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Simulation Study on the Effect of Heterogeneity in Reservoir for Oil Production from Nanoparticle Combined with Surfactant

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Amid a burgeoning decline in oil production in the reservoir, the tertiary phase of the oil production named enhanced oil recovery (EOR), especially chemical EOR, has gained some advantages. Conventional chemicals like surfactant combined with nanoparticles have emerged as a potential candidate to recover more oil. The heterogeneity in the reservoir is one of the main factors for oil production represented by Lorenz coefficient reflecting the distribution of permeability versus porosity or the degree of heterogeneity in a pay zone section. The heterogeneity data of the reservoir properties are required for reservoir simulation to control the oil production process of the reservoir. The aims of this research are to simulate the heterogeneous models of reservoir and to evaluate the effectiveness of nanoparticles combined with surfactant for EOR in the Northern oilfield in Thailand. For this study, 5 randomized data set with a fixed range of porosity and permeability value are used to calculate the Lorenz coefficient and applied to simulate the chemical injection process. The Lorenz coefficients range from 0.137 to 0.849. Also, the injection rates from 15.9 to 47.7 m^3/d and the surfactant concentration from 1,000 - 4,000 ppm are the parameters that have been studied. The simulation results show that the Lorenz coefficients provide 17.91 % difference in oil recovery factor. Also, the efficiency of nanoparticles coupled with surfactant flooding can increase the recovery factor up to 67.97 %. The proper surfactant concentration is 2,000 ppm. An increase in injection rate can enhance the recovery factor up to 6.81 %. This research provides a significant scientific evaluation of heterogeneous factors in the structure of the reservoir. It will create further improvement of the process and the application of nanoparticles for injection flooding in the real field.

1. Introduction

The world supply-demand gap for petroleum was 135 Mt in 2019 and total oil demand has kept the uptrend since the last 4 decades, which has led to a continuous increase of oil and gas production to bridge this gap (IEA, 2020). Approximately 55 % of original oil in place (OOIP) is exploited by the first two phases of production for light oil, which means roughly 45 % of OOIP still remand underground (Gbadamosi et al., 2019). The future request for the tertiary phase of oil production, named enhanced oil recovery (EOR) such as chemical EOR, is introduced to produce more oil (Husein et al., 2018) and applied to tight reservoir (Liu et al., 2021).
The main mechanisms of chemical EOR are a decrease in the oil-water interfacial tension (IFT) and an increase in the mobility ratio. Besides conventional methods like miscible gas method by CO_2 injection (Li et al., 2016) or alkaline, surfactant, polymer (Maneeintr et al., 2020), nanotechnology is a new application of chemical EOR to dismiss limitations of conventional chemical EOR methods. The polymeric nanofluids can be formed when the nanoparticles combine with surfactants (Gbadamosi et al., 2019).
The heterogeneity in the reservoir is one of the main factors for oil production. The definition of the reservoir heterogeneity is a variation in reservoir properties as a function of space. These properties may incorporate permeability, porosity, thickness and rock characteristics (Ahmed, 2010). The Lorenz coefficient and the Dykstra–Parsons coefficient are used to present the reservoir heterogeneity. Compare with Dykstra–Parsons Coefficient, the Lorenz coefficient is widely applied in the reservoir characteristics. The definition of Lorenz is

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also mentioned in other fields like economics, technology and so on. The development laws of a reservoir with its heterogeneity are studied in this work as the Lorenz coefficient. The value of the Lorenz coefficient or Lorenz factor ranges from 0 to 1. The reservoir is completely homogeneous when the Lorenz coefficient is equal to 0. An increase in the value of the Lorenz coefficient increases the heterogeneity in the model. The ordinary values of the Lorenz coefficient are in the scope from 0.2 to 0.6 (Fanchi, 2010).

