International Journal of Petroleum and Petrochemical Engineering (IJPPE)
Volume 5, Issue 2, 2019, PP 1-8
ISSN 2454-7980 (Online)
DOI: http://dx.doi.org/10.20431/2454-7980.0502001
www.arcjournals.org

Evaluation of Various Water Flooding Patterns in the Kube Field

E. M. Amarfio[1*], O. Brobbey[1]

[1]*University of Mines and Technology, P.O. Box 237, Tarkwa, Ghana*

Corresponding Author:** ***E. M. Amarfio, *University of Mines and Technology, P.O. Box 237, Tarkwa, Ghana*

Abstract: *Water flooding is a process used to restore and maintain pressure in an oil reservoir. It enables better recovery of crude oil over longer periods of time. An important factor to consider when planning a water flood operation is the pattern arrangement of the wells to be used. As such, this project sought to determine the profitabilities of various flood patterns in an offshore field, the Kube field. Black oil simulations of 11 different patterns were created and ran using ECLIPSE 100 in order to obtain the necessary recovery factors. These patterns were used in the development of the field over a 10-year period. Results showed that the normal 5-spot pattern provided the greatest recovery while the direct line drive gave least recovery. Also, extreme water cuts as a result of the flood process limited the recovery of oil a few years after the operation began. In addition, it was discovered that normal flood patterns performed better than their inverted equivalents. It was thus concluded that from a purely technical standpoint, the normal 5-spot pattern provides the highest profits.*

Keywords: *Water flooding, Pressure maintenance, 5-spot patterns, inverted patterns, Oil Recovery*

1. INTRODUCTION

Crude oil is one of the most important resources a country can have; it greatly contributes to the economy of a nation. However, not all crude oil can be produced from known reservoirs because of inevitable pressure losses (within the reservoirs) with time, and thus methods of secondary and tertiary recovery, as well as other improved oil recovery methods must be employed. Many oil fields in the world are subject to this phenomenon and the Kube oil field is no exception. Under natural drive mechanisms, a reservoir can produce anywhere from 5% to 65% of oil initially in place (OIIP), the specific recovery factor depending on the drive mechanism(s) at work in the reservoir (Glover, 2010).

In order to improve recovery from a reservoir, secondary recovery mechanisms can be employed. Dankwa (2017) stated that secondary recovery operations seek to restore and maintain pressure in the formation by voidage replacement. The most commonly used methods are water flooding and gas injection, with water injection having the highest recovery factors. According to Marek and Sullivan (2013), water floods should recover an additional 10% to 40% of OIIP. The efficiency of a water flood depends on certain factors, some of which include the formation lithology, fluid properties, reservoir depth, reservoir geometry and the pattern arrangement and well spacing involved in the flood operation (Tarek, 2010).

The goal of a water flooding project is to contact as much oil as possible in the reservoir with injected water. Several well injection patterns (configurations of producers and injectors) exist for improved recovery, the main ones being the peripheral pattern, four-spot, five-spot, seven-spot, nine-spot, direct line drive and staggered line drive. A three-spot pattern also exists, though this is mainly used for pilot tests. Regular patterns may also be divided into normal and inverted patterns, such as the normal five-spot and inverted five-spot patterns. Basically, there is a large pool of patterns to choose from; therefore extensive simulations of the field of interest need to be created and ran to ascertain the best pattern.

The choice of the most efficient pattern for use is subject to the properties and features of the reservoir in question, as well as the available capital. The cost of crude oil recovery is directly proportional to the number of wells used in the flood process. Each of these patterns gives a range of recovery, and some patterns perform better than others. The general notion is that a greater number of producers and injectors lead to higher recovery efficiencies, though this is not always the case. This work is hence geared toward determining the recoveries that the various flood patterns will offer in the Kube field, against their economic requirements. It will also address the field water cuts for each of the patterns.

2. METHODOLOGY

Under this section, we give the vivid description of the modeling of the reservoir field from geologic to dynamic status showing how the various water flooding patterns were developed.

2.1. Reservoir Description

The reservoir is an under saturated black oil reservoir with an area of 413 acres and is located at a depth of 13 200 feet sub surface. It has a thickness of 140 feet and a uniform net to gross of 1. Porosity, permeability and initial water saturation are all heterogeneous and anisotropic in the given reservoir. It has an initial average pressure of 13 000 psi. The reservoir rock is made up of sandstone. It has no supporting aquifer, no faults and no fractures.

