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Basic Understanding of Water Flooding as a Secondary Recovery Concept: Literature Review

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Abstract

The need for energy and mineral resources is needed for the survival of human life. One of the results of minerals contained in the bowels of the earth is crude oil. Natural resources crude oil is still a top priority for natural resource needs in Indonesia. So it is necessary to explore and exploit crude oil resources. Secondary recovery (water flooding) and tertiary recovery methods are carried out on an oil and gas well to assist the process of producing oil to the surface. Water flooding is a method that is widely used because water is easy to obtain, water supply is quite cheap and mobility is low. Water injection is a second stage recovery method by injecting water into the reservoir so that the remaining oil can be pushed to the production well. Water flooding in its application can show a decreasing trend in production if the efficiency of this method in the reservoir has decreased, therefore after the water flooding recovery method has decreased production, the EOR method as a tertiary recovery method can be applied. The application of water flooding as a secondary recovery concept was carried out in field X in Indonesia and based on this method, the profit value obtained from the implementation of water flooding can be calculated.

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1 Introduction

For the last decade, the Indonesian oil reserve is gradually depleting. There are six primary inhibiting factors in the realization of oil and gas production in Indonesia namely unsuspected rapid production deceleration, drilling activities that did not meet expectations, a weather condition that leads to rescheduling of numerous operational and drilling activities, operational disruptions, also production curtailment problem due to commercial issues. Because oil and gas are still dominating national energy utilization, a number of oil and gas reserve improvement efforts are still being implemented (Putra & Kiono, 2021). Oil production volume in a reservoir will gradually decrease along with lowered pressure level and production period. That is why, further oil production stages through both secondary and tertiary recovery should be implemented by also considering the reservoir's characteristics. The secondary recovery method is an oil recovery method that aims to optimize and improve oil production in reservoirs that are yet to reach optimum production levels (Satter & Iqbal, 2015). One type of secondary recovery method is known as water flooding implemented to drive oil deposits on the reservoir's rock pores into production wells on the surface without altering the physical reservoir's rock formations. Water flooding is a relatively popular method because of the abundant amount of water, lower costs, and easier mobility (Satter & Iqbal, 2015). In the water flooding process, injection water quality that met the quality standardization is vital.

2 Materials and Methods

Oil exploration is conducted by implementing three phases namely primary, secondary, and tertiary phases. The primary phase is implemented as the first stage of oil production by making use of natural driving energy in the reservoir without heat or fluid injection treatments. The natural energy source comes from rock and liquid expiation, gas solution, gas cap, and gravitational drainage. After that, the secondary phase is often implemented by injecting water to preserve the level of pressure in the reservoir which is often lowered after the primary phase implementation (Alagorni et al., 2015).

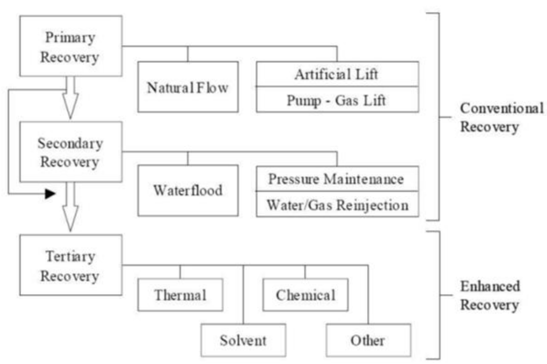

Figure 1: Oil Recovery Phases (Abdillah, 2018)

Water flooding is the most popular recovery method and pressure maintenance technique in the field of petroleum engineering due to its simple technological implementation, abundant level of injection fluid, and its decent performance on environmental preservation. Water flooding can be considered effective if the production level, injection well patterns, and sweep efficiency are showing decent technical achievement. However, the speed and volume to recover potential oil reserves are unpredictable and uncontrollable. Water flooding management will be able to point out if the quality pattern identification is unacceptable and further improve it to lower asymmetrical conditions between technical potential and the initial performance.

According to Siswanto (2020), pressure maintenance on oil refineries is vital and able to improve field development efficiency, especially water flooding efficiency. Water flooding analysis is conducted based on field development, while also considering geological structure. The goal of water flooding management formulation is to preserve ideal reservoir pressure level, sweep efficiency, production improvement by obtaining difficult oil reserves, and water flooding efficiency improvement.

