Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 8 Issue 8, August - 2021

Integrated Reservoir Connectivity Analysis and Hydrocarbon Saturation Distribution in the Oil Field

Dedy Kristanto[1*], Hariyadi[2], V. Dedi Cahyoko Aji[3], Ferdinandus Klea Latuan[4*], Tria Arumni[5]
[1-5] Petroleum Engineering Department, Universitas Pembangunan Nasional "Veteran" Yogyakarta
Jl. Padjajaran 104 (Lingkar Utara) Condongcatur, D.I. Yogyakarta 55283, Indonesia
[*] Correspondences e-mail: dedykris.upn@gmail.com and ferdilatuan@gmail.com

Abstract*—*Samael oil field has been in production since 1979 and already in secondary oil recovery through waterflooding. Based on reservoir management analysis, polymer injection has been scheduled to improve oil recovery in reservoir A through well S-0inj as the injection well and 6 (six) monitoring (production) wells: S-1, S-1, S-3, S-4, S-5, and S-6. Therefore, integrated analysis is required to have a comprehensive overview of reservoir connectivity and hydrocarbon saturation distribution around the injection pattern area. The analysis was done by integrating tracer test result on the hall plot analysis, water diagnostic plot, and decline curve analysis were conducted to known the effect of waterflooding and polymer injectivity test. Streamline and vector analysis also conducted to know the connectivity and saturation distribution of dynamic reservoir modeling. This paper discusses an integrated and comprehensive analysis to see deeply the reservoir connectivity and remaining oil saturation distribution. The tracer test result shows that all monitoring wells are connected to the injection well. Hall plot analysis on waterflooding indicates negative skin, while the analysis indicates wellbore plugging on polymer injectivity test. Production analysis shows that there is declining in water production, followed by the decline rate increment and oil production after the polymer injectivity test. The streamline analysis result is in line with the tracer test result. Flow vector analysis shows the change in oil saturation distribution as the impact of waterflooding and the polymer injectivity test.

Keywords*—*Integrated Analysis; Reservoir Connectivity; Saturation Distribution; Injection and Production; Streamline Analysis

I. INTRODUCTION

According to Satter, A and Thakur, G.C (1994), reservoir management is a dynamic process in formulating and implementing the optimum and economics strategy for hydrocarbon recovery of a reservoir, well planned and executed by integrated teamwork based on available resources (data, human, natural resources, and technology) utilization. One of the strategies in oil recovery optimization is by doing polymer injection as enhanced oil recovery. To do that, a reservoir connectivity study is required so the design and the evaluation of polymer injection could lead us to determine the optimum strategy.

Samael oil field has been in production for 40 years since 1979. In April 2017, the oil recovery method of the field is waterflooding (secondary oil recovery). In December 2018, a polymer injectivity and tracer test were conducted as a preliminary study of reservoir connectivity regarding the polymer injection plan that was executed in January 2019. In the tracer test program, the chemical tracer was injected into S-0inj injection well. After that, the production of the injected chemical is being observed through six monitoring wells (S-1, S-1, S-3, S-4, S-5, and S-6). The injection pattern is inverted-7 spots since the injection well is located in the middle of the pattern area.

This paper discusses about a comprehensive and integrated analysis and evaluation by applied reservoir management principle related to the well connectivity analysis. In this paper, the well connectivity analysis includes polymer injectivity analysis, tracer test result analysis, hall plot analysis, water diagnostic plot analysis, decline curve analysis, until the flow vector and streamline simulation analysis. In this paper we can see the effect of water and polymer injection, water production problem caused by injection activity, the well connectivity, also the saturation movement after the water and polymer injection.

II. LITERATURE REVIEW

A. Tracer Test

Schlumberger (2020), define that tracer is a chemical or any other material that is being put inside or around a wellbore to measure or to quantify the fluid movement on injection wells. The chemical will be injected into the injection well in a certain concentration. The breakthrough time and the breakthrough concentration will be observed as the function of time at monitoring wells. Christian, C.T.B et al. (2019), state that the tracer test is conducted by considering the dynamic condition that occurs during the injection process in reservoir management and considering the needs to minimize the uncertainty related to the wells or the productive zones connectivity. Fig. 1, shows the illustration of the tracer test process.

Having a good understanding of the fluids flow direction and the connectivity between injection and monitoring (production) wells is an important thing.

The tracer test can give a better view of describing the material balance process in the reservoir. Besides, the tracer test can be applied to identify or to determine the production; even the injection well candidate, so the injection process can be optimized to increase the volumetric sweep efficiency.