2.1.1. Overview

The work was carried out by first creating a static model, then creating twelve dynamic models based on the static model. The static model served as the geological model of the reservoir, without any production. Eleven of the dynamic models represented the flood patterns which were evaluated. The remaining dynamic model was created to try to maximize production from the reservoir without any form of pressure support. It served as the control of the entire work. The patterns evaluated are:

1. The normal and inverted 4-spot patterns;
2. The normal and inverted 5-spot patterns;
3. The normal and inverted 7-spot patterns;
4. The normal and inverted 9-spot patterns;
5. The direct and staggered line drives; and
6. The peripheral flood pattern.

The static model description is as follows:

The reservoir was represented by a 4000-cell grid with dimensions 20*40*5 in the x, y and z directions respectively. The phases contained in the reservoir are oil, dissolved gas and water. Each cell has lengths of 150 ft in the x and y directions and a length of 28 ft in the z direction. OIIP is 24.34 MMbbl and GIIP is 22.47 Bcf.

2.1.2. Flood Pattern Simulations

For all the flood patterns, an initial field production rate of 10 000 bopd was used. A field injection rate of 60 000 bwpd was used. These values were made constant for all patterns to provide a basis of comparison and to take out any possibility of bias. All wells were perforated in all five layers of the reservoir, in each pattern. Injectors also began injecting exactly on 1st April 2019 to help maintain the plateau of the production profile. All producers were controlled by oil production rates and all injectors were controlled using water injection rates. The bottom hole pressure in each producer was set to 1 500 psi. Control of the producers thus switched from oil production rate to bottom hole pressure control when the reservoir pressure declined so much that the required production rate could not be sustained.

Table 1 shows the number of producers and injectors, and production and injection rates per well used in each pattern. The well spacings used in each pattern are indicated in Table 2. In the normal 4-spot and 5-spot patterns, two injectors were made communal, that is, two injectors were shared by the two producers used. The inverse was used in the inverse 4-spot and 5-spot patterns (two producers were shared by the two injectors). The 7-spot had one communal injector. The inverse pattern had one communal producer. In the 9-spot pattern, three injectors were communal. Three producers were communal in the inverted 9-spot pattern. The direct line drive was created using alternate rows of producers and injectors, and the staggered line drive was obtained by modifying the direct line drive.

Table1. *Pattern Variables*

Flood Pattern	No. of Producers	No. of Injectors	Production Rate per Producer (bopd)	Injection Rate per Injector (bwpd)
Normal 4-Spot	2	4	5 000	15 000
Inverted 4-Spot	4	2	2 500	30 000
Normal 5-Spot	2	6	5 000	10 000
Inverted 5-Spot	6	2	1 666.67	30 000
Normal 7-Spot	2	11	5 000	5 454.55
Inverted 7-Spot	11	2	909.09	30 000
Normal 9-Spot	2	13	5 000	4 615.39
Inverted 9-Spot	13	2	769.23	30 000
Direct Line	10	10	1 000	6 000
Staggered Line	8	10	1 250	6 000
Peripheral	2	12	5 000	5 000

Table2. *Well Spacings*

Pattern	Producer Spacing (ft)	Injector Spacing (ft)	Pattern	Producer Spacing (ft)	Injector Spacing (ft)
4-Spot	1 950	4 050	9-Spot	3 000	1 500
Inv. 4-Spot	4 050	1 950	Inv. 9-Spot	1 500	3 000
5-Spot	3 000	3 000	Direct Line	1 500	1 500
Inv. 5-Spot	3 000	3 000	Staggered Line	1 500	1 500
7-Spot	3 000	Varied	Peripheral	3 000	1 500
Inv. 7-Spot	Varied	3 000			

3. RESULTS AND DISCUSSIONS

3.1. Recovery Factors

Using the energy of the reservoir only, production amounted to 22.1% of the oil initially in place. The normal 5-spot pattern gave the highest recovery factor (69.50%), followed by the inverse 5-spot pattern (68.90%). The direct line drive had a recovery factor of 66.62%, making it the least-performing. The RFs of the patterns are shown in Figure 1 in order from the highest to the least. All secondary recovery factors fell between 66.5% and 70%.

