Re-design Waterflood Pattern by Utilizing the Tracers Test Technique and Interwell Streamline Simulator

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Abstract. The objective of this study is to evaluate the optimum flow path of an existing pattern by utilizing a streamline simulation for the inter-well tracer test technique. Hopefully, the best scenario can be obtained for the new scheme waterflood to increase oil incremental. This study focuses on selecting the best scenario based on several parameters, including tracer time breakthrough, tracer production concentration, cumulative tracer production, and how the tracer flows path in the streamlined model. The analysis of four settings outcome will give different looks of the relationship between injection wells and production wells. The new flow path delivers a new scheme waterflood that may introduce into the field. The waterflood introduced couples years ago in the field. Many scenarios of waterflood schemes have been implemented to get the best incremental oil. The robust numerical model is one of effort to mimic the real field. Then, the tracer streamline is used to get a better picture of the reservoir in terms of transmissibility as well as the current water flow path with the existing parameters, such pressure, water cut, GOR, and etcetera. From the streamline model, it concludes the best position of the injector to have the prime oil cumulative. Subsequently, the continuous huff and puff method is acquainted with the specific condition into the field. The outcome exhibits the utmost oil incremental. The novelty of this method is the ability to solve the low sweep efficiency due to non-appropriate pattern design in reasonable understanding by utilizing a robust inter-well tracer test simulation and continued by a new arrangement of waterflood schemes.

Keyword: *Tracer, Streamline, Waterflood, Pattern Design*

INTRODUCTION

The water injection is the most method widely used to increase oil incrementally, despite the many characteristics of the reservoir are favorable there are also some characteristics of the reservoir are detrimental, such reservoir heterogeneity, especially the value of high permeability, it reflects poorly on water injection flow path and distribution. The conformance problem in waterflood is a common challenge in an oil field with high reservoir heterogeneity (Thrasher, D. et. al., 2016). The very high permeability can disturb the sweeping effect in the waterflood scheme (Alhuthali, et al., 2006).

The success of waterflood injection is depended heavily on continuity and uniformity of transmissibility fluid form in rock formation as well as how much the volume of the reservoir fluids contacts to fluid injection. To fully explain the connectivity between injection wells and production wells is to do a tracer test before the waterflood project. This tracer test is an important and necessary task to make a waterflood success to advance the oil incremental.

The tracer test objective in the oil and gas industry is to assess the connectivity and communication among wells and their relationship to the reservoir heterogeneity level. The tracer assessment provides a variety of information about the heterogeneity of the reservoir as a fluid flow path. This path is geologically identical or highly heterogeneous due to natural fracturing, fracture networks, faulting, high permeability streak, thief zones with high permeability, or flow-barrier. Keeping track of the fluid flow path as the fluid carrier, in this case, the numerous types of injection fluid added as tracer fluid (Du & Guan, 2005). The flow path fluid is defined as preferential pathways to move reservoir fluid from one point (injection wells) to the other point in the reservoir (production wells) (Zemel, 1995). It is expected to know the breakthrough time of tracer fluid in the producer as well as the flow path of fluid injected.

TRACER TEST METHOD

Interwell Tracer is significantly contributed to the reservoir characterization that is crucial in defining the best scenario to improve recovery effort and create production strategy (Dugstad, 2007). Interwell test is conducted by injecting tracer in the injection wells in conjunction with the carrier fluid injected / carrier (water on waterflooding and gas in gas flooding) and then be detected in production well at a certain period (Sanni, et al., 2015)

Interwell tracers can provide information about the flow pattern in the reservoir. This information is reliable, definitive, and instantly recognizable, so tracer help reduces the uncertainty of flow path, reservoir continuity, and flow patterns reservoir. Therefore, petroleum engineers can obtain information reservoir continuity of the amount of each tracer produced.

Design a tracer test is a vital step in the field tracer test. The poor project design will lead to achieving an unsuccessful tracer field test. In designing inter-well tracer tests, which should consider as follows:

1. Clearly and proclaims the objective test (Du & Guan, 2005)
2. The applicable test area selection
3. The appropriate tracer.
4. The concentration of tracer (Zemel, 1995) (Anisimov, 2009).

