Effect of Improvement of Temperature and Gas Amount on Nitrogen Flooding

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Abstract. Oil and natural gas are energy resources with high demand, so it is very important to implement enhanced oil recovery technology in old fields to obtain optimum oil production. The enhanced oil recovery technology that will be discussed on this occasion is more specifically related to the gas flooding method, namely nitrogen flooding. Nitrogen flooding is currently used more often as an alternative to CO₂ flooding. However, the limitation of this method is that it is only effective when used in a field with a high depth, because it requires a constant high pressure and temperature so that this gas can dissolve into the reservoir fluid. Therefore, it is necessary to conduct a more in-depth study of the nitrogen flooding method, so that its application can get optimal, efficient, and economical results. The results of laboratory research were carried out to study the displacement of crude oil using the high pressure nitrogen injection method. It aims to study the effect of temperature and GOR on crude oil recovery and the solubility process in high pressure nitrogen injection. In addition, the effectiveness of nitrogen injection after water flooding, and the effect of propane slug driven by nitrogen injection were also analyzed. There are nine types of experiments carried out using crude oil 42.3° API which is recombined with natural gas. This experiment used two temperatures, 70° F and 120° F, and three GORs, namely 575 scf/stb, 400 scf/stb, and 200 scf/stb. The reservoir model used was a stainless steel tube 125 feet long and 0.435 inches in diameter, packed with consolidated sand to provide an average permeability of 910 mD. The recovery factor in nitrogen injection is influenced by the gas content in the system. If the gas content is high, then nitrogen injection will result in a higher oil recovery compared to conditions where the gas content is low.

Keywords: Nitrogen flooding, gas flooding, enhanced oil recovery, propane slug

1. Introduction
In producing hydrocarbons, primary recovery uses methods that utilize natural flow power. If the thrust of natural bursts has weakened, it will be continued by using artificial lift methods which are classified into two categories, namely pumping systems and gas lifts. Secondary recovery uses an injection method called water flooding and gas flooding which is injected into the reservoir.
Primary and secondary recovery methods, on average, produce 1/3 of the OOIP (Original Oil In Place). However, by applying the enhanced tertiary recovery (Enhanced Oil Recovery), the production of petroleum from reservoir rocks can increase by 40 to 60%. EOR is generally divided into two methods, namely thermal and non-thermal methods [1].

2. Literature review
On this occasion, the author will discuss the non-thermal method, namely gas flooding, more specifically nitrogen flooding (N\textsubscript{2}) which discusses "the effect of increasing temperature and the amount of gas". Nitrogen gas injection (N\textsubscript{2}) can be used in the application of EOR to carbonate rock which has cavities, because it has a high efficiency in removing oil. Nitrogen gas injection can be classified into two types, including: miscible gas injection and immiscible gas injection. In mixed gas injection, gas is injected above the minimum miscibility pressure (MMP), so that it will cause the gas to dissolve in oil [2]. In contrast to unmixed gas injection, which is injected under MMP, in order to maintain reservoir pressure, as well as to prevent production cut-offs, thereby increasing production rates.

In the immiscible nitrogen flooding process, nitrogen gas is injected into the top of the formation in order to maintain reservoir pressure, to recover the hydrocarbon liquid in the gas cap, and to stabilize the gas/oil (GOC) contact [3]. In the miscible nitrogen flooding process, gas is injected into the reservoir rock, with the aim that nitrogen gas can mix/dissolve with oil, so that it can help flow oil from the reservoir rock to the production well. The injected nitrogen gas is an inert gas that will dissolve at a very high pressure, and will reduce the viscosity of the oil, as well as provide efficient displacement of the mutually soluble fluids.

The aim of the current nitrogen gas injection is to achieve solubility with reservoir fluid [4]. The phenomenon of dissolving nitrogen gas with reservoir fluid is very complex, depending on the conditions of the reservoir fluid including pressure, temperature, and other factors such as mass transfer between phases, relative permeability, capillary pressure, gravity, etc. Nitrogen gas flooding is an EOR technology with a non-thermal method, which is optimal for use in many reservoirs [5].