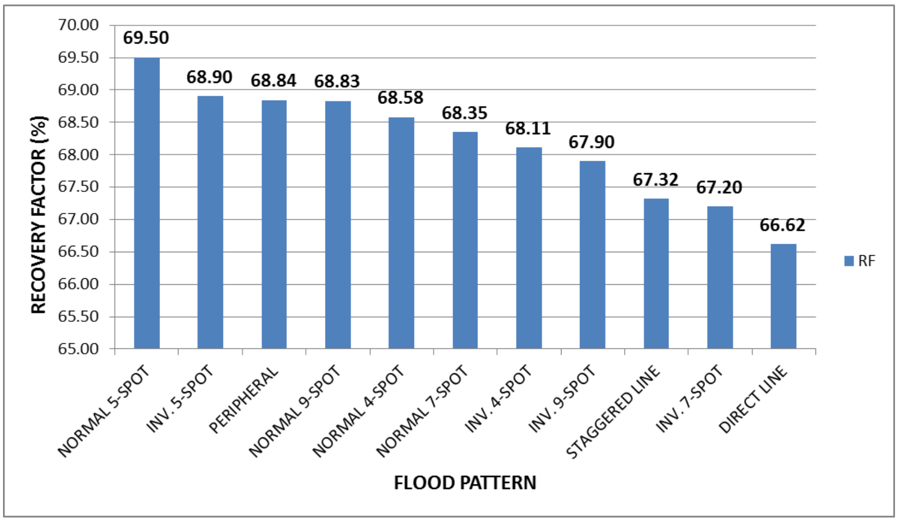

Figure1. *Recovery Factors for Flood Patterns*

3.2. Field Water Cuts

Water cut values in each pattern were minimal (less than 1%) within the first 500 days of production. In some patterns, the rise in water cut occurred prior to the 500th day, while in others it occurred after. This period of negligible water production was from Jan 1, 2018 to about May 21, 2019. Generally, there were sharp increases in water cut values from less than 1% to about 87% from the 500th day to about the 1 000th day. In some patterns like the direct line drive, the rise was steeper, leading to field water cuts (FWCTs) of 87% before the 750th day was reached. In other patterns like the inverted 7-spot pattern, the rise in FWCT values was comparatively gentler. However in all patterns, water accounted for 90% of liquid production by September 7, 2020. This was approximately 33 months (2 years and 9 months) after production started. Water cuts then rose slowly and steadily from 87% to about 97% from September 2020 to the end of December 2027, when production ended. The rise was fairly constant over all patterns. The field water cuts can be seen in Figures 8 to 12.

3.3. Recovery Factor Analysis

The patterns evaluated had different recoveries because of several possible reasons. Some of the most likely reasons are discussed in this section.

3.3.1. Normal and Inverted Patterns

From the results shown in Figure 1, it can be seen that the normal flood patterns performed better than their inverted counterparts. This can be attributed to the fact that inverted patterns have fewer injector wells to effectively sweep oil. Oil thus remained trapped in certain areas in the reservoir; reducing the expected recovery factors.

3.3.2. Rank of Pattern Recoveries

The normal 5-spot pattern recovered the most amount of oil because it had just the right number of injectors to effectively sweep oil from all corners and directions in the reservoir. It could be argued that the peripheral flood pattern also had the means to sweep oil from all directions toward the producers and prevent entrapment. Theoretically, more injectors should lead to more recovery, but in this case, the higher number of injectors in the peripheral pattern led to earlier water breakthrough in the producers and higher water cuts after breakthrough. This limited the production of oil. The same situation can be observed between the peripheral flood pattern and the normal 9-spot pattern. The peripheral pattern, shown in Figure 2, had a higher recovery because it lacked an in-field injector that the normal 9-spot pattern (Figure 3) had. The extra injector only promoted water breakthrough and did nothing for oil sweep. At a certain point in time, using more injectors becomes counter-productive.