The selection of the monitor well is also essential to the success of the tracer test. Theoretically, it is necessary to monitor all active wells in the field. However, the capital cost of the project will limit the number of wells monitor. Therefore, the monitor wells around the production wells where the tracer penetration is estimated based on the latest knowledge in the field of study. Designing of the tracer test should consider all the possibilities that will happen, and various alternative plans should arrange for tracer tests to avoid failure. For example, the tracer follows the abnormal water flow path, which is trapped in a large potential of water imbibition (Dugstad, 2007).

Interwell Objective Tracer Test

An objective tracer test should be known before a viable field test can be carried out and should describe as specific as possible. A well-defined purpose test is a key to success tracer tests. The first question in explaining the purpose of the tracer test is to identify the properties of the reservoir.

Selection Interwell Tracer

The objective election tracer test is to choose the right tracer that meets the objective described earlier and behave satisfactorily in hydrocarbon reservoirs. The right tracer will be dissolved and move correspondingly with the speed of the injected tracer carrier. It must be stable and not be absorbed or broken down by chemical substances in formation. The concentration should not lower than the target formation. It must be detected and measured in minute concentrations. It should be cost-effective or economical as well as can be safely injected and produced, then meet environmental regulations.

It is almost impossible to find a tracer deal for all material that has been known to be absorbed and decomposed by chemical substances that exist below the surface with high reservoir conditions of pressure and temperature. Therefore, laboratory studies are often performed to screen and evaluate the performance of the candidate tracer before executing a real field test. A correlation between laboratory tests and real field tests sometimes cannot correspond to each other. It is quite difficult to replicate all conditions of the reservoir in the laboratory with the current conditions.

STUDY CASE

GF field is a field located in block 34/10 Norwegian sector of North Sea, approximately 190 km from Northwest Bergen, Norway. The sea depth of GF reefs is ranging from 130 m to 160 m, and the reservoir field locates at a depth of 1700 to 2400 m below the sea surface.

Field History GF

The field was found in mid-1978 and began to be produced in December 1986 using three platforms. This field can produce 283 MMm^3 oil and 25 $MMMm^3$ gas. GF Reservoir has a category as a high-quality reservoir, and this field gets supporting of water injection. The ultimate recovery in this field about 50%.

Structure of the Reservoir in the GF Field

Block 34/10 lies in the central part of the East Shetland Basin, which includes structural elements Tampen Spur, Viking Graben, and Sogs Graben. This reservoir has a fracture structural-stratigraphic traps that are very complex, with the oil that is in the layer of sandstone in the Brent group, the Cook and Statjord. The reservoir structure has two parts of the West and East. The structure of the Northeast called GF Field.

Reservoir GF formed during the period Jurassic, this is what caused the fracture irregular reservoir GF, fracturing North-South has a throw of the largest and because the structure to the east down 60°, this fault extends as far as 1 - 1.5 km, some faults resulting in the disruption of the flow horizontally on the pitch GF.

Group B1 has five formations, namely: Broom, Rannoch, and Etive (Lower B1), Ness and Tarbert (Upper B1). Broom formation is a thin shale formation, formations Rannoch has a thickness of about 50-90m composed of coarse sandstone, Etive formations have a thickness of about 20-40m composed of medium to coarse sandstone, formations Ness has a thickness of about 85-110m composed of sandstone, shale, and coats, composed by sandstone formations Tabert good quality. The composite log shows the quality and variability of various formations as well as the oil-water contact that locates at a depth of 1947 m MSL. **FIGURE 1** shows the porosity of the model developed for the GF field. The porosity range is between 5 – 33%. Meanwhile, the permeability is between 0.1 – 1000 mD.