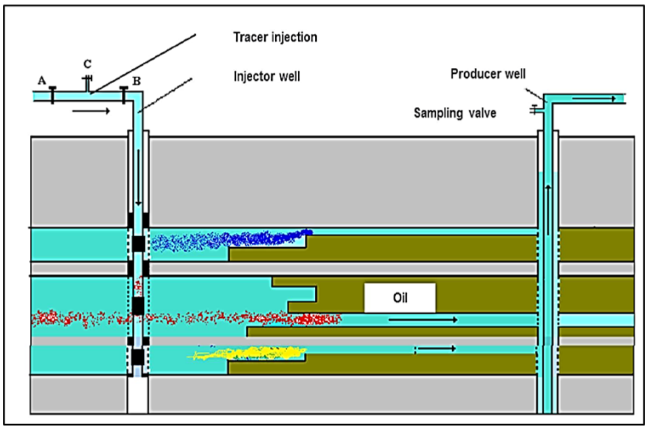

Fig. 1. The Illustration of the Tracer Test Process (Christian, C.T.B et al., 2019)

B. Polymer Injection

Polymer injection is one of the enhanced oil recovery methods by using water and soluble polymer to increase the water viscosity. The water viscosity is increased until the mobility of injected fluid (water) is lower than the mobility of reservoir fluids. Hence, the un-swept area can be displaced and being produced through the production wells. Benjamin, G et al. (2019) state that polymer injection can cause the reservoir pore plug or the surfactant adsorption. The phenomena contribute to the permeability reduction of the reservoir.

C. Hall Plot

Hall (1963) and Jarrel, P.M., and Stein, M.H. (1991) proposed a technique to evaluate the injection well condition. The evaluation is based on the plot of cumulative water injection against cumulative injection pressure or against cumulative injection pressure per cumulative injection time. The plot is recently known as Hall Plot, as shown in Fig. 2.

D. Water Diagnostic Analysis

Chan. K.S (1995) introduces a technique to determine the wellbore condition related to the problem mechanism occurs. The technique is based on a numerical model study of problem water coning and channeling in form of a log-log plot of Water-Oil Ratio (WOR) and derivative WOR (WOR’). The plot is also known as Chan’s Plot or Water Diagnostic Plot, as shown in Fig. 3. Sukubo, I. et.al. (2016) continuing with an integrated approach to water diagnostic analysis in a mature field.

By using Chan’s Plot, we can see the well’s behavior, whether there is water coning, channeling, multilayer channeling, rapid channeling, or normal displacement, even includes the trend of WOR and WOR’ of waterflood production history (Fig. 3). The trend of WOR and WOR’ for each behavior is clearly shown and described (Chan. K.S. 1995). The equation to calculate the WOR and WOR’ are as follows:

$$\mathrm{WOR} = \frac{q_o}{q_w} \quad (1)$$

$$\mathrm{WOR}' = \frac{\mathrm{WOR}_{n+1} - \mathrm{WOR}_n}{\mathrm{Day}_{n+1} - \mathrm{Day}_n} \quad (2)$$

Where q_o is the oil production rate (bbl/day), q_w is the water production rate (bbl/day), WOR_{n+1} is the Water-Oil Ratio at day n+1, and WOR_n is the Water-Oil Ratio at day n.

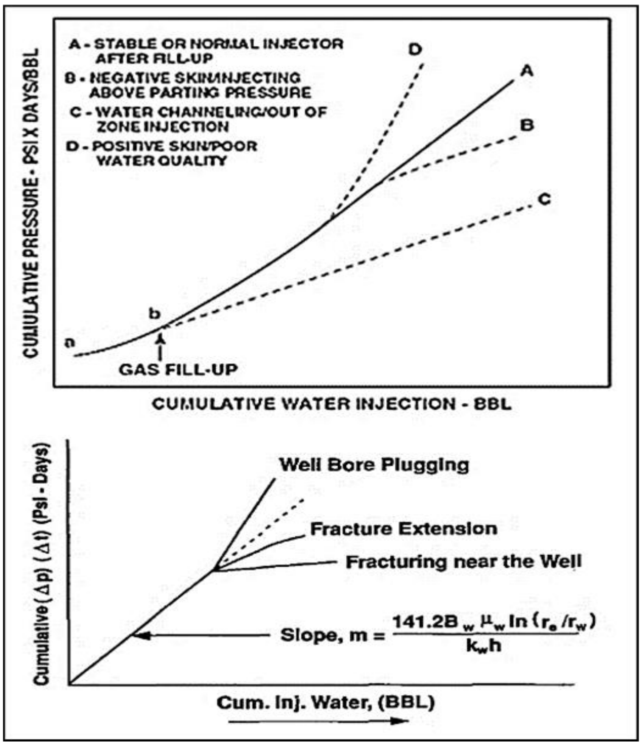

Fig. 2. The Hall Plot Trend in Certain Conditions (Jarrel, P.M., and Stein, M.H., 1991)