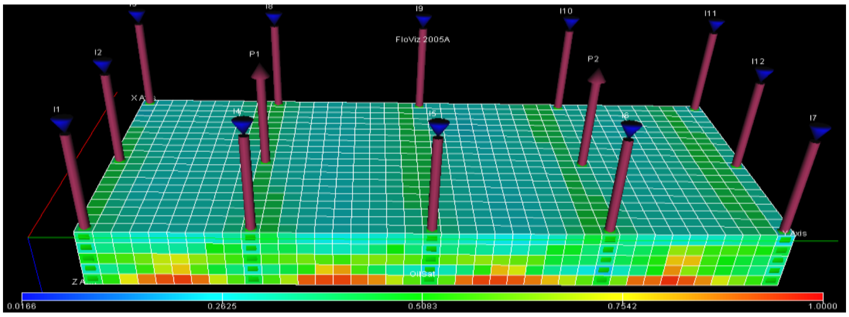

Figure2. *The Peripheral Flood Pattern at the Start of Injection*

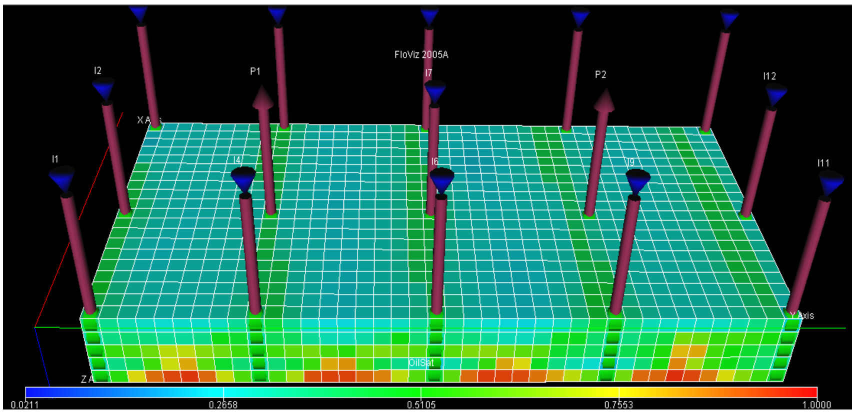

Figure3. *Normal 9-Spot Pattern at the Start of Injection*

The normal 4-spot pattern should then have performed better than the normal 9-spot pattern (since it had fewer injectors), but that is not the case in Figure 1. It did not occur as expected because the 4-spot pattern lacked injectors in vital zones in the reservoir, shown in Figure 4.Some corners were left completely unattended to, and this led to higher residual oil saturations in such zones after the flood process ended.

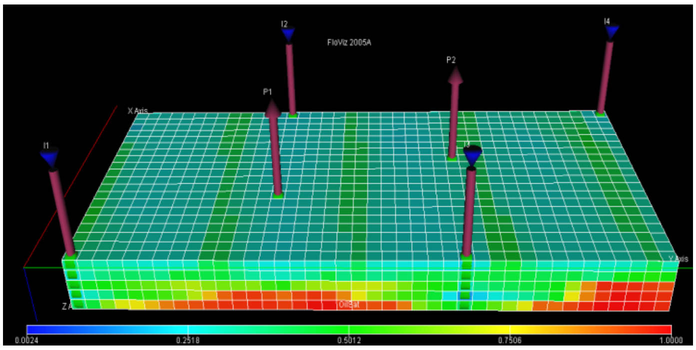

Figure4. *Normal 4-Spot Pattern at the Start of Injection*

The performance of the normal 7-spot pattern, shown in Figure 5, could be due to the number of injectors used. It made use of 11 injectors, most of which only increased water production. The peripheral and normal 9-spot patterns also had many injectors, but they were not as close to the producers as some of the normal 7-spot injectors were. The proximity in the normal 7-spot pattern led to lower recoveries than the normal 9-spot and peripheral patterns.