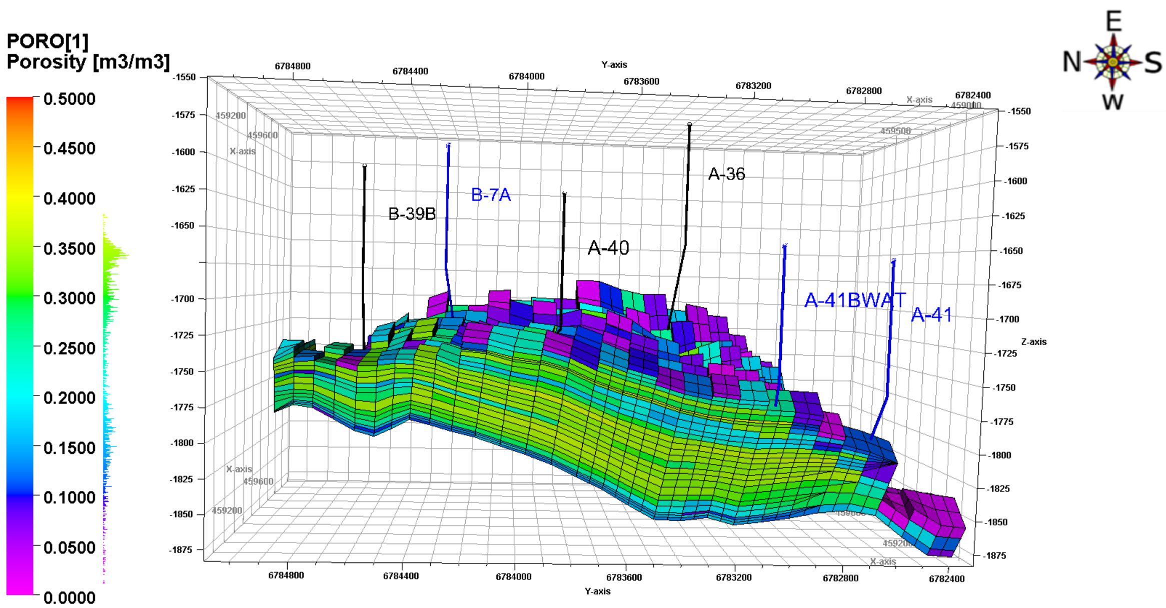

FIGURE 1. Reservoir porosity distribution in GF model

TRACER ANALYSIS

Tracer Analysis of Well A-41BWAT

Tracer analysis was conducted to determine the connectivity between injection wells and production wells as well as observing breakthrough. The tracer analysis performed on three wells that will be used as injection wells, while three wells include: A-41BWAT, A-41, and B-7A. Of the three wells to be seen whether these wells have realistic connectivity with production wells if the well has good connectivity with three production wells of the well worth of the injection well.

Besides that, other relevant information is the inter-well sweep efficiency and the preferential fluid flow that is driven by high-quality formation, such as permeability.

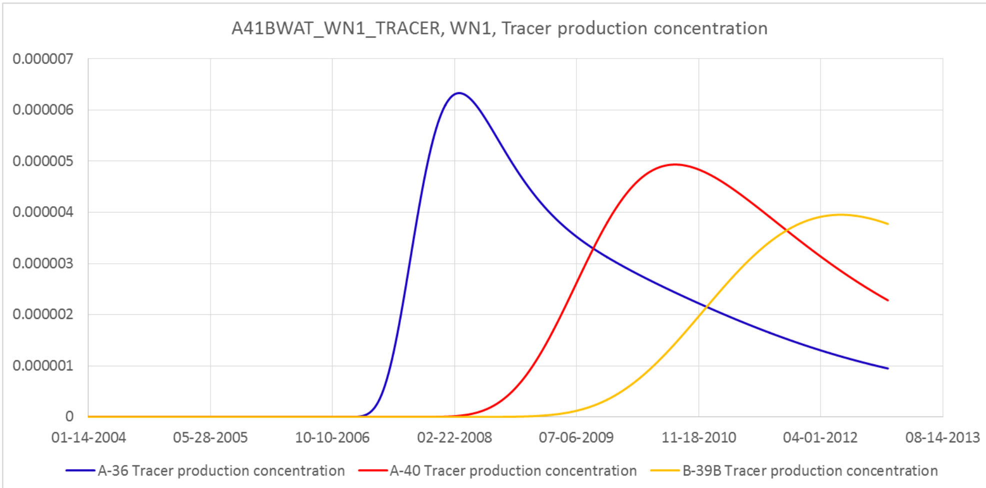

FIGURE 2. Tracer Production Concentration vs. Time (WN1)

FIGURE 2 exhibit WN1 tracer emerged in wells A-36 on October 1, 2006, with an average concentration of 9.75E-13, then it emerged in wells A-40 on January 24, 2007, with an average concentration of 1.35E-17, meanwhile in wells B-39B on April 23, 2007, with an average concentration of 3.47E-17. Hence, it summarizes WN1 tracer injected into the wells A-41BWAT will be up to the well A-36 for 30 days since the first injection on September 1, 2006; it will be up to the well A-40 for 146 days and reach the B-39B wells for 204 days.