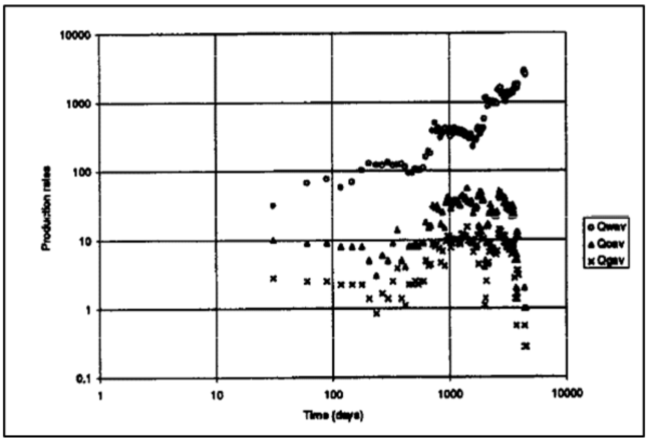

Fig. 3. Chan’s Plot for Waterflood Production History (Chan. K.S., 1995)

E. Decline Curve Analysis

Decline curve analysis - based on Arps, J.J (1945) - is one of methods to describe the production behavior and to estimate the oil reserve based on production data in a certain period. Ahmed, T (2010), Rukmana, D et al. (2018; 2020), and Fetkovich, M. J. (1987) state that decline curve analysis can be conducted in a certain period with constraints:

- The mechanical condition and the reservoir drainage area is constant (boundary-dominated flow condition);
- Each well is being produced at each capacity; and
- Each well is being produced at constant bottom-hole pressure.

In other words, the methodology only applicable when there is no skin or formation damage, no change in lifting method, and there's no equipment or production facilities failure.

Table 1, shows decline curve analysis equation where D is the decline rate (fraction), q is the production rate at time t (bbl/days), q_i is the initial production rate (bbl/days), N_p is the cumulative oil production (bbl), and b is the decline exponent factor.

Table 1. Decline Curve Analysis Equations (Rukmana, D et al., 2018; 2020)

	Tipe Decline		
	Exponential	Hyperbolic	Harmonic
Characteristics	Decline is constant	Decline varies with instantaneous rate raised to power "b"	Decline is directly proportional to the instantaneous rate.
Exponent	b = 0	b ≠ 0, b ≠ 1	b =1
Rate time relationship	$q = q_i . e^{-D_i . t}$	$q = q_i(1 + bD_i t)^{\frac{1}{-b}}$	$q = q_i(1 + D_i t)^{-1}$
Rate cumulative Relationship	$N_p = \frac{(q_i - q)}{D_i}$	$N_p = \frac{q_i^{\,b}}{(1-b)D_i}(q_i^{\,1-b} - q^{1-b})$	$N_p = \frac{q_i}{D_i}\ln\left(\frac{q_i}{q}\right)$
Dimensionless Time, t_D	$D_i t = \ln\left(\frac{q_i}{q}\right)$	$D_i t = \frac{\left(\frac{q_i}{q}\right) - 1}{b}$	$D_i t = \left(\frac{q_i}{q}\right) - 1$
Dimensionless Production, q_D	$\frac{N_p}{q_i t} = \frac{1 - \left(\frac{q_i}{q}\right)^{-1}}{\ln\left(\frac{q_i}{q}\right)}$	$\frac{N_p}{q_i t} = \frac{1 - \left(\frac{q_i}{q}\right)^{b-1}}{\left(\frac{q_i}{q}\right)^{b} - 1}\left(\frac{b}{1-b}\right)$	$\frac{N_p}{q_i t} = \frac{\ln\left(\frac{q_i}{q}\right)}{\left(\frac{q_i}{q}\right) - 1}$

F. Streamline and Flow Vector

The streamline and flow vector are the reservoir fluid flow direction modeling in form of grid mapping in the reservoir dynamic model. The streamline simulation shows the reservoir fluid flow direction line and shows the flow connection between the injection and the production well. The image can be one of the validation methods in the pattern injectivity optimization (Zhao, P et al. 2020). The flow vector shows the direction and the characteristic of oil, water, or gas flow. The flow vector is shown in an arrow, represents the flow domination in a certain area of the reservoir. The bigger the arrow of a certain fluid vector, the more dominant the flow of the fluid.

III. RESEARCH METHODOLOGY

The flow chart of research methodology is shows in Fig. 4. The data preparation includes the polymer injectivity data (Production Logging Tool/PLT data), the tracer test data, waterflooding data, the polymer injection data, and the production data. After that, PLT data analysis data is done to see the performance of the polymer injectivity test, continued by tracer test data analysis regarding the tracer breakthrough time and the tracer concentration covered by monitoring wells. Then, the Hall Plot, Water Diagnostic Plot, dan Decline Curve analysis is done to see the effect of the waterflooding and the polymer injection on the monitoring wells and to the reservoir. After that, the simulation of the streamline and the flow vector could be conducted in dynamic reservoir modeling.