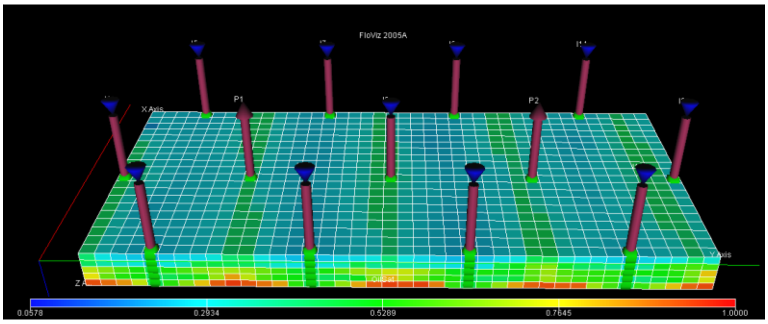

Figure5. *Normal 7-Spot Pattern at the Start of Injection*

It was also discovered that there exists an inverse relationship between the number of producers used and the recovery obtained. This was evident in the inverted 9-spot, staggered line, direct line and inverted 7-spot patterns. These patterns make up the four least-performing patterns. The low recoveries could be as a result of water production. This will be discussed in the next section. The low recoveries from the direct (Figure 6) and staggered (Figure 7) line drives could also be attributed to the number and locations of the injectors used.

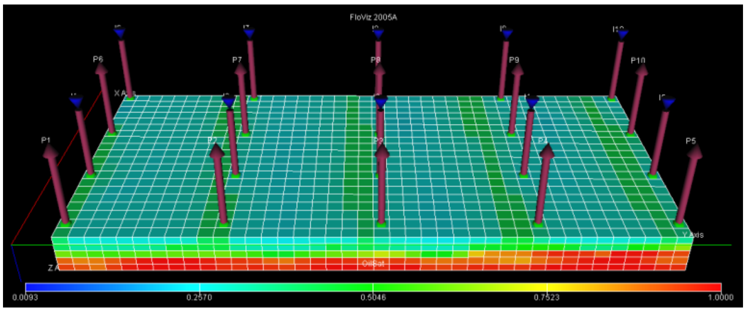

Figure6. *Direct Line Drive at the Start of Injection*

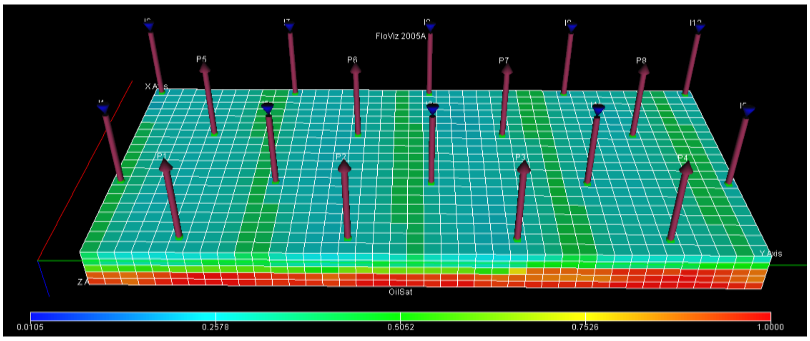

Figure7. *Staggered Line Drive at the Start of Injection*

3.4. Water Cut Analysis

Generally, for all the patterns modelled, oil production decreased with increasing water and gas production. As shown in Figure 8, the graphs of the normal 4-spot and inverted 4-spot water cuts are similar. The similarity is due to the absence of a large difference in the number of producers and injectors in the two patterns.

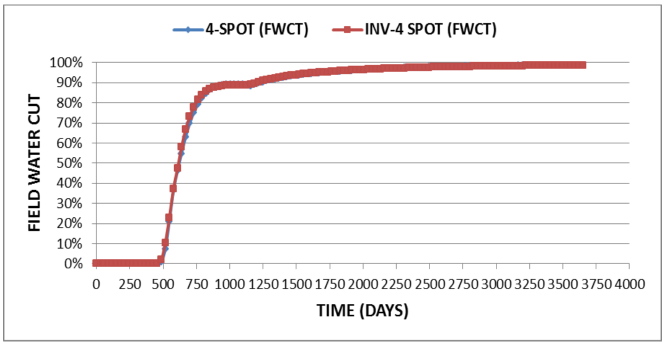

Figure8. *Field Water Cuts for the Normal and Inverted 4-Spot Patterns*

A disparity exists in the water cuts for the normal and inverted 5-spot patterns. The inverted 5-spot pattern had 6 producers, compared to the normal 5-spot pattern which had two. Because of the increased number of producers, water that had been injected into the formation left fairly easily and quickly. There were several available conduits for the water to escape the reservoir. This accounts for the crossover around the 750th day of production as shown in Figure 9. Wells also preferentially producing water led to lower oil recovery rates, and this is evident in all the normal and inverted patterns. It can therefore be stated that a greater number of producers leads to greater water production, greater water cuts and ultimately, lower oil recovery factors. It was observed that higher pressure drops existed in the inverted patterns. The reservoir pressure was maintained primarily by the water being injected.