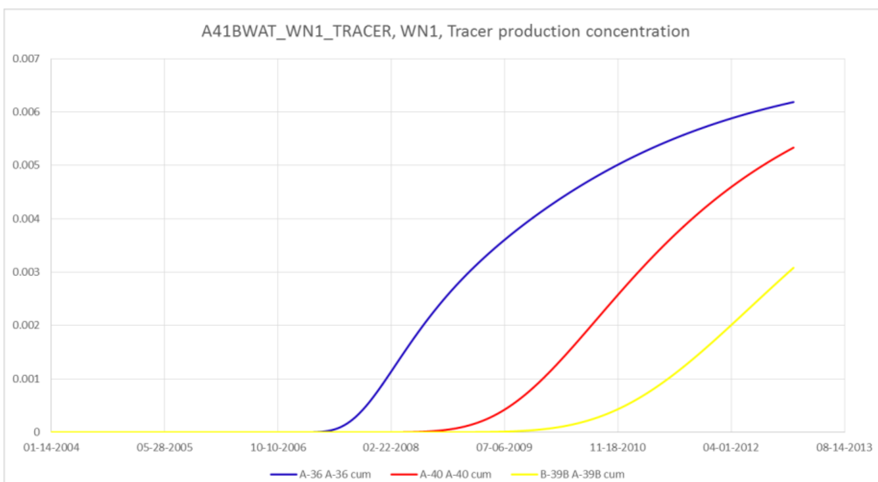

FIGURE 3 Tracer Production Cumulative Vs. Time (WN1)

FIGURE 3 shows total tracer WN1 produced in wells A-36 as much as 12.77 M^3, in wells A-40, about 8.07 M^3, and the B-39B up to 3.37 M^3 at the end of the simulation. The total tracer produced until Jan 2013 was 24.21 M^3, or it was produced up to 64.56%

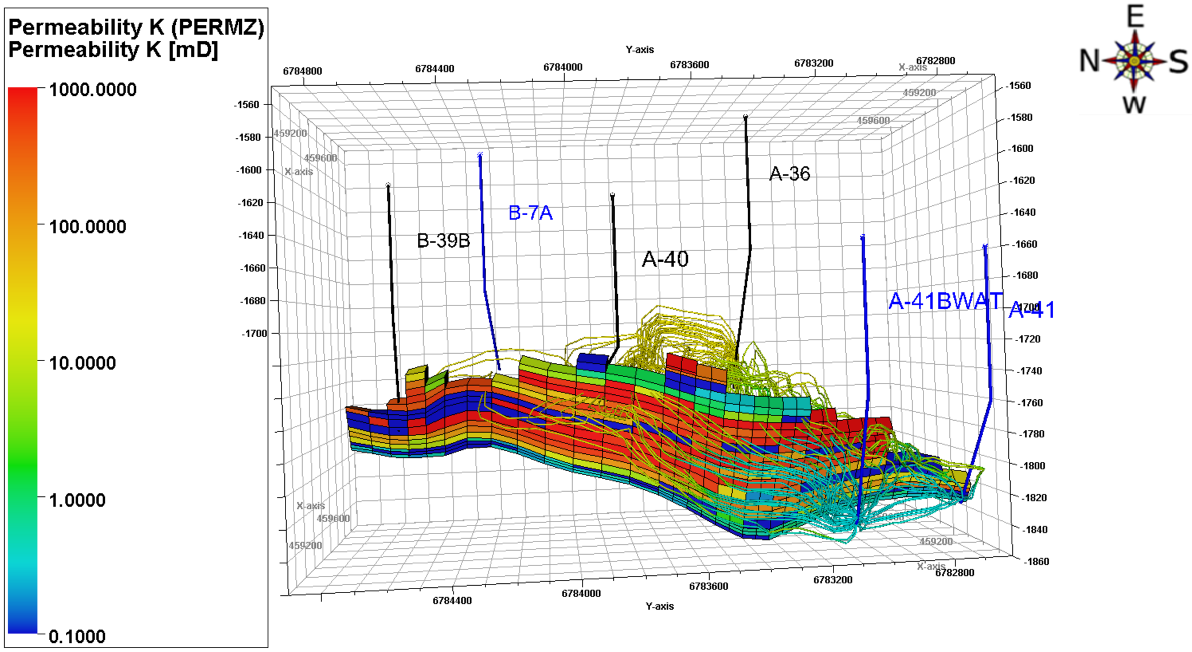

FIGURE 4. The movement of water injection wells A-41BWAT; Vertical (K) direction (1 January 2010)