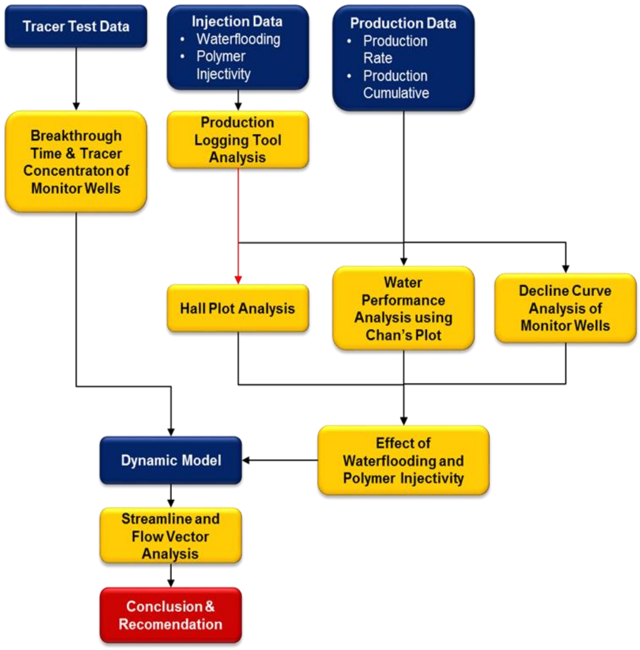

Fig. 4. Research Methodology of Integrated Well Connectivity Analysis

IV. RESULTS AND DISCUSSION

A. Polymer Injection Analysis

Reservoir A as the tracer test injection target zone is divided into Upper Zone A and Lower Zone A. Based on lithology interpretation, both the Upper and the Lower Zone are dominated by sandstone. Field trial polymer was conducted through an injectivity test to see the water injection distribution before and after the polymer injection. Based on the production logging tool analysis of the polymer injectivity test (Fig. 5), both before and after of the polymer injectivity test, the injected water tends to flow through the Lower Zone of reservoir A.

B. Tracer Test

After the polymer injectivity test, on December 24, 2018, 2 kg of chemical tracer is injected into Reservoir

A through S-0inj. Based on the field observation, the breakthrough time occurs on all monitoring wells on the 90th days of the injection (Fig. 6). This is a unique phenomenon, but since this study only focused on the well connectivity, then we just conclude that all monitoring wells are connected to the injection well.

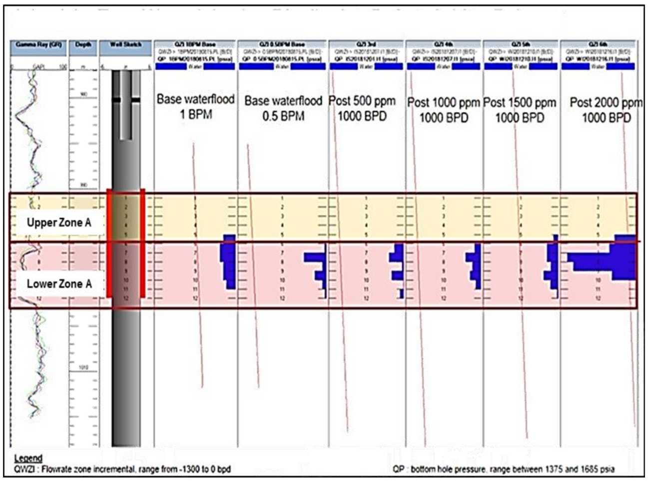

Fig. 5. Production Logging Tool (PLT) Result of Polymer Injectivity Test

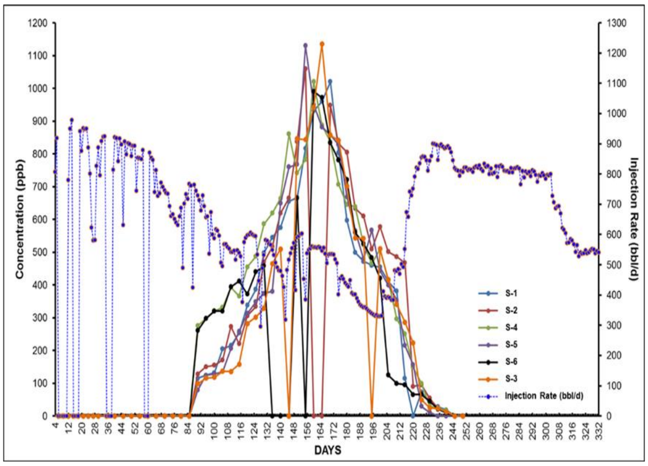

Fig. 6. Tracer Test Result of the Pattern

C. Hall Plot Analysis of Waterflooding and Polymer Injection

For Reservoir A, there are four injection activities: waterflooding, polymer injectivity test, tracer test, and polymer injection. Hall Plot analysis was conducted on the waterflooding and the polymer injection to see the impact of both injection activities on the reservoir.

Based on Hall Plot analysis of waterflooding (Fig. 7) the change of slope shows the indication of negative skin, injection above parting pressure, fracture extension, or fracturing near well. Since the indication of injection above parting pressure requires the validation from step rate test, and the indication of fracture extension or fracturing near well require the validation from transient pressure test analysis, it is concluded that the waterflooding on the injection pattern gives the negative skin impact on the reservoir around the injection well.