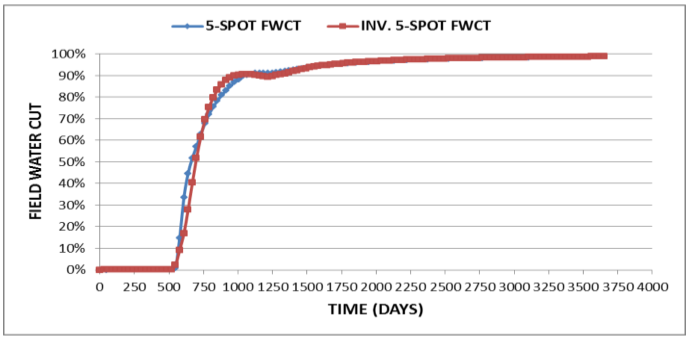

Figure9. *Field Water Cuts for the Normal and Inverted 5-Spot Patterns*

Inverted patterns not only produce water preferentially, they are also characterised by large pressure drops due to excessive water production (voiding the reservoir of that which maintains its pressure). This is clearly seen in the water cuts for the normal and inverted 7 and 9-spot patterns. The difference in the water cut profiles is due to the difference in the number of producers. The peripheral (figure 13) water cuts resemble those of the normal 9-spot pattern because their field developments were similar, the only difference being one in-field well as stated earlier.

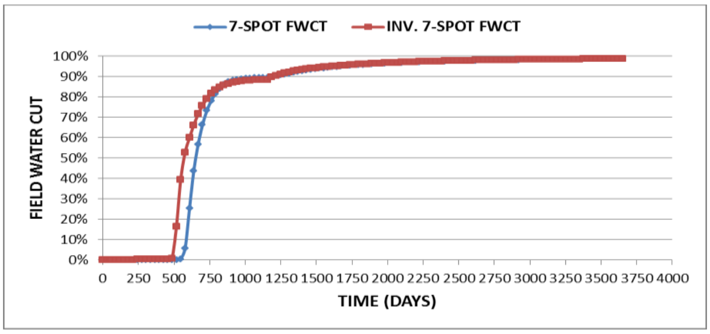

Figure10. *Field Water Cuts for the Normal and Inverted 7-Spot Patterns*

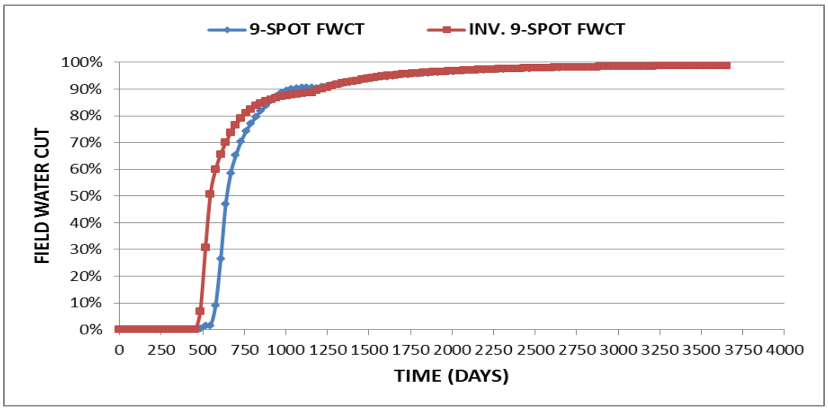

Figure11. *Field Water Cuts for the Normal and Inverted 9-Spot Patterns*

From Figure 12, it can be seen that the direct line drive produces more water than the staggered line drive. Both patterns also produce more water than the other patterns do. This is due to the placement of the injectors at certain locations with respect to the producers. The spacings used here between injectors and producers are much less than those used in other patterns. This allows for faster movement of the advancing water front toward the producers and hence higher water production and earlier breakthrough. The staggered line drive had less water production because it had fewer production wells.