FIGURE 4 shows a streamline simulation on January 1, 2010, shows A-41BWAT has good connectivity to all three production wells and the best connection with A-36. Anyhow, the water started to reach the wells A-40 and wells B-39B after April 23, 2007, due to permeability drives the fluid flow path. Permeability propagation in vertical (K) direction shows that permeability is up to 800 mD from A-41BWAT into layer 15th, 16th, 17th. Meanwhile, 39B and A36 paths have the permeability in range 100 mD up to 400 mD. Hence, dominantly fluid flow drives through A-40 first rather than other. Laterally, this permeability feast also shows off in layer 16th and 17th with permeability assortment between 500 mD up to 1000 mD.

Tracer Analysis of Well A-41

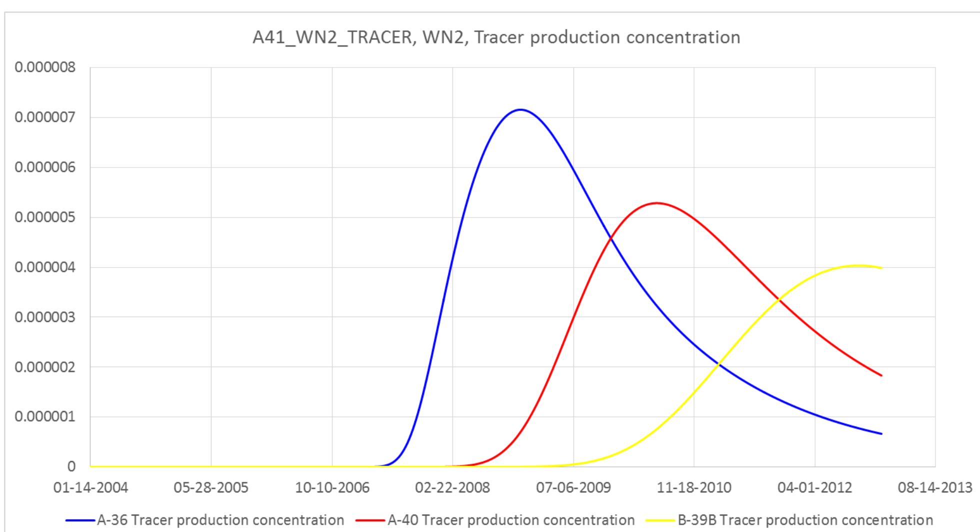

FIGURE 5 Production Tracer Concentration vs. Time (WN2)

FIGURE 5 Production Tracer Concentration vs. Time (WN2) exhibits WN2 visible tracer first produced in wells A-36 on November 6, 2006, with an average concentration of 1.04E-17, was first produced in wells A-40 on February 22, 2007, with an average concentration of 7.93E-19, and the first time produced in wells B-39B on May 29, 2007, with an average concentration of 2.04E-18. It concludes that WN2 tracer injected into the wells A-41BWAT will reach up to the well A-36 for 67 days, and reach up to the well A-40 for 175 days and will be up to the B-39B wells for 271 days.