Based on Hall Plot analysis of polymer injection (Fig. 8), the change of slope shows the indication of positive skin, poor water quality, or wellbore plugging. Therefore, it is concluded that there are two periods of wellbore plugging caused by the polymer injection.

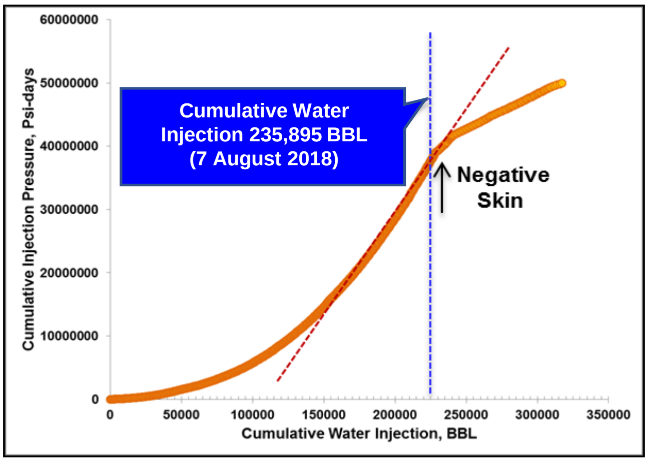

Fig. 7. Hall Plot Analysis of Waterflooding

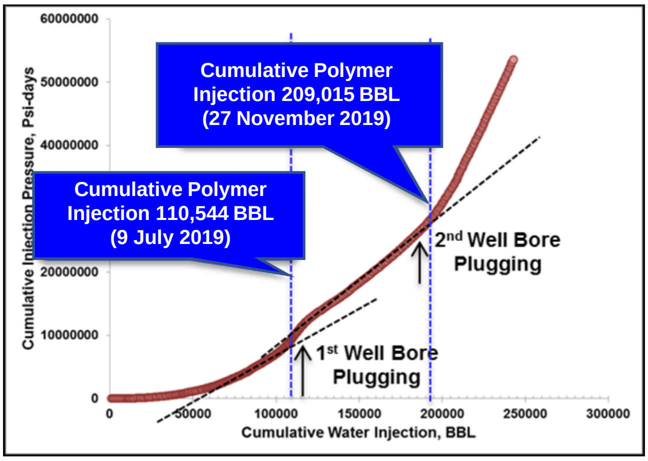

Fig. 8. Hall Plot Analysis of Polymer Injection

D. Water Diagnostic Plot

Based on Chan's Plot analysis (Fig. 9), at the early stage of production after waterflooding, monitoring wells show the trend of waterflood extended. The normal displacement trend occurs in the early stage with high WOR. The breakthrough is indicated by the change of slope where WOR and WOR' increasing quickly. After the polymer injection, each well shows a different trend. Summary of water diagnostic analysis is shown in Table 2, where the polymer injection can cause the channeling, multilayer channeling, or even the WOR declining.

E. Decline Curve Analysis

Fig. 10, shows the decline curve analysis of monitoring wells. Trend-1 shows the declining trend before water flooding. Trend-2 shows the declining trend during the water flooding, and Trend-3 shows the declining trend during the polymer injection. The analysis shows that the decline rate increased after the polymer injection. This is a validation to the Hall Plot analysis result that shows that there is the pore plugging/wellbore plugging after the polymer injection. The summary Decline Curve Analysis of production (monitoring) wells shown in Table 3.