The Northern oilfield is an onshore reservoir in Thailand containing oil viscosity of approximately 10-120 cP and density ranging from 824.3 to 933.3 kg/m^3. Approximately 1,430,885.7 m^3 was produced in here from the 6th decade of the 20th century until today (Settakul, 2009). Yoosook and Maneeintr (2018) have evaluated the effects of total injected hydrocarbon pore volume and water alternating gas ratio on oil production and CO_2 consumption and storage. This work focuses on the evaluation of the effect of heterogeneity in the reservoir on the oil recovery factor (RF), which is the ratio between cumulative oil production and OOIP, and the simulation of oil production from the combination of nanoparticles and the surfactant solution by various injection rates and surfactant concentrations. This research can provide a significant scientific evaluation of heterogeneous factors in the structure of the reservoir in the oilfield. It can create further improvement of the process and the application of nanoparticles for injection flooding in the real field.

2. Simulation

2.1 Reservoir data

The details of formation and fluid properties in this area presented in the previous study (Yoosook and Maneeintr, 2018) and obtained from the Defense Energy Department (DED), Ministry of Defense are showed in Table 1. Also, Figure 1 presents the 3D model of porosity distribution in this area from ECLIPSE software. The reservoir model is built in heterogeneous models with each grid in all reservoirs and set with the porosity data ranging from 0.2 to 0.3. The grid cell size is assumed 7.26 m * 7.26 m * 0.305 m. An injection well and a production well located at the 2 corners of the reservoir and through from the top layer to the bottom layer for 538.8 m.

Table 1: Reservoir properties using for simulation model (Yoosook and Maneeintr, 2018).

Parameter	Values
Grid dimension (cell)	50 x 50 x 30
Reservoir size (m)	381 x 381 x 9.144
Top of reservoir depth (m)	1,347.216
Reservoir thickness (m)	9.144
Porosity (%)	20–30
Horizontal permeability (mD)	1-750

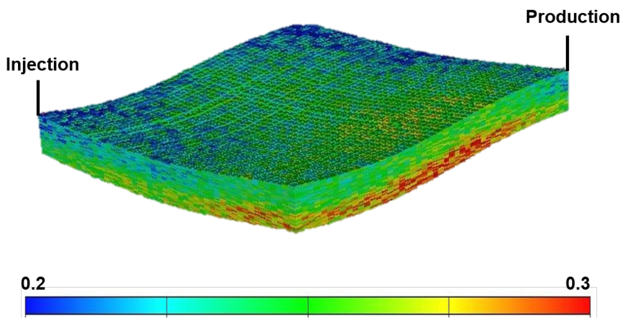

Figure 1: 3D model of porosity

2.2 Methodology

In this article, MATLAB and ECLIPSE are used to build the heterogeneous models by setting the random data of porosity and calculating the permeability value with 5 correlations and different *a*, *b* and *q* values from followed correlation by Lake et al. (1987) as shown in Eq(1):

$$log(k) = a * (\phi)^q + b \quad (1)$$

where k is the permeability (mD), ϕ is the porosity (fraction), a, b and q are the regression parameters.

Figure 2 shows the correlation of the average permeability versus Lorenz coefficient after calculation.

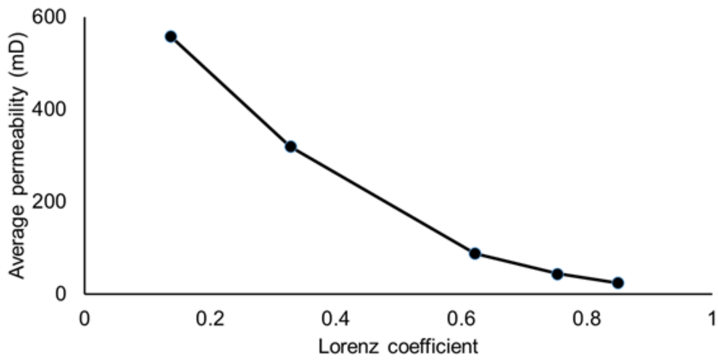

Figure 2: The correlation of average permeability versus Lorenz coefficient

The simulation is run with ECLIPSE software from Schlumberger. This study aims to simulate the 5 main Lorenz coefficients by nanosilica flooding combined with surfactant of sodium dodecyl sulfate (SDS). The SDS surfactant concentration is ranged from 1,000 to 4,000 ppm and the injection rates are varied from 15.9 to 47.7 m^3/d. Within 12 y of a studied plan of injection, the parameters are presented in Table 2.