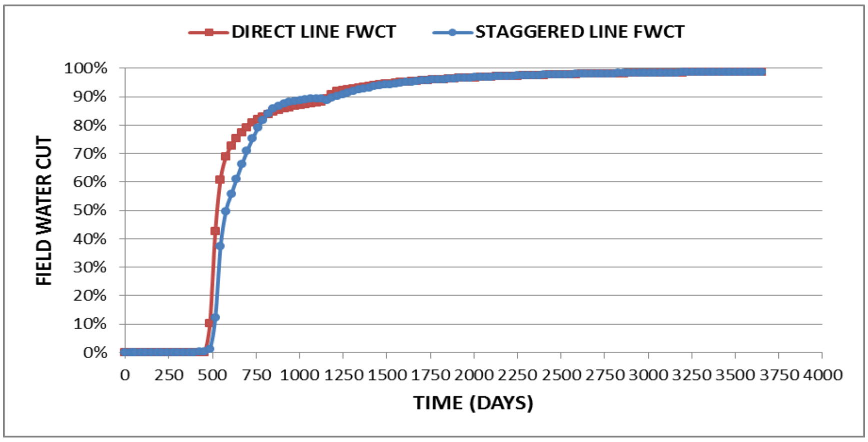

Figure12. *Field Water Cuts for the Direct and Staggered Line Drives*

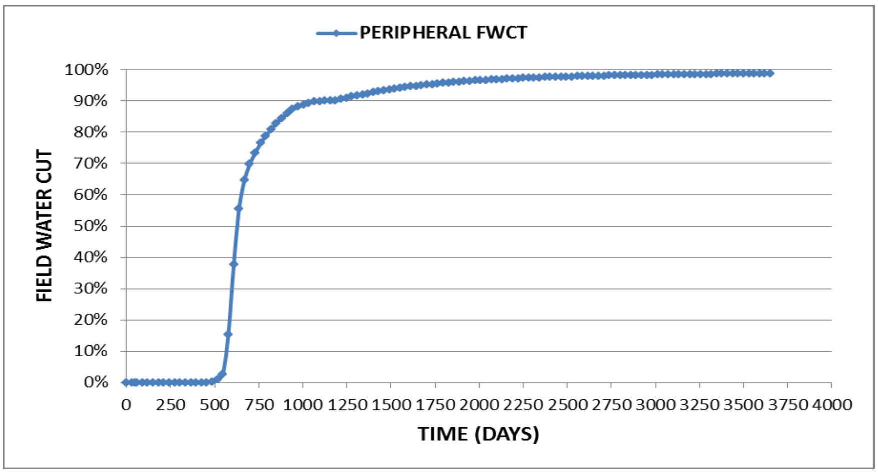

Figure13. *Field Water Cuts for the Peripheral Flood Pattern*

4. CONCLUSION

- The normal 5-spot pattern gives the highest recovery when used in the Kube field, while the direct line drive results in the lowest recovery.
- Field water cuts rise sharply when water flooding commences, and extreme water production as a result of water flooding limits the recovery of oil.

- Normal flood patterns perform better than their inverted equivalents. This is credited to the fact that inverted patterns have fewer injectors to effectively sweep oil, and they have more producers that result in excessive water production.
- In creating the optimal flood pattern, injectors have to be placed in vital zones to enable the effective sweep of oil. Drilling wells beyond the required number results in lower recoveries.

REFERENCES

[1] Dankwa, O. K. (2017), "Lecture Notes on Enhanced Oil Recovery", *Unpublished BSc Lecture Notes*, University of Mines and Technology, Tarkwa, pp. 6 – 9.

[2] Glover, P. (2010), "Formation Evaluation MSc Course Notes", *Unpublished MSc Lecture Notes*¸ University of Leeds, Leeds, pp. 20.

[3] Marek, F. J. and Sullivan, B. R. (2013), "Water flooding: A Tried and True Technique for Secondary Oil Recovery", William M. Cobb & Associates, Inc., pp. 37.

[4] Tarek, A. (2010), "Factors to Consider in Water flooding", In Chap. 14 of *Reservoir Engineering Handbook*, 4th edition, Elsevier Inc., pp. 910.

Citation: *E. M. Amarfio, O. Brobbey, (2019). "Evaluation of Various Water Flooding Patterns in the Kube Field", International Journal of Petroleum and Petrochemical Engineering (IJPPE), 5(2), pp.1-8, DOI: http://dx.doi.org/10.20431/2454-7980.0502001*