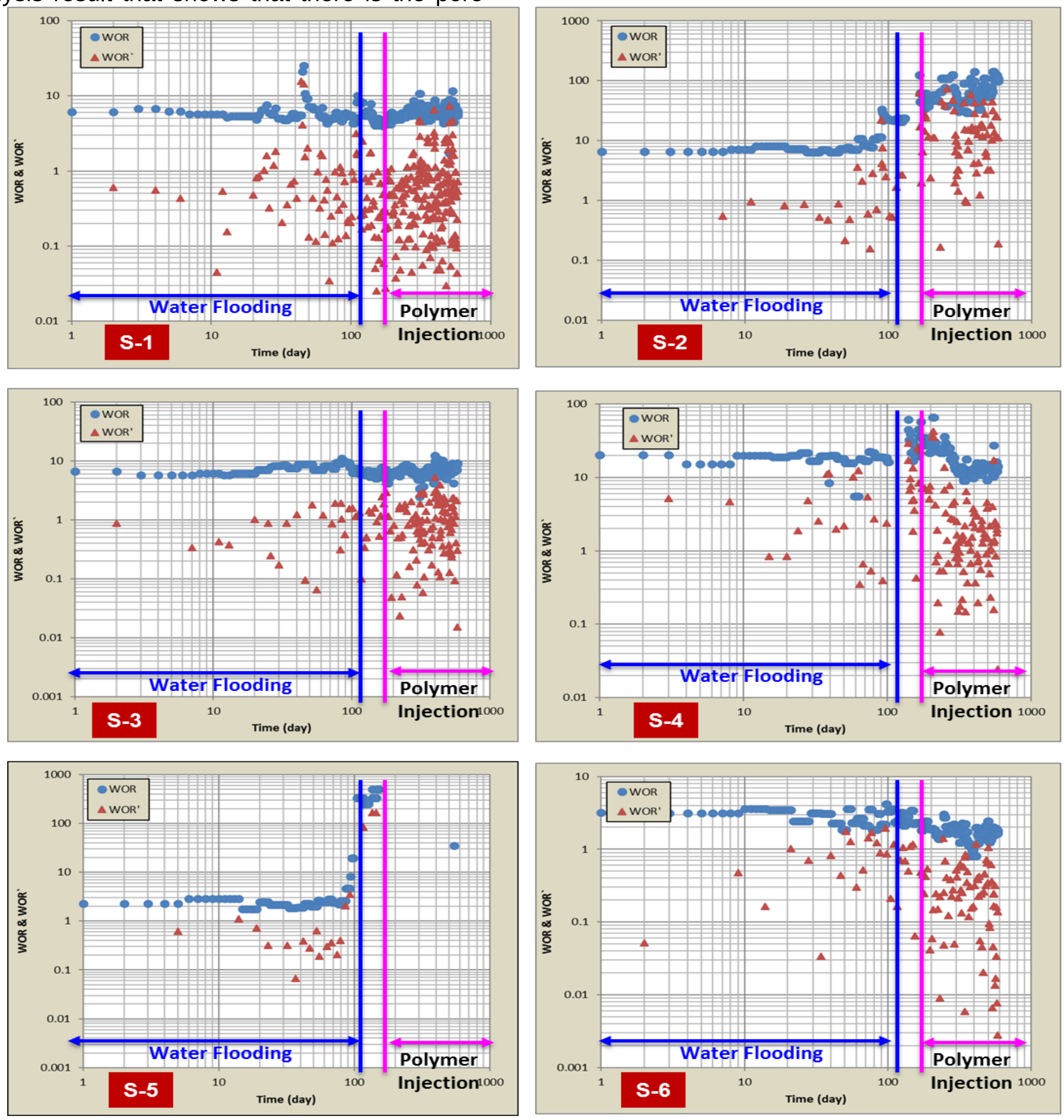

Fig. 9. Water Diagnostic Analysis of Monitoring Wells

Tabel 2. Summary Water Diagnostic Analysis of Production (Monitoring) Wells

Wells	Indication of Waterflood Expended	Indication of Polymer Injection	Description
S-1	Normal Displacement	Channeling	WOR is increased as the effect of waterflooding and polymer injection
S-2	Normal Displacement	Multilayer Channeling	Multi-layer channeling with the change in production method
S-3	Normal Displacement	WOR Decrease	Oil and water production is declining as the effect of the stop of waterflooding
S-4	Normal Displacement	WOR Decrease	Water production is declining and oil production is increased as the effect of polymer injection
S-5	Near Wellbore Channeling	Unidentified	Water source well
S-6	Normal Displacement	WOR Decrease	Water production is declining and oil production is increased as the effect of polymer injection