Table 2: Study plan

Parameters	Strategies
Lorenz coefficient	0.137, 0.328, 0.622, 0.753 and 0.849
Injection rate (m^3/d)	15.9, 31.8 and 47.7
Surfactant concentration (ppm)	1,000, 2,000, 3,000 and 4,000

3. Results and discussions

3.1 Effect of Lorenz coefficient on oil recovery factor

Figure 3 shows the correlation of recovery factor (RF) and Lorenz coefficient at the surfactant concentration 2,000 ppm and injection rate at 15.9, 31.8 and 47.7 m^3/d. For 3 cases of injection rate, the same trend is that RF decreases with the increasing Lorenz coefficient due to the higher heterogeneity. The highest RF is always in the lowest Lorenz coefficient in all injection rates. The simulation results show that the Lorenz coefficients provide 17.91 % difference in oil RF. An approximate straight correlation of RF and Lorenz factor at an injection rate of 15.9 m^3/d can be observed. But the same thing does not show at 31.8 m^3/d and 47.7 m^3/d, the change of the direction shows at Lorenz factor from 0.622 to 0.849. Even case of Lorenz 0.849, the result of injection rate at 47.7 m^3/d has smaller RF than that of 15.9 m^3/d injection rate. The reason is that the rate of 47.7 m^3/d is too high in the heterogeneous reservoir with the Lorenz factor is 0.849. A water breakthrough time occurs too early, 92 d and 167 d for the water breakthrough time with the injection rate of 15.9 m^3/d to 47.7 m^3/d. So, the water channel from the injection well to the production well will be formed at the early of the injection period.

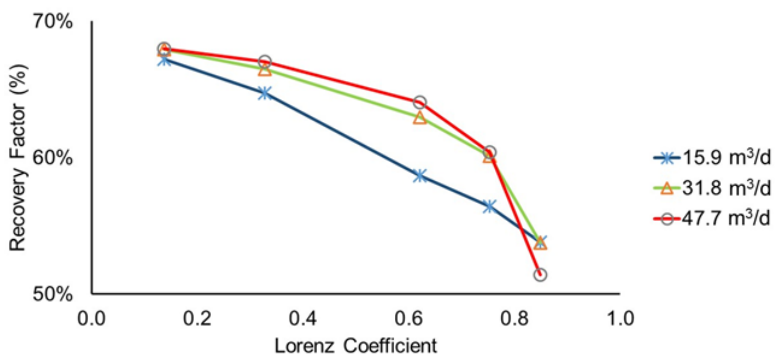

Figure 3: Comparison of the effect of Lorenz coefficient for oil recovery in various injection rate

3.2 Comparison of the various chemicals used for injection

To compare the various types of chemicals used for the injection, this section will keep constant some parameters like 2,000 ppm surfactant, 1,000 ppm nanosilica and 15.9 m^3/d injection rate. Figure 4 shows the technology comparison of Nanosilica, SDS surfactant and combination for oil recovery versus Lorenz coefficient within 12 y. Like Section 3.1, not only RF from nanosilica coupled with SDS decreases when the Lorenz coefficient increases but also the RFs from only nanosilica and from SDS surfactant show the same behavior. Also, the results illustrate that, among them, the RF from the mixture of nanosilica with surfactant is always higher from 8.23 % to 12.47 % with SDS and from 9.63 % to 10.67 % with nanosilica. According to Mohajeri et al. (2019), the concentration of nanoparticle is set at 1,000 ppm for the further study because it can provide the better result for oil production.

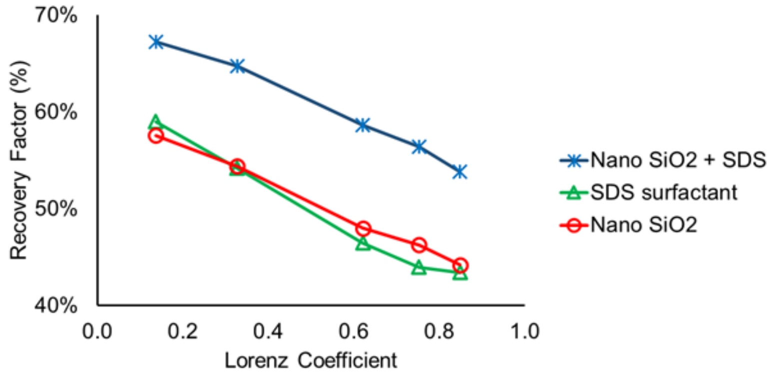

Figure 4: Comparison of technology for oil recovery within 12 y.