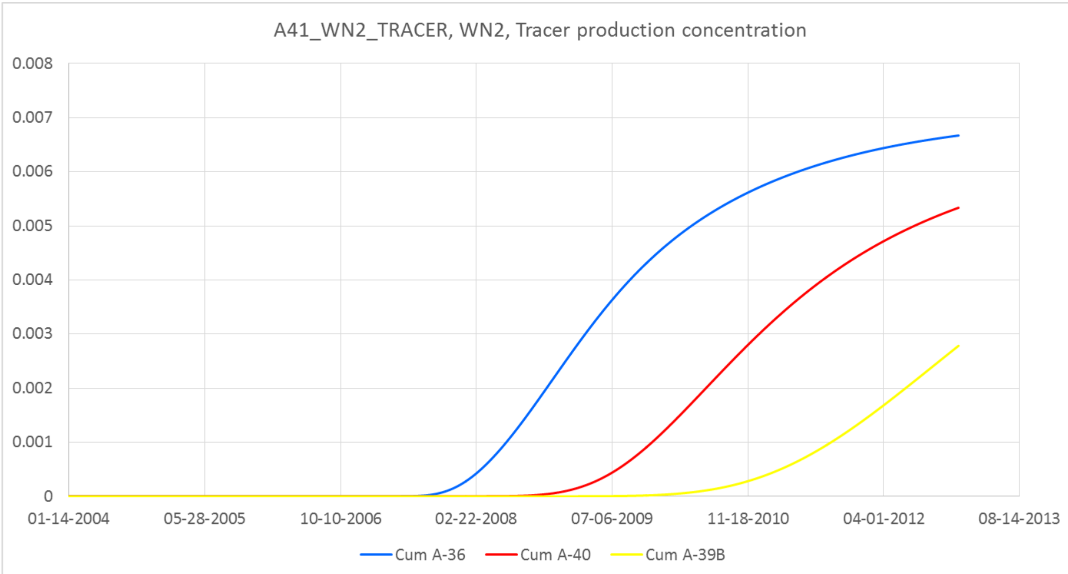

FIGURE 6. Cumulative production Tracer against Time (WN2)

FIGURE 6 until the end of the simulation total tracer WN2 are produced in wells A-36 as much as 13.82 M^3, in wells A-40 8.07 M^3 and the B-39B wells 3.09 M^3. Therefore, the total tracer produced up to date around 24.98 M^3, or it was produced up to 66.61%.

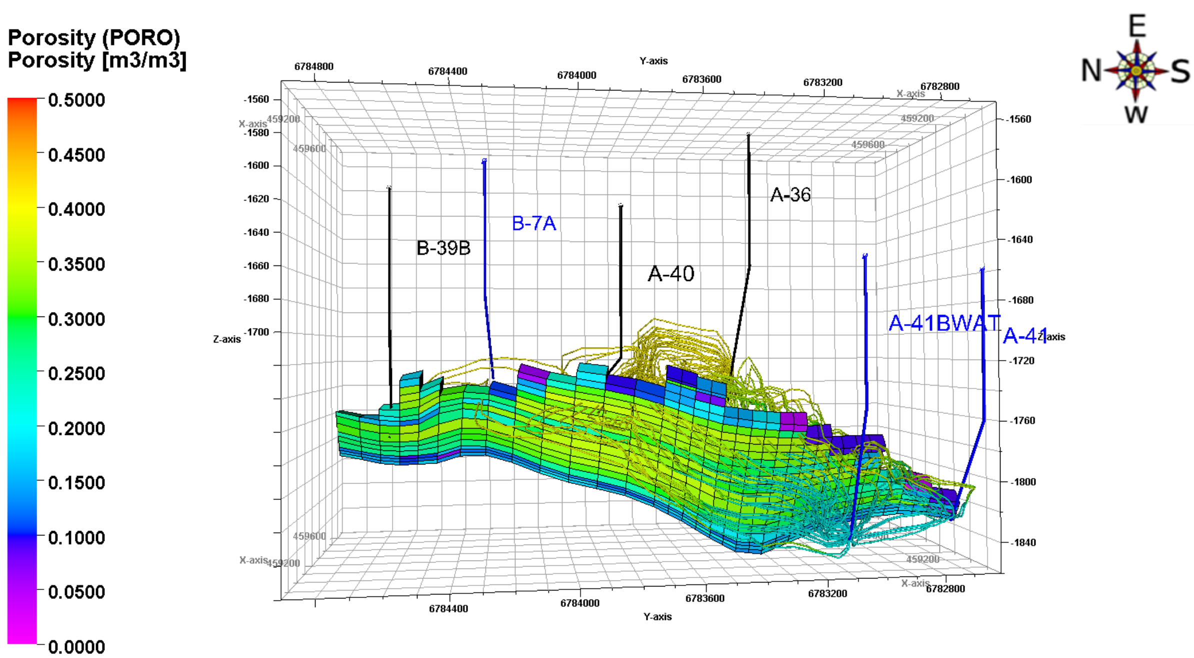

FIGURE 7. The movement of water injection wells A-41 (1 January 2010)

FIGURE 7 shows the lateral porosity has a variant of value 20% up to 35% in layer 14^{th} to 17^{th} as well as layer 22^{nd} to 23^{rd} from A-41BWAT to other wells. Vertically, the porosity value of the grid in direction A-40, A-36, and B-39B wells are 30% -35% for certain grids. It also displays a relatively qualitative evaluation.