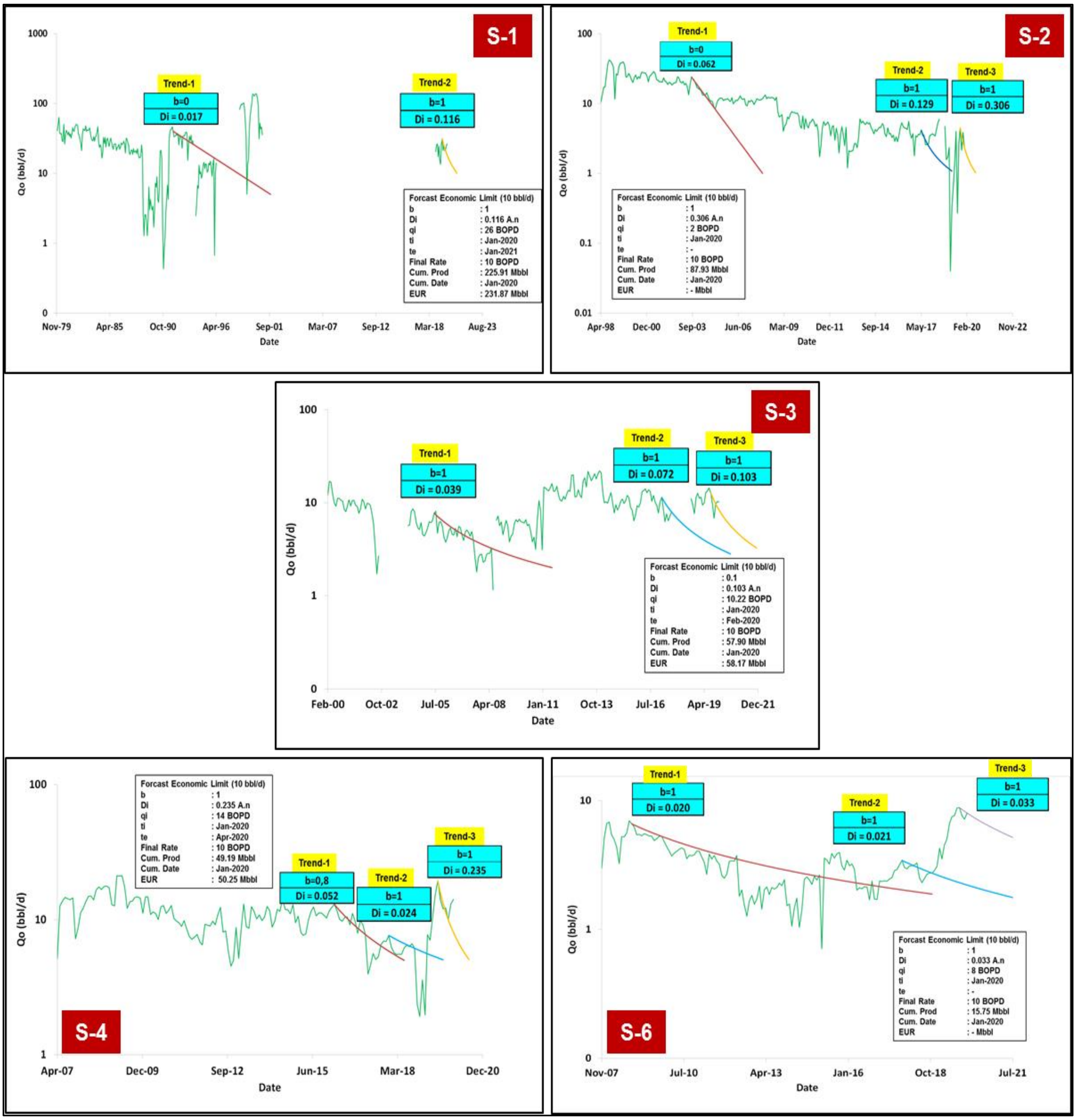

Fig. 10. Decline Curve Analysis of Monitoring Wells

Table 3. Summary Decline Curve Analysis of Production (Monitoring) Wells

Wells	Decline Rate before Waterflooding	Decline Rate at Waterflooding	Decline Rate at Polymer Injection	Description
S-1	0.017	-	0.116	Decline rate incerased as the indication of pore plug caused by the polymer injection
S-2	0.062	0.129	0.306	
S-3	0.039	0.072	0.103	
S-4	0.052	0.024	0.235	
S-5	-	-	-	
S-6	0.020	0.021	0.033	

F. Streamline and Flow Vector Analysis

By using the dynamic model, the streamline and flow vector simulation is conducted. By seeing the water flow vector, we can see the tracer movement (since the tracer is soluble in water) from the injection well in the reservoir. Meanwhile, by seeing the streamline model, we can see the fluid movement and the inter-well connectivity.

From the water flow vector simulation result (Fig. 11) we can see that the water dominantly flows to the S-1. We also can see from the streamline simulation result (Fig. 12) that all production wells are connected to the injection well, in line with the tracer test result. Besides, we can see that as the effect of waterflooding, the oil saturation tends to move to the area around S-1 and S-3. By so, it is necessary to reconsider the location of injection well to increase the sweep efficiency of the polymer injection.

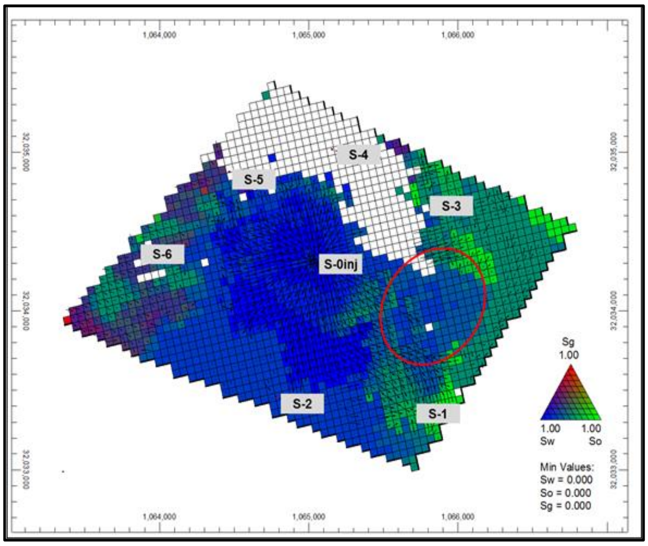

Fig. 11. Flow Vector Simulation Overlay the Ternary Distribution (January 2021)