3.3 Effect of surfactant concentration on oil recovery factor

The surfactant concentration is one of the main parameters when the EOR method with surfactant is applied, as the surfactant adsorption provides the effect on the benefit from the production. The results of the effects of the surfactant concentration are presented in Figure 5 - 7 for the injection rate at 15.9 m^3/d, 31.8 m^3/d and 47.7 m^3/d. The RF increases with an increase in concentration until it reaches at 2,000 ppm and becomes reduced. It can be explained that at concentration higher than 2,000 ppm, for all cases of Lorenz coefficients, the critical micelle concentration can be occurred and the interfacial tension (IFT) cannot be reduced. Oil cannot be mobilized or produced more and the RF becomes slightly reduced. Consequently, the optimum SDS surfactant concentration should be 2,000 ppm based on the results for this heterogeneous reservoir with any injection rates. It will be used to study for the next parameter.

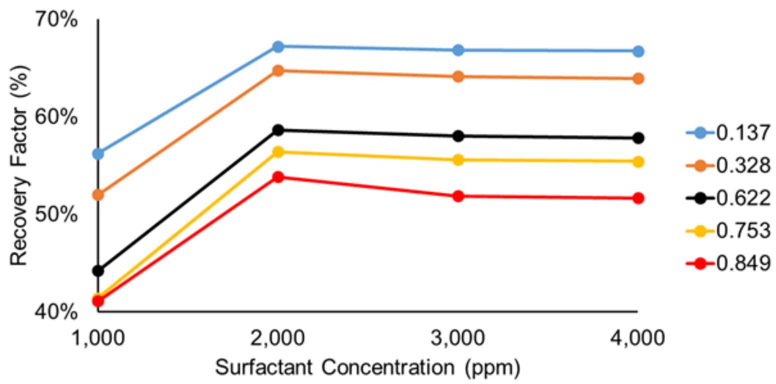

Figure 5: Comparison of the effect of surfactant concentration for oil recovery with injection rate 15.9 m^3/d

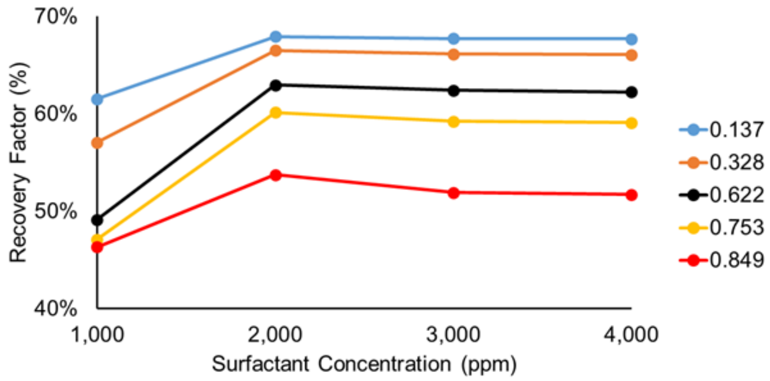

Figure 6: Comparison of the effect of surfactant concentration for oil recovery with injection rate 31.8 m³/d

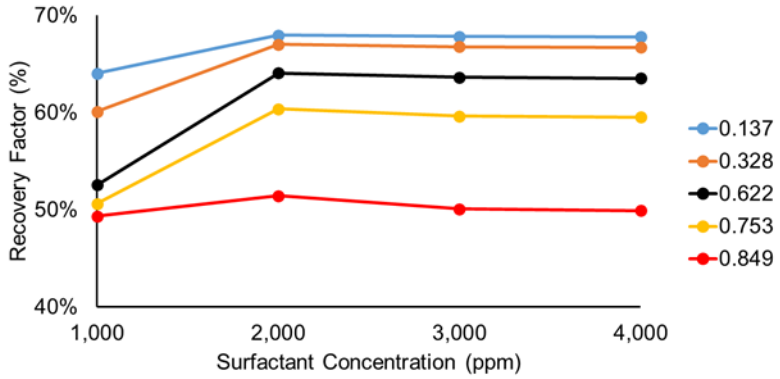

Figure 7: Comparison of the effect of surfactant concentration for oil recovery with injection rate 47.7 m³/d

