Effect of Heterogeneity of Reservoir Properties on Sandstone Formations in Oil Recovery

Samsol*, Sigit Rahmawan, Onnie Ridaliani

Petroleum Engineering Department, Universitas Trisakti, Jl. Kiyai Tapa No 1, Grogol, Jakarta Barat, Indonesia

*samsol@trisakti.ac.id

Abstract. The case study for this research is an oil field with sandstone formations. The background of this problem is that many oil fields in Indonesia have been operating for a long time. The method used to analysis heterogeneity and its effect on oil recovery was carried out by using Dykstra Parson[1] analysis, analysis of porosity and permeability data distribution, analysis of the calculation of the mobility ratio[2][3]. Furthermore, it can be calculated the efficiency of oil sweeping[4][2]. Based on the Dykstra Parson analysis, the value obtained is 0.93 and the mobility ratio is more than 1. The next method is to determine the efficiency of mobility (sweep efficiency) which is associated with the average standard deviation of the values of porosity and permeability. The mobility efficiency value of this field is 47.12%. From the relationship between the value of mobility efficiency to the standard deviation of porosity and permeability, it shows that the greater the standard deviation value, the smaller the oil sweeping gain. Finally, this research aims to know the heterogeneity of the rocks to obtain predictions of oil recovery.

1. Introduction

The background of this research is that oil fields in Indonesia, in particular, have experienced a very sharp decline in production, while there is still a lot of oil in the layer. Therefore, analysis is needed before selecting and implementing the appropriate method for field development. The results of this study are expected to provide a more comprehensive technical justification in the optimization of production using the water injection method (water flood).

Information regarding the heterogeneity and mobility ratio of this field is expected to provide recommendations or suggestions for the selection of injection well patterns, the number of wells and placement of water injection wells, and the amount of water injection rate. Besides, according to the basis of this field planning, the results of this study are expected to be applied in preparation for the development of this field to an advanced stage, either the secondary recovery or the EOR stage, by validating production data and completing data deemed important.

Microscopic flow[5] heterogeneity in reservoir rocks is related to pore size, pore shape, and location of the different pore sizes that determine flow paths of various permeability. In this paper, microscopic flow heterogeneity is expressed by a breakthrough recovery in a nitrogen/helium miscible displacement[6][7]. The breakthrough nitrogen earlier indicates a higher degree of heterogeneity.
2. Methods

2.1 Data Collection and Measurement Techniques

- Preparation Data

This data preparation stage is carried out by collecting the data needed for a study. The collected data is then recapitulated so that it can be seen what data has been obtained and which has not been obtained.

- Production Data

Production data were collected based on the production history for each well and layer. This production data will be complemented with a history of completion or formation of perforation data and the completion interval. This history explains when and at what depth the well was opened or closed (squeeze). Completion interval data will also be used to match the layer names with geological markers.

- Geological Data

Geological data is a geological model that describes subsurface conditions. This model is made by the rules of geological engineering using geological computer software. The resulting geological model is a static model, in the form of a fine grid. To be used in reservoir simulation, the model must be up-scaled to a coarse grid.

- Reservoir Data

The reservoir data required for reservoir simulation includes data from the results of PVT analysis, core analysis data, routine core analysis, SCAL, formation water analysis, and pressure history of each well.

- Data Validation and Analysis

In this stage, the data that has been collected and sorted are then validated to find out whether the data can be used or not in this study, especially those related to data for each reservoir layer. The next stage is to perform data analysis, compiling the data according to a ready format for reservoir simulation input.

- Reservoir Simulation

Reservoir simulation is the main stage in this research. Reservoir simulation is a computer-assisted mathematical model that describes the dynamic behaviour of the reservoir. This dynamic model is used to predict future reservoir behaviour.