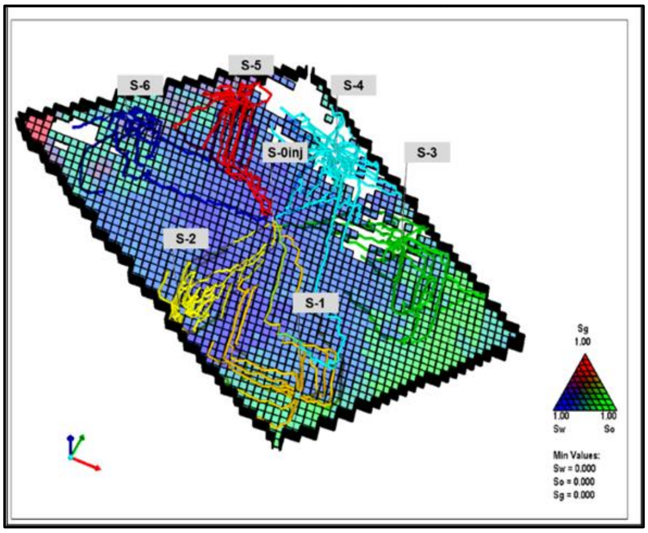

Fig. 12. Streamline Simulation Overlay the Ternary Distribution (January 2021)

V. CONCLUDING REMARKS

Based on Production Logging Tool (PLT) analysis, it is better to inject the polymer through the Lower A Zone since the zone will give a higher oil recovery than the Upper Zone A. Based on Hall Plot analysis, the waterflooding causes the negative skin impact, while the polymer injection caused the wellbore plugging impact on the reservoir around the injection well. After the polymer injection, there are problem channeling, multi-layer channeling, and WOR declining on monitoring wells. Also, the decline rate of monitoring wells is increased. This is a valid justification that there is pore plugging caused by polymer injection. The vector and the streamline of tracer test result analysis show that all monitoring wells are connected to the injection well. After waterflooding and polymer injection, since the oil saturation tends to move to the area around S-1 and S-3, then it is recommended to move the injection well to increase the sweep efficiency of the polymer injection.

ACKOWLEDGEMANT

The authors would thank the Petroleum Engineering Department of Universitas Pembangunan Nasional “Veteran” Yogyakarta Indonesia for the supports to the research.

REFERENCES

Arps, J.J. (1945). Analysis of Decline Curves, APE of Trans. AIME, Society of Petroleum Engineers, Houston-Texas, USA.

Ahmed, T. (2010). Reservoir Engineering Handbook, 4th Edition, Chapter 16, Elsevier Publishing Company, Tulsa, Oklahoma, USA.

Benjamin, G et. al. (2019). Best Surfactant for EOR Polymer Injectivity, SPE-198097-MS, SPE Kuwait Oil & Gas Conference and Show, Kuwait.

Christian, C.T.B et. al. (2019). Understanding Flow through Interwell Tracers, SPE-195251-MS, SPE Western Regional Meeting, San Jose - California, USA.

Chan, K.S. (1995). Water Control Diagnostic Plot, SPE 30775, presented at the SPE Annual Technical Conference and Exhibition, Dallas, USA.

Fetkovich, M. J. (1987). Decline Curve Analysis Using Type Curve Case History, SPE Reprint Series, Tulsa, Oklahoma, USA.

Hall, H. N. (1963). How to Analyze Waterflood Injection Well Performance, World Oil, October, p. 128-130.

Jarrel, P.M., and Stein, M.H. (1991). Maximizing Injection Rates in Wells Recently Converted to

Injection Using Hearn and Hall Plots, SPE 21724, SPE Production Symposium, Oklahoma, USA.

Rukmana, D., Kristanto, D., and Cahyoko A.D. (2018). Reservoir Engineering (Theory and Application), 2nd Edition, Pohon Cahaya Publishing Co., Yogyakarta, Indonesia, p. 142-148.

Rukmana, D., Kristanto, D., Permadi, A.K, Cahyoko Aji, D., (2020). Improvement of Recovery of Mature Field (Theory and Application), Pohon Cahaya Publisher Co., Yogyakarta, Indonesia, p. 112-116.

Sukubo, I. et.al. (2016). An Integrated Approach to Water Diagnostic Analysis in a Mature Field: SPDC Case Study, SPE-184274-MS, SPE Nigeria Annual International Conference and Exhibition, Lagos, Nigeria.

Satter, A., and Thakur, G.C. (1994). Integrated Petroleum Reservoir Management, PennWell Publishing Company, Tulsa, Olakhoma, USA.

Schlumberger. (2020). Oil and Gas Field Glossary, https://www.glossary.oilfield.slb.com/en/Terms/t/tracer.aspx, accessed on November 1.

Zhao, P et.al. (2020). Streamline Simulation Based Vector Flow Field Characterization and Reconstruction Method for High Water Cur Reservoir, IPTC-20291, Saudi Arabia.