3. Methodology and EOR Method Implementation
In this study, the experimental equipment was divided into several systems, including: PVT-Injection System, Reservoir Physical Model, Temperature Control System and Production and Analytical System [6]. Petroleum from the ‘X’ field used in this study has several PVP characteristics, as shown in the following table.

| No. | Parameter | Parameter Value |
|-----|-----------|-----------------|
| 1.  | Avg IPA at 60°C | 42.4 |
| 2.  | Specific Gravity at 60°C | 0.814 |
| 3.  | Oil Viscosity at 70°C (Cp) | 3.2 |
| 4.  | Formation Volume Factor @pressure 2000 psi (Bbl/STB) | |
|     | @ GOR = 200 SCF/STB | 1.1 |
|     | @ GOR = 400 SCF/STB | 1.2 |
|     | @ GOR = 575 SCF/STB | 1.29 |
| 5.  | Bubble point pressure @70°C (psi) | |
|     | @ GOR = 200 SCF/STB | 750 |
|     | @ GOR = 400 SCF/STB | 1550 |
|     | @ GOR = 575 SCF/STB | 1790 |

Gas is used to combine oil from the ‘X’ field. The data shown in Table 2 is data on gas properties and their composition.

The procedure applied to this experiment is divided into 6 procedures, namely: Procedure for Recombination Process, Procedure for PVT Analysis, Procedure for Saturation of Reservoir Model,
Procedure of Nitrogen Displacement, Procedure for Oil Recovery by Water flooding and Procedure for Oil Recovery by Propane Slug Driven by Nitrogen [7].

In this research, Nitrogen gas injection was carried out at a pressure of 2000 psi which was set on the back pressure regulator. The steam samples obtained were then analyzed using chromatography. After saturation of crude oil, the system is replaced with water. After the water injection is carried out, it is then replaced by starting to inject nitrogen. This process records the pressure drop that occurs during water injection. After the reservoir model is ready to be moved (displacement), then the propane that has been calculated and prepared beforehand is transferred to the chamber. Furthermore, propane slugs are pushed into the reservoir using nitrogen injection using high pressure [8].

| No. | Composition | Mol (%) |
|-----|-------------|---------|
| 1   | C₁          | 78.32   |
| 2   | C₂          | 11.32   |
| 3   | C₃          | 4.96    |
| 4   | i-C₄        | 0.75    |
| 5   | N-C₄        | 2.49    |
| 6   | i-C₅        | 0.79    |
| 7   | N-C₅        | 0.98    |
| 8   | C₆⁺         | 0.39    |
|     |             | 99.99   |

The following are some important parameters in the experiment, namely: Temperature across the reservoir model (°F), Barometric Pressure (mmHG), Nitrogen Injection Pressure (Psi), Outlet Pressure (Psi), Time (min), Oil Recovery (cc), Gas Produced (scf), Water Saturation at Initial Condition (%), Pore Volume (%), Oil Saturation (%), GOR (scf/stb), Formation Volume Factor (bbl/stb), Oil Gravity (°API) and Room Temperature (°F)

4. Discussion

This experiment is categorized into nine activities based on their own specific purposes and results. The following discussion will elaborate all nine activities in this experiment.

The first experiment to test whether the recovery factor is significant if the process occurs with a pressure greater than the pressure miscibility. The injected pressure varies, from 4000-6000 psi for 30 minutes. From the results of this first experiment, it was discovered that there was an increase in oil recovery by 83% from OOIP. The analysis shows that it is very clear that there are 3 zones in the process of moving oil with nitrogen injection, including: virgin zone (leading zone), second zone (two phase flowing zone), third zone (one phase flowing zone). Oil recovery in this second experiment was 81.1% from OOIP. The second experiment is designed to build the reliability and validity of the model used. This test is used in comparative analysis with tests to study the effect of temperature and gas oil ratio on the recovery factor and solubility of gas in oil, which can be seen in the figure below. In the third experiment, using high pressure nitrogen injection for light crude oil transfer. The value of the GOR in this experiment is 400 scf/stb. Oil recovery in this second experiment was 75.4% from OOIP. In the fourth experiment, the amount of dissolved natural gas in petroleum was reduced to 200 scf/stb. Therefore, FVF and saturation pressure experience decrease. Oil recovery in this second experiment was 66% from OOIP. The fifth experiment was carried out at a temperature of 120°F. Oil recovery in this second experiment was 84.5% from OOIP. The sixth experiment has the aim of comparing the combined effect of GOR in solution and the previous recovery temperature and miscibility. This experiment was carried out at a temperature of 120°F, and GOR was valued at 200 scf/stb. Oil recovery in this second experiment was 69.4% from OOIP. In the seventh experiment this is a water flooding process at 120°F. Meanwhile, the eighth experiment is the recovery of petroleum in a tertiary manner by nitrogen injection, with GOR valued at 575 scf/stb. Oil recovery in the seventh and eighth experiments was 68.8% and 10.2% of the OOIP. Experiment 9, with GOR 200 and a pressure of 4000
psi succeeded in increasing oil recovery to reach 88.90%. Oil recovery in this second experiment was 88.9% from OOIP[9].

This study shows that the yield of crude oil and its miscibility in this type of oil depend on the temperature and the oil-gas ratio in solution [10]. From the results of research through 9 experiments that have been carried out, as shown in table 3, it turns out that the recovery factor is not affected by changes in temperature, as evidenced in experiment 1, with a temperature of 72°F, recovery factor was at 83%. Meanwhile on experiment 5 with a temperature of 200°F, recovery factor also reaches a high percentage of 84.50%. To be able to see a more detailed summary of all experiments carried out, it can be seen from the following table.

| Test | Temp °F | GOR | S_o | S_w | FV | STOIP | RF (%) | TYPE | Pressure |
|------|---------|-----|-----|-----|----|-------|--------|------|----------|
| 1.   | 72      | 575 | 77.00 | 23.00 | 1.29 | 689.92 | 83.00  | Miscible | Variable |
| 2.   | 69.5    | 575 | 76.38 | 23.62 | 1.29 | 621.75 | 81.10  | Miscible | 4000     |
| 3.   | 70.5    | 400 | 78.00 | 22.00 | 1.20 | 762.50 | 75.40  | Miscible | 4000     |
| 4.   | 69.5    | 200 | 77.00 | 23.00 | 1.10 | 809.00 | 66.00  | Immiscible | 4000     |
| 5.   | 120     | 575 | 80.20 | 19.80 | 1.29 | 647.28 | 84.50  | Miscible | 4000     |
| 6.   | 120     | 80.88 | 19.12 | 1.10 | 738.18 | 69.40  | Immiscible | 4000     |
| 7.   | 120     | 575 | 80.20 | 19.80 | 1.29 | 652.71 | 68.80  | Immiscible | Variable |
| 8.   | 120     | 575 | 25.00 | 75.00 | 1.29 | 203.71 | 10.20  | Immiscible | 4000     |
| 9.   | 120     | 200 | 79.00 | 21.00 | 1.10 | 747.27 | 88.90  | Miscible | 4000     |

Different things with GOR (gas oil ratio), in experiment 1 the value of GOR 575, the recovery factor reached 83%, while in experiment 3, GOR 400, the recovery factor reached 75.40% and at a lower GOR, namely GOR 200, recovery factor only reached 66%. In the experimental section 1 to 4, with a decrease in temperature and a decrease in GOR, the recovery factor also decreases. But in experiments 5 - 9, with a constant temperature of 120°F, GOR 575, the recovery factor reached 84.50%, while in GOR 200, the recovery factor only reached 69.40%. So, the recovery factor is influenced by the gas content in the system. If the gas content is high, then nitrogen injection will result in a higher oil recovery compared to conditions where the gas content is low.

According to the miscibility between gas injection and oil displacement, gas injection can be classified into two main types: mixed gas injection and unmixed gas injection. Under miscible conditions, gas is injected at or above the minimum miscibility pressure (MMP) which causes the gas to dissolve in oil [11]. In immiscible gas injection, gas injection is performed under the MMP. It is used for low pressure gas injection maintain reservoir pressure to prevent production stoppages and thereby increase production rates [12, 13]

5. Conclusion
Based on the results of the research and discussion that has been described, several conclusions can be drawn that the increase in oil recovery by nitrogen injection is influenced by the gas content in the system. If the gas content is high, the recovery factor will also be high. The increase in crude oil revenues could be caused by the increase in GOR. This recovery factor is not affected by the temperature in the reservoir system. Crude oil produced using nitrogen injection is not affected by changes in temperature.

6. References
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