The movement of water injected into the wells A-41, starting from September 1, 2006, and then on January 1, 2010, the water had already been moving to production wells A-36 and A-40 as well as wells B-39B. Finally, on January 1, 2013, the injected water has all wells. The best connectivity to A-41 is A-36. The A-41 has a similar flow path of A-41BWAT. Mostly, fluid flow paths transmit into the formation that has a porosity between 25% - 32% that was driven by permeability between 700 – 1000 mD.

Tracer Analysis of Wells B-7A

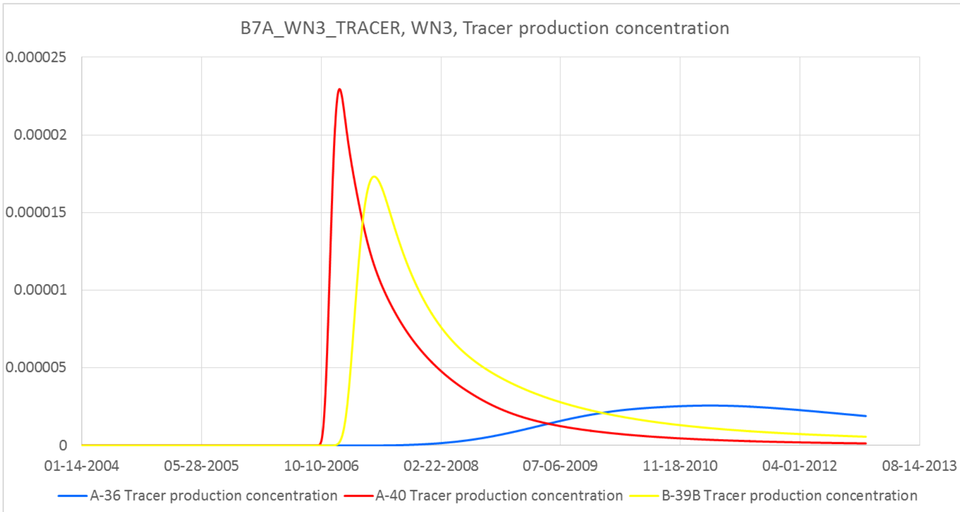

FIGURE 8. Production Tracer Concentration against Time (WN3)

FIGURE 8 WN3 tracer was first produced in wells A-40 on September 12, 2006, with an average concentration of 4.01E-13. It emerged in wells A-36 on October 1, 2006, with an average concentration of 1.58E-13, and it emerged in wells B-39B on December 1, 2006, with an average concentration of 4.39E-14. Hence, it summarizes that the WN3 tracer injected into the wells B-7A reaches the well A-36 for 12 days, then up to the well A-40 and well B-39B for 30 days and 92 days respectively.

