Journal of Science and Technology vol. 13
ISSN 1605 – 427X
Engineering and Computer Sciences (E C S No. 1)
www.sustech.edu

June 2012

Modeling of Cyclic Water Injection, East Unity Oil Field – Sudan

Tagwa A. Musa[1], Ahmed A. Ibrahim [2]

College of petroleum Engineering & Technology, Sudan University of Science and Technology (SUST)

Abstract: In this study cyclic water flooding method using numerical model was tested in a middle to a high permeability zones and compared with the actual water injection method used in the field. The study was carried out on a Sudanese oil reservoir which resulted of fluvial and lacustrine deposition. The field is a highly complex anticline with major flanking faults extended to east and west. The reservoir highly heterogeneous is characterized by mid to high porosity and permeability. The actual water injection method used in East Unity is a continuous method (twelve months per year) through a three injection wells. In this study, cyclic water injection was evaluated in Aradeiba formation simulating several cyclic water injection scenarios by "injection/no injection" time ratios such as 2:1, 1:1, and 1:2. Improved sweep, accelerated oil production, and reduced water-cut were the main advantages that could be obtained from cyclic waterflooding. The total oil production was predicted to show an increase of 2% from the targeted reservoirs after 10 years, while the cumulative water injection is expected to decrease by 15 – 18%. However, 28.22% of the oil in the area can be produced during 10 years using the scenario 2:1 which is expected to result in an increase of 2.54% compared with the water injection method used.

Keywords**:** *Water flooding numerical model reseriow, Porosity , Permeability, water - cut .*

مستخلص:

فى هذه الدراسة تم اختبار طريقة حقن الماء الدورى فى المكامن ذات النفاذية المتوسطه والعاليه وقورنت بالطريقة الحالية للحقل وذلك باستخدام التمثيل العددى. تمت الدراسة فى حقل سودانى غير متجانس بدرجة كبيرهو يمتاز بمساميه ونفاذية متوسطه الى عالية.

طريقة الحقن الحالية بالحقل هى الطريقة المستمرة (12 شهر بالسنه) عبر ثلاثة ابار حقن. فى هذه الدراسة تم تقييم طريقة الحقن الدورى بطبقة عرديبة. تم بناء عدد من السيناريوهات "حقن/عدم حقن" بنسب زمنيه 2:1 ، 1:1 ، و 1:2. أدت نتائج الحقن الدورى الى تطور فى الازاحه ، زيادة فى انتاج النفط التراكمى، وتقليل نسبة المياه المنتجه. من هذه الدراسة اتضح ان إستخدام الحقن الدورى يزيد نسبة النفط الكلى المنتج بنسبة 2% عن الانتاج بالطريقة المستمرة بعد 10 سنوات من الانتاج وتنقص كمية المياه الكلية المنتجه بنسبة 15 –18 %. كما انه يمكن انتاج نسبة 28.22 % من الاحتياطى النفطى اذا تم استخدام الحقن الدورى 2:1 والتى تمثل زيادة بنسبة 2.54 % مقارنة بطريقة الانتاج الحالية.

Introduction:

Optimization of oil and gas reservoir development requires integration of quantitative geological and geophysical analysis with appropriate flow models to assess alternative development and completion schemes and their relative economic values. It is critical to make optimal development decisions in order to obtain the maximum profit from the future of oil and gas production [(1)].

Cyclic injection or periodic injection is a method that was conceived to improve water flooding efficiency in heterogeneous reservoir. The main purpose of the cyclic injection method is to create transient pressure pulses between zones with contrasting reservoir properties in order to accelerate oil saturation re-distribution by capillary and gravity forces by alternating dominance of viscous forces. Variation of flow directions through the reservoir is considered as natural part of the cyclic injection method [(23)].The most important factors that affect water injection are rock properties, fluid properties, and the reservoir actual drive mechanism.

Many studies were carried out to improve oil recovery by cyclic water injection. In one study [(4)] a large scale water flooding was applied in the fractured, very low permeability Spraberry Field of West Texas (All sands have permeability of ≤ 1 Mel Darcy (md) and porosity of 8-15 per cent). The results obtained showed that the field performance has improved by at least 50 per cent faster and with lower water percentage. It was claimed that [(3)], oil recovery could be increased by 5- 6 % in Heidrun field which is highly heterogeneous with large permeability contracts after 10 years of cyclic water injection [(3)]. Other studies focused on Joint Inversion of Pressure by cyclic water injection using numerical simulation [(1)]. A full-field model of an extensively investigated reservoir of Western Venezuela where the reservoir has been proposed as a candidate for enhanced oil recovery immiscible Water Alternating Gas (WAG) injection, cyclic water injection proposed as a technique to improve water sweep in stratified and fractured reservoirs[(5)]. The results obtained show that it is possible to yield an additional recovery between 2 and 7% over continuous waterflooding and a significant reduction in water cut. However, permeability trends, reservoir pressure, well distance and water saturation at the startup of the process have high impact on the potential additional recovery [(5)]. Other studies proved that the process of displacement and imbibition is alternative in the cyclic water injection. If the time of imbibition is short than needed time, the balance of imbibition cannot be attained [(6,7)]. The cyclic water injection process was successfully applied in a number of sandstone and carbonate oil fields in Russia, USA and China [(6)].

The data used in this paper was collected from a Sudanese field (Unity oil field – Muglad basin). The sediments of the Muglad Basin consist of a monotonous succession of sand, sandstones, shale, clay, and silts. Each formation is likely to contain varying amount of each facies, and massive sandstone beds are rarely found[(8)]. Reservoirs in Unity oil field are the result of fluvial and lacustrine deposition. Sands formations are characterized by good porosity and permeability. Geological correlation of reservoir zones is complicated by about 5 fold [9]. The area is highly heterogeneous even within each reservoir zone, where the oil viscosity varies.

