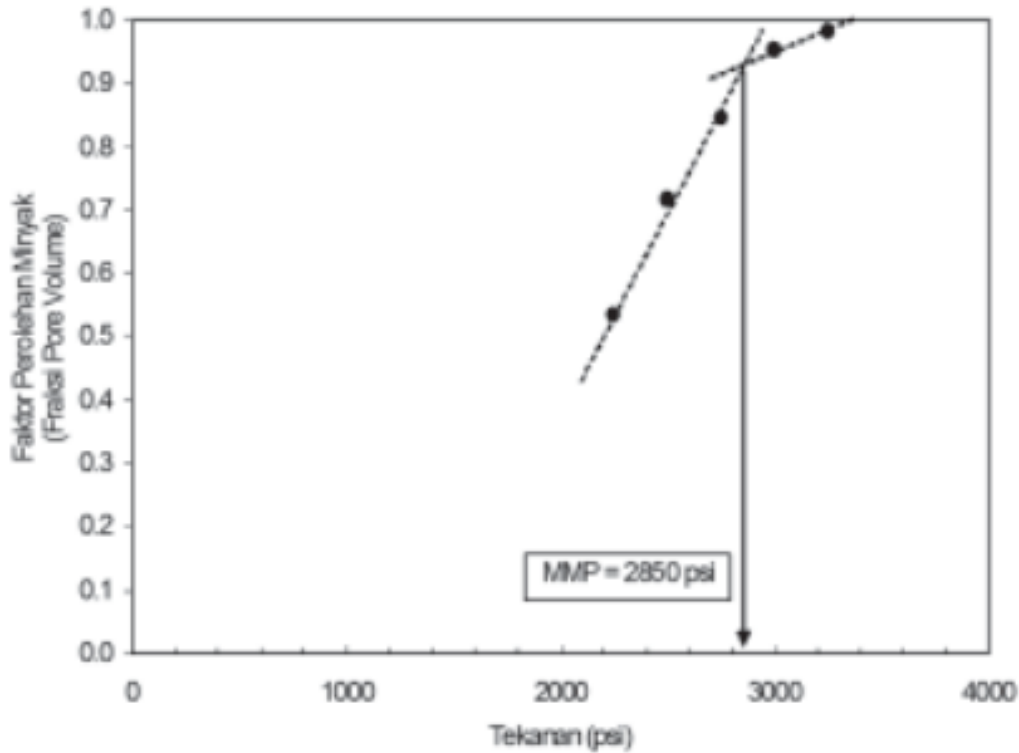Rini Setiati, Gilbert Soenarjo, Ixora Karundeng, Vicky Dimas Widoseno

Figure 9. A laboratory test to determine minimum miscible pressure (Syahrial, 2009)

In Indonesia, oil fields are categorized into three areas, namely, west area, central area, and east area. West area includes North Sumatera, Central Sumatera, and Natuna. The central area includes South Sumatera and Java. Meanwhile, the east area includes Borneo, Sulawesi, and Papua. Oil fields in the west and central areas are generally mature fields. Almost 90% of Indonesian oil is produced in these areas, which is more than 86% of Indonesian oil reserves. In Sumatera, CO2 supply is provided by the gas field in Natuna (Block D Alpha), North Sumatera (Arun LNG), and South Sumatera (Muara Tengah, power plant, gas, and flare gas fields or several oil fields). In Java, CO2 can be supplied by gas processing factories (Subang, Merbau, Cimalaya), and in West Java, CO2 is produced from Muara Tawar Power Plant, several petrochemical industries, and flare gas from several oil fields. In Borneo, CO2 supply can be obtained from East Borneo (LNG Bontang, Muara Jawa Power Plant, and flare gas of several oil fields). In Sulawesi and Papua, CO2 supply can be sourced from Tangguh LNG, gas fields, and flare gas of several fields (Muslim, 2013). CO2 injection simulation has been conducted on several oil fields in Indonesia, as shown in the following table.

Table 2 CO_2 Injection Simulation Results on Oil Fields in Indonesia (Sugiharjo, 2012)

No.	Field	MMP (psig)	Recovery Factor (%)
1	Attaka, East Kalimantan	2150	90
2	Sanggata, East Kalimantan	2800	93.26
3	Jati Barang, West Java	2575	96.37
4	Tugu Barat, West Java	3000	52.67
5	Kaji Semoga, South Sumatera	2420	70.00
6	Jene, South Sumatera	3200	91.33

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CO_2 injection method is divided into four parts. The first part is the continued CO_2 injection. During this part, CO_2 is also sometimes injected together with nitrogen. This method is aimed to maintain a better reservoir sweeping effectiveness and optimality. The second part is periodically CO_2 and water injections. After the miscibility process between CO_2 and crude oil is produced, formation water is injected to lower CO_2 utilization to push oil to the surface. The third is CO_2 injection, periodically with water injection (Water Alternating Gas conventional). On this CO_2 injection method, the determined CO_2 volume was injected on a periodic cycle along with similar water volume. CO_2 injection in a periodic manner with water will help overcome gas override and lower excessive CO_2 channeling while also improve CO_2 sweeping efficiency as a whole. The last part is CO_2 injection and water in a stimulant manner. This part is almost similar to Water Alternating Gas Conventional (WAG) method, but a gradual subtraction of CO_2 injection volume is conducted relatively with water volume addition according to reservoir condition.

CO_2 injection mechanism process is divided into two parts, namely the immiscible CO_2 mechanism and miscible CO_2 mechanism. The immiscible CO_2 mechanism is a condition where reservoir pressure is lower than MMP pressure (Minimum Miscibility Pressure). MMP is ranged between 1300=2500 Psi. MMP pressure will determine whether the injected fluid will react with crude oil or not or can flow through the rock pores. Because of the immiscible process, the reservoir pressure is higher than MMP. The injected CO_2 gas will dissolve into the oil and increase oil volume also lower viscosity and increase oil density. With this mechanism, it will be easier to produce oil. The immiscible process is highly suitable to be utilized on reservoirs that contain heavy crude oil or commonly known as heavy oil. Miscible process CO_2 injection is conducted when the reservoir pressure is higher than MMP pressure so that CO_2 injection can mix together with crude oil and create a single phase. Miscibility between CO_2 and crude oil can happen through multiple contacts, where heavy hydrocarbon with middle and high molecule weight vaporized into CO_2, or commonly known as driver gas. Movement between oil and CO_2 enables both phases to be mixed together into a complete single phase without any difference in its surface tension (Dessouky, 2018). During CO_2 injection, the expected process is a miscible process so that CO_2 injection doesn't have to be channeled with continuity. CO_2 injection works maximally on 2500-3000 feet of depth, with reservoir temperature, not more than 120 degrees Fahrenheit.

V. CONCLUSION AND FURTHER RESEARCH

Based on the discussion and literature above, there are several conclusions made which are:

1. CO_2 injection is a highly prospective EOR for Indonesia at the current moment with vast CO_2 gas sources available from oil fields in Indonesia.
2. CO_2 injection is a decent method to increase production rate in reservoir that contains heavy or light oil.
3. During light oil production improvement, CO_2 injection must be conducted constantly to maintain the miscibility process between CO_2 and crude oil. Meanwhile, during heavy oil recovery, pressure was delivered similarly to the reservoir condition so that CO_2 bubbles will be produced on hydrocarbon, which functions as a driving power to improve oil recovery.

CO_2 injection can improve crude oil production in a large number and lower gas emission pollution on the environment.

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