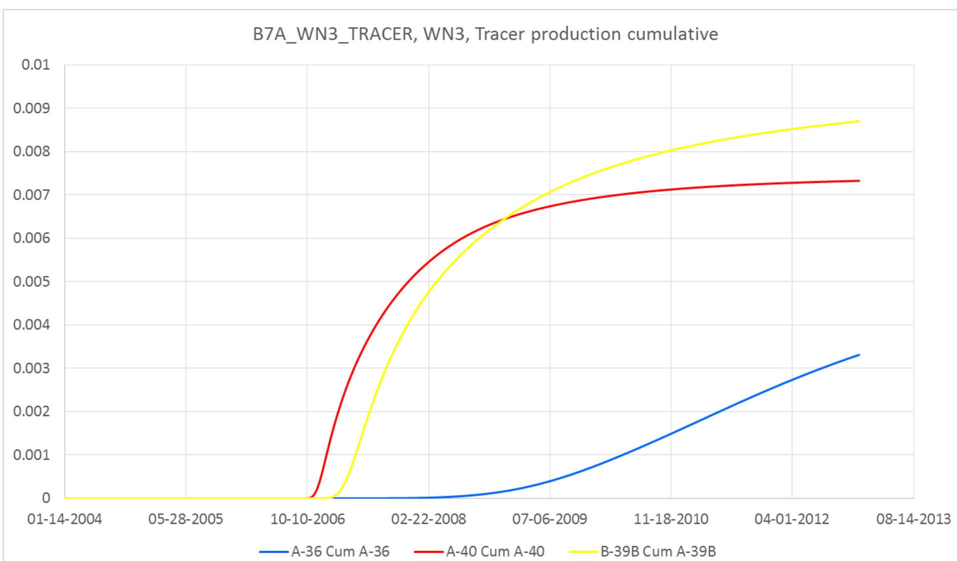

FIGURE 9. Cumulative production Tracer against Time (WN3)

From **FIGURE 9** seen until the end of the simulation of total tracer WN3 produced in wells A-36 as much as 6.52 M^3, in wells A-40 11.11 M^3 and the B-39B wells 8.93 M^3. Therefore the total tracer produced up to 26.56 M^3 or 70.81%.

Table 1 shows the result of the three tracer scenario tests include time, first concentration identified, and cumulative tracer volume collection.

Table 1 Conclusion of 3 cases tracer test

Tracer	**Injector Wells**	**A-36**			**A-40**			**A-39B**		
		DATE	CONC, %	CUM, M^3	DATE	CONC, %	CUM, M^3	DATE	CONC, %	CUM, M^3
WN1	A-41 BWAT	01.10.06	9.74E-13	12.77	24.01.07	1.35E-17	8.07	23.04.07	3.47E-17	3.37
WN2	A-41	06.11.06	1.04E-17	13.82	22.02.07	7.94E-19	8.07	29.05.07	2.04E-18	3.09
WN3	B-7A	01.10.06	1.58E-13	6.52	01.09.06	4.01E-13	11.11	01.12.06	4.39E-14	8.93

All three cases demonstrate that the total cumulative tracer has produced from all producer wells are more than 50% of the total volume injected, which is over than the volume required for the tracer analysis criteria. Therefore, the three cases meet the requirements of excellent communication between injection wells and production wells. From those cases, we have to select the best recovery achieved within the same period of production.

RE-DESIGN PATTERN SCENARIO

From the analysis of the tracer, the simulation result can conclude that the proposed third injection wells have functional connectivity to the three production wells. To select the best option, the oil cumulative is the best parameter for assessment. Six scenarios will be simulated as a water-flood pattern (see **Table 2**). Total water injected into injection wells of 6 scenarios are the 5250 bbls/day with an injection pressure of 3000 psi.

Table 2 Scenarios to simulate the pattern

Scenario	**Production Well**			**Injection Well**		
1	A-36	A-40	B-39B	A-41BWAT		
2	A-36	A-40	B-39B	A-41BWAT	A-41	
3	A-36	A-40	B-39B	A-41BWAT		B-7A
4	A-36	A-40	B-39B	A-41BWAT	A-41	B-7A
5	A-36	A-40	B-39B			B-7A
6	A-36	A-40	B-39B		A-41	

RESULT AND CONCLUSION

Table 3 Simulation result and summary

Scenario	**Oil Cumulative**	**Oil Prod rate in the first date of pattern setting**	**Intersect time base-case and any case**	**Duration period prior intersect time, month**
1	1,294,307.00	1,271.79		
2	1,295,456.00	1,269.01	01/09/2007	12
3	1,138,143.00	1,478.55	01/11/2007	14
4	1,213,696.50	1,408.25	01/03/2007	9
5	978,031.00	1,647.93		
6	1,290,671.50	1,266.37		

The six simulations outcomes display in **Table 3**. Based on the result, it could conclude as follows:

1. The single optimum scenario is scenario 1 (Injector is A-41BWAT) based on the oil cumulative.
2. The combination scenario where the injection conducts through A-41BWAT and B-41 show better one than scenario 1 in term of oil cumulative, but unfortunately, on September 1, 2007, or 12 months after the kick-off of the injection, the water flow path of both wells are intersecting which impact water excess in some flow path. It will make an early water breakthrough.
3. The heterogeneity level and the distance between the two wells are key factors of tracer test monitoring.
4. The early arrival of a tracer fluid may indicate that the fluid flow has a contactless in the reservoir.

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