3.4 Effect of injection rate on oil recovery factor

Another parameter to consider is the injection rate. The result of the effect of this parameter on the oil RF is presented in Figure 8. From the figure, almost all Lorenz coefficients show that the RF will increase with an increase in injection rate, except 0.849 Lorenz factor. The reason is that the water breakthrough can be formed in the reservoir. The RF with Lorenz at 0.849 is lower for -2.39 %, The efficiency of nanoparticles coupled with surfactant flooding can increase the RF up to 67.97 %. The highest recovery percent change by the change of the injection rate from 15.9 m^3/d to 47.7 m^3/d, at Lorenz factor of 0.622. An increase in injection rate can enhance the RF up to 6.81 %. At higher injection rate, the RF can increase with slower rate. For the application to the real field, an injection rate of 31.8 m^3/d is recommended to the reservoir because it can provide the optimum result.

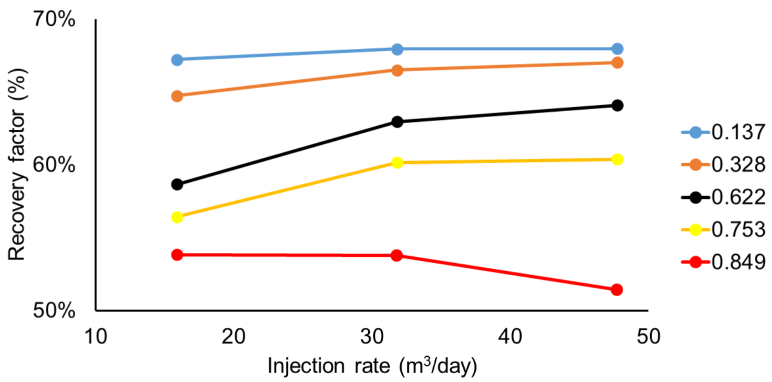

Figure 8: Comparison of the effect of injection rate for oil recovery with surfactant concentration 2,000 ppm

4. Conclusions

To produce more oil in the Northern oilfield in Thailand, the EOR methods especially chemical EOR are the way to increase the recovery factor in the present and the future work. The correlation between porosity and permeability reflected by the heterogeneity in the reservoir is the important key to correctly evaluate the amount of produced oil. The Lorenz coefficient can be represented the heterogeneous reservoir. For this study, the Lorenz coefficient is ranged from 0.137 to 0.849. In addition, the chemicals used to produce more oil are the mixture of nanosilica and sodium dodecyl sulfate (SDS) as a surfactant for chemical EOR. The parameters such as surfactant concentration from 1,000 ppm to 4,000 ppm as well as injection rate from 15.9 m^3/d to 47.7 m^3/d are investigated the effect on oil recovery factor. The results show that the lower Lorenz coefficient in the reservoir can provide a better flow in the porous media, producing more oil with higher RF up to 17.91 % difference. Furthermore, the optimum surfactant concentration of SDS combines with nanosilica is 2,000 ppm. The efficiency of nanoparticles coupled with surfactant flooding are able to increase the recovery factor up to 67.97 %. Higher RF can be obtained with the higher injection rate up to 31.8 m^3/d; then RF becomes lower. For the higher Lorenz coefficient, the high injection rate can create the water channel from the injection well to the production well earlier than the low injection rate, producing less oil and the recovery factor for 47.7 m^3/d is 51.44 % less than that of injection rate at 15.9 m^3/d. This research can offer an important scientific evaluation of heterogeneity in the structure of the reservoir. It can be applied in the Northern oilfield in Thailand to make a progress of the process and the application of nanoparticle combined with the surfactant injection for enhanced oil recovery in the real field.

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