The reservoir simulation phase begins with the selection of the reservoir simulation type and the porosity model to be used, then what is done is to input the geological model and reservoir parameters. The next stage is carrying out the initialization process. This process aims to establish the initial condition of reservoir equilibrium so that the initial hydrocarbon reserve in the reservoir model will be the same or close to the initial hydrocarbon reserve as a result of volumetric calculations from geology. Initialization is carried out to the maximum or minimum is 5% of the initial volumetric reserve.

The step after initialization is doing history matching. This process aims to test the validity of dynamic models created by aligning the simulation model production performance with the actual field production performance.
The final stage of this simulation is to predict the performance of the reservoir model using several cases. From the results of this prediction, it can be seen which cases can produce the most optimal hydrocarbon production and can be implemented economically.

- **Heterogeneity Analysis and Conclusions**

The method used to analysis heterogeneity and its effect on oil recovery was carried out by using Dykstra Parson analysis, analysis of porosity and permeability data distribution, analysis of the calculation of the mobility ratio. The conclusion obtained from this reservoir simulation is based on the results of the scenario prediction that gives the most optimal and economical results. While recommendations are some suggestions that can be given by referring to the results obtained during the simulation stage.

3. **Results and Discussion**

Displacement of hydrocarbon in heterogeneous reservoirs has always been a challenge since heterogeneity induced instability (channelling of the injected fluid in the high permeability paths) result in a reduction of the sweep efficiency of the process.

3.1 **Heterogeneity analysis**

Heterogeneity analysis of the physical properties of the studied reservoir includes oil saturation, porosity, and permeability. The analysis grid layer is represented by 6 layers out of 28 constructed grid layers. Heterogeneity analysis was carried out by calculating that the VDP value (heterogeneity variation) was close to the value of 1, this meant that the reservoir studied tended to be heterogeneous. As for the comparative analysis of mobility, based on the calculation the value is greater than 1.

![Figure 1. Analysis Heterogeneity by Dykstra Parson Coefficient](image)

Permeability heterogeneity is commonly measured by the Dykstra Parsons Coefficient (VDP), which is indicative of the variance in permeability. A reservoir considered to be highly heterogeneous if a large flow capacity is associated with a small storage capacity. Heterogeneity analysis calculations or heterogeneity variations based on **Figure 1.**, then using **equation 1**[1] as follows:

\[
V_{DP} = \frac{K@50\% - K@84.1\%}{K@50\%} 
\]

\[
V_{DP} = 0.93
\]
3.2 The Effect of heterogeneity on oil sweep efficiency[8]

Supplementary recovery results from increasing the natural energy of the reservoir, usually by displacing the hydrocarbons towards the producing wells with some injected fluid. By far the most common fluid injected is water because of its availability, low cost and high specific gravity which facilitates injection.

In the ideal case, there is a sharp interface between the oil and water. Ahead of this, oil is flowing in the presence of connate water (relative mobility = kro (Sw=Swc)/μo = ro k’/μo), while behind the interface water alone is flowing in the presence of residual oil (relative mobility = krw(Sw = 1 - Sor)/μw = ro k’/μw). This favourable type of displacement will only occur if the ratio:

\[
\frac{k_{rw}}{k_{ro}} = M \leq 1
\]

where M is known as the end point mobility ratio and, since both ro k’ are rw k’ the end point relative permeability, is a constant. If M ≤ 1 it means that, under an imposed pressure differential, the oil is capable of travelling with a velocity equal to, or greater than, that of the water. Since it is the water which is pushing the oil, there is therefore, no tendency for the oil to be by-passed which results in the sharp interface between the fluids.