The main reservoir is: Aradeiba formation which is relatively thick mudstones dominated sequences potential reservoir horizons, notably in the upper part of the formation (Aradeiba A (AA), Aradeiba B (AB), and Aradeiba C (AC) zones). The thickness and field wide lateral extent of these impermeable barriers preclude any connection between the main reservoir zones. These zones are mainly gray shale, siltstone interbedded with sand stone layers [10].

The area has eleven wells subjected to optimization; three injectors and eight producers [11]. Water injection in East Unity oil field started in December 2001 on wells UN32 and UN33. These two wells as well as UN11 were planned to be water injection wells by CNPC in 1998[10].

The objective of this work was to study the effect of cyclic water injection (CWI) in East Unity oil field which characterized by mid to high permeability reservoir and compare the results with continuous water injection.

Data Collection and Model Construction:

The following data was collected and prepared so that it could be used in Eclipse simulator version 2005:

Reservoir Fluids: Oils within East Unity oil field are characterized by medium gravity, low shrinkage and waxy [10]. The oil gravity varies from 28.9 API° to 36.2 API°. It contains little gas and consequently the bubble point pressure and the formation volume factor are low [10].

Reservoir sand properties:

The predictions of reservoir performance often requires a reservoir simulation model in which rock properties such as porosity and permeability can be specified at all block locations[1]. Reservoirs in East Unity oil field are strongly heterogeneous where porosity varies from 0.10 to 0.5. Permeability in the x direction varies from less than 10 md to more than 6000 md. Permeability in y and z directions is taken to be 1.0, 0.01 respectively multiplied by the permeability in the x direction. Net thickness also varies from 0.3 meter to 13 meter in some blocks in Ab zone [9]. Six regions were subjected to study with inactive top and bottom zones (region one and six) where as no active block in region five.

Grid Selection: 3D reservoir model was constructed from 51744 cells [$X(i) \times Y(j) \times Z(k) = 49 \times 44 \times 24$].

Well Data: Additional well information such as perforations, hole size, Production and injection data was needed to build up the model, and were defined separately for each well.

The completion intervals in the model were checked to make sure that they did not result in well connection in void grid blocks, or in no-flow zones.

History Matching:

Monthly oil production was used as constraint in the simulation history runs. Water-cut, cumulative production oil, and cumulative production water match were used as qualitative indicator to determine the matching quality. Water oil ratios (WOR's), gas oil ratios

(GOR's) history matching is usually the best way to confirm the effective zonation and zonal continuity estimates validity [(12)]. In this study after comparing the original oil in place that resulted from the geological/simulation and then matching actual/simulated production data (i. e. well bottom hole pressure, production rate, cumulative production and water cut) the model was theoretically accepted.

Simulation Model for Cyclic Injection:
Numerical simulation was used in order to identify more specifically the optimal cyclic conditions for Aradeiba formation, and evaluate the potential of cyclic water injection in terms of the additional oil and minimum water production. Different injection pulses scenarios were simulated in order to evaluate the cyclic effect and optimize injection parameters. Simulation was run without any changes in the field conditions and this case named as base case (do nothing case). In the base case simulation scenario was ten years, the production of the wells is constrained by liquid production rate (LPR = 500 – 600 M^3/d), and by maximum bottom hole pressure (BHP = 219 bar) in the injection wells. In order to keep the decline in the field pressure moderate, the reservoir volume water injection rate (controlled by the total reservoir volume injection rate of the field) was three times the production void age rate. The cumulative water injection for the selected injection wells and the field in the base case are summarized in Table 1.

Table 1: Cumulative water injection (base case)

Well	UN11	UN32	UN33	Field (Total)
Cumulative water injection in 10 years, M^3	2507923.05	7590176.47	3880823.25	13.978922×10^6
The average water injection rate, M^3/d	730.1	2125.5	1081.9	3937.5

The simulated cyclic injection scenarios were divided into four groups by "injection/no injection" time ratios which can be described as follows:

* Water will be injected in the three wells for two continuous months and then the wells will be closed for one month and reopen again in the next two months. The injection period is eight months per year (240 days / year).

* Injection will be for one month and then no injection in the following month. The total alternative period for injection is six months (180 days / year).

* Water injection done for one month and stopped during the following two months. The total injection period will be four months (120 days / year).

Constant case: in this case the water injection is carried out continuously every day. The total period for injection is 12 months (360 days).

In all simulation runs the total cumulative water injection over ten year’s period for every injected well;

was adjusted so that it should be equal to the cumulative water injection for the base case. Therefore the total sweep efficiency for all the cyclic cases may not need to be calculated since the cumulative volume of water injected per the cumulative volume of water injected at break through is similar to the base case. The water injection rate used in the numerical simulation for injected wells was calculated based on the injection scenario ratios given in Table 2.

Simulation was performed in every case while monitoring the oil rate, cumulative oil production, water cut and pressure. This was mainly done in order to observe the effectiveness of the simulation experiments. Simulation results showed that in case **1:2** the water injection rate for the selected wells was too high and it exceeded the maximum bottom hole pressure; therefore the injection rate was reduced by the simulator as shown in Table 3.

The cumulative water injection in case **1:2** become only 10.445931×10^6 M^3 which was less than the cumulative water injection in the base case and the others cyclic water injection scenarios. This case was ignored since it has different date than the others. Also case "constant" was ignored because the water injection rate for this case was similar to the base case average water injection rate.

Cyclic Water Injection Scenarios and Base Case Comparison:

After withdrawal of the constant case and