According to Hamdy et al. (2019), the objective of the water flooding pilot project is to gather data (injectivity, break-through timing, areal/vertical sweep efficiency), water flooding performance evaluation (oil response improvement), as a base to decide whether to continue water flooding project or not, pattern measurement optimization, and injection rate tests and optimization. Area selection criteria for the water flooding pilot project include an area with high productivity and decent reservoir characteristics (Net Pay), the existence of fault within the area, pressure data, low water cut (WC), and Gas Oil Ratio (GOR), and reservoir continuity (Yi et al., 2012). Water flooding is proven to be utilizable to improve the ultimate recovery rate of a conventional oil reservoir (Kułynycz & Janowski, 2017).

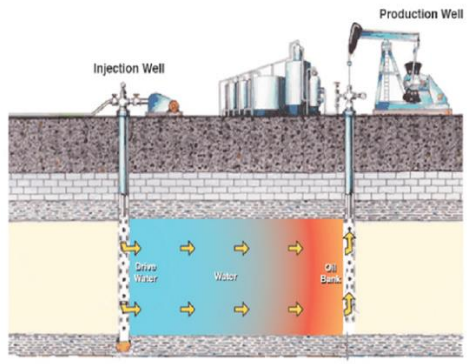

Figure 2: Water Flooding Illustration (Kułynycz & Janowski, 2017)

Water flooding is a vital process to preserve pressure inside an oil reservoir. During oil production, the reservoir will gradually lose its pressure level. To countermeasure lowered reservoir pressure, water or any commercially, physically, and chemically suitable substance is driven inside the drilling hole. Water illustration can be seen in the following Figure 2. However, the composition of reservoir water is expected to be significantly different than the injected water composition. This transformation occurs as a result of a chemical reaction between various chemical compositions within the reservoir (Abdillah, 2018).

3 Results and Discussions

A number of resumes have been produced from the published research literature. According to Hamdy et al. (2019), water flooding evaluation in a certain field is essential to be utilized as a valuation basis to measure water flooding success. The intended evaluation is a connectivity analysis of injection and production wells (Zeng et al., 2022). This connectivity analysis is also enhanced by a number of analyses such as Hall Plot analysis to acknowledge problems occurring in the injection well, Chan's WOR analysis to identify problems in the production well, and Voidage Replacement Ratio (VR) analysis to compare injection and production volumes. Besides that, additional recovery factor measurement is also conducted to measure the oil production of both activities by using the Buckley-Leverett method.

Table 1
Fanning pressure modeling parameter input

Parameter	Value
Gravitation(m/s^2)	9.8
Flow diameter(m)	0.089
Depth(m)	1067
Injection pressure(psia)	1300
Injection water mass rate(kg/s)	0.30443
Injection temperature(^oC)	25
Thick tubing(m)	0.005
Over-all heat transfer coefficient ($Btu/h.F.ft^2$)	2

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Water flooding implementation as a secondary recovery concept on field X conducted with injection rate condition (MMscf/day), well depth (m), rock formation temperature (oC), minimum miscibility pressure (MMP) (psia), rock formation permeability (mD), rock formation porosity and 41 API oil compound data. Reservoir thickness is at (m), the distance between the injection well and the production well is at (m), and the reservoir shape is assumed to be in a cylindrical shape. The objective function is required to acknowledge the goal of implemented optimization. The goal of water flooding optimization is to maximize the production rate on the production well to generate more profit. However, the more amount of water injected under certain pressure, the larger the energy required to do so. That is why the operational cost will also be affected. Besides that, there is also the cost to recycle water contaminated by oil in a production well before the water can be reused as a soluble compound in an injection well (Barnaji et al., 2016; Hussain et al., 2013; Bartels et al., 2019).

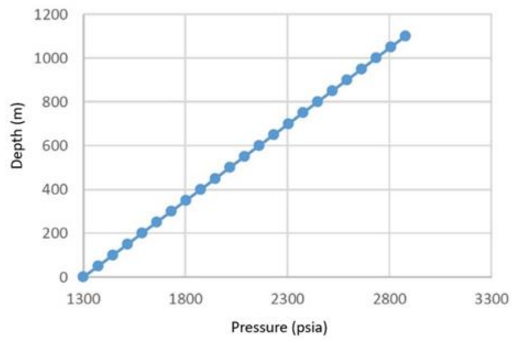

Figure 3. The curve of the influence of pressure on injection well depth

The daily production rate is measured based on the sweep efficiency value. Sweep efficiency is a comparison of oil saturation before and after the operation. This value is a pressure gradient function. That is why the daily production rate is depending on the injection pressure and injected water volume. Pressure modeling based on the Fanning method on injection well is compared with obtained data (Salehi et al., 2014; Mokhtari et al., 2019; Hadia et al., 2013; Thyagaraju, 2016), as shown in the following table. Sweep efficiency is a comparative result of oil saturation alteration before and after water flooding, with an initial saturation level. Sweep Efficiency is obtained through fluid pressure gradient on the reservoir. Fluid pressu gradient on the reservoir has been calculated with injection pressure condition at 1,300 psia, mass flow rate at 0.30443 kg/s, and temperature at 25◦C. Based on the calculation we obtained a sweep efficiency value of 12.51%. The collected crude oil production rate is at 78,733 barrel per day.

Discussion regarding water flooding understanding can be interpreted by using the decline curve method to obtain the total estimated ultimate recovery (EUR) and injection scenario (Belyadi et al., 2019). As for injection water, the quality should met the company's standardization (Siswanto, 2020). The influence of injection well performance on the production well is seen with a significant decrease of obtained net value due to increased water content. This is generally happens along with the improvement of injection rate that diminishes water quality (Ahmed et al., 2019). That is why the injection rate should be constantly monitored in order to control the water content levels from increasing.

The success of water flooding implementation is measured by the increase in the rate of oil production. Water flood operation EOR uses 2 kinds of modeling methods, namely the Fanning method (in injection well and production well) and Darcy method (at the reservoir). The modeling results were validated using PIPESIM and COMSOL. Successful water flood management can efficiently result in maximum sweep efficiency as well as gain more production by maintaining reservoir pressure above the fluid level, allowing for higher production rates. This higher production increase can be obtained by the Craig Geffen Morse forecasting method for the calculation of the Recovery Factor (Fink, 2012; Sheng, 2014; Li et al., 2008; Alhomadhi et al., 2014).

A critical water flooding element is the injector-manufacturer relationship which can be regressed from production data or from simulations. The effective water injection scheme is implemented with moderate water injection which involves monitoring all water injection parameters from flow rate to water injection pressure to provide support for natural energy and at the same time increase oil recovery.

Based on the studied references the basic elements of the injection system and reservoir are:

1) Reservoir Simulation
   Before water flooding, simulation data as previously mentioned must be generated. Simulation can be implemented on 1 dimensional systems, 2 dimensional systems, and 2 dimensional systems combined with numeric techniques.
2) Laboratory
   Laboratory research was conducted to find a match between the water flooding process and the rock and fluid properties.
3) Pilot Project
   Implementation on problems found in the real situation. There are two types of injection patterns that are commonly used, namely the five-spot pattern and the single-injection pattern. These two patterns can maximize the amount of oil migration.
4) Monitoring
   Witness and evaluate the obtained results including evaluation of the oil stream coming out of the pilot area.
5) Repeated Simulation
   Results from the field study are compared to the simulated reservoir and an adjustment between field condition and reservoir simulation is synchronized.
6) Economical evaluation
   This includes estimated required cost, calculations, and presentation.

Water flooding is widely used in the petroleum industry, because of its various advantages, including the abundant amount of water, it is relatively easy to inject, can be spread through oil-bearing formations, and is more efficient to drive oil. Several questions emerge; how large the volume of produced crude oil is and how long can it be implemented until it loses its economic value; what is the volume of oil recovery in the secondary production stage? These questions must be answered before taking a decision to conduct water flooding. Before implementing water flooding, a preliminary study to obtain data on the reservoir rock formation, average permeability of the reservoir area, the porosity of the reservoir area, and heterogeneity of permeability change on each thickness (Ali & Stephen, 2018; Alisawi, 2020; Ayoub et al., 2015; Archana et al., 2016).

4 Conclusion

Water flooding implemented as a maintenance tool on a field to obtain a high expected recovery level, must be formed of various programs that are conducted on daily, monthly, and yearly programs, along with the other activities that can support water flooding implementation. Daily activity implemented is an activity that consists of injection and pressure level recording meanwhile monthly activity is implemented to evaluate water flooding performance of water flooding and supporting activities to acknowledge indications of problems or to obtain required data to enhance water flooding achievement. The main indicators of water flooding success are the increased oil production volume, especially when water flooding is designed with oil driving or sweeping oriented and improved oil quality on production.

Conflict of interest statement
The authors declared that they have no competing interests.

Statement of authorship
The authors have a responsibility for the conception and design of the study. The authors have approved the final article.

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