The effect of heterogeneity on the efficiency of oil sweeping, in this study, was calculated based on the mobility ratio (M) analysis equation 3 as follows.

\[
M = \frac{\text{Mobility of the displacing fluid}}{\text{Mobility of the displaced fluid}}
\]

Table 1 is the result of processed data used for analysis.

| LAYER GRID | INITIAL SATURATION | RESIDUAL SATURATION | POROSITY | PERMEABILITY |
|------------|-------------------|---------------------|----------|--------------|
|            | Average | Std Dev | Average | Std Dev | Average | Std Dev | Average | Std Dev |
| Layer 6    | 0.67    | 0.10    | 0.36    | 0.20    | 0.22    | 0.06    | 195.84  | 399.44  |
| Layer 7    | 0.69    | 0.10    | 0.38    | 0.19    | 0.24    | 0.07    | 657.88  | 1105.58 |
| Layer 8    | 0.70    | 0.10    | 0.37    | 0.19    | 0.25    | 0.07    | 938.08  | 1636.74 |
| Layer 9    | 0.69    | 0.12    | 0.38    | 0.20    | 0.27    | 0.07    | 1502.35 | 1742.39 |
| Layer 10   | 0.68    | 0.11    | 0.39    | 0.20    | 0.26    | 0.06    | 836.45  | 1025.25 |
| Layer 11   | 0.70    | 0.13    | 0.36    | 0.19    | 0.26    | 0.04    | 646.90  | 845.21  |
| Layer 12   | 0.70    | 0.12    | 0.32    | 0.15    | 0.27    | 0.04    | 945.33  | 918.58  |
Mobility efficiency is the efficiency which is influenced by the saturation value of the remaining oil and the wetting properties of the rock. It is defined as the fraction of oil at the start of the process which can be recovered in 100% of the vertical area. The mobility efficiency equation is as follows:

$$E_m = \frac{S_{oi} - S_{or}}{S_{oi}}$$

(4)

Based on equation 4, the value of the mobility efficiency of the field under study can be calculated.

**Table 2. Efficiency Mobility ($E_m$)**

| LAYER GRID | INITIAL SATURATION | EM ( % ) |
|------------|--------------------|---------|
|            | Average            | Average |         |
| Layer 6    | 0.67               | 0.36    | 45.97   |
| Layer 7    | 0.69               | 0.38    | 45.60   |
| Layer 8    | 0.70               | 0.37    | 46.44   |
| Layer 9    | 0.69               | 0.38    | 45.00   |
| Layer 10   | 0.68               | 0.39    | 43.23   |
| Layer 11   | 0.70               | 0.36    | 48.84   |
| Layer 12   | 0.70               | 0.32    | 54.80   |
| Average of EM |                   |         | 47.12   |

Based on the calculations and analysis from **Table 2**, a relationship was made between the distribution of rock characteristics from this field and the percentage of the oil recovery pressing efficiency. **Figure 2** shows that the greater the standard deviation of porosity, the smaller the sweeping efficiency.

**Figure 2. Comparison of Porosity Deviation on Sweeping Efficiency**

Furthermore, the same thing is done to determine the effect of permeability on the sweeping efficiency of the obtained oil. This can be seen in **Figure 3**.
Figure 3. Comparison of Permeability Deviation on Sweeping Efficiency

From Figure 3 of the data that was calculated, it can be concluded that the greater the value of the standard deviation of permeability, the smaller the oil sweeping efficiency.

4. Conclusions

The research conducted at this time can be concluded, among others:
1. The heterogeneity of the sandstones can be seen from the distribution of porosity, saturation, and rock permeability values in the reservoir.
2. The determination of heterogeneity is based on the calculation of the VDP (heterogeneity variation) value close to 1, this indicates that the reservoir is studied tends to be heterogeneous.
3. Further heterogeneity analysis was carried out based on the porosity and permeability values. From the results of the average value and standard deviation, the greater the standard deviation of porosity and permeability, the smaller the sweeping efficiency.
4. Meanwhile, the heterogeneity analysis using the ratio mobility ratio analysis, the calculated value is greater than 1. This means that if the injection is insisted, the results will be more optimal.
5. The percentage of Mobility Efficiency ($E_m$) obtained from this calculation is an average of 47.12%. This value is quite good in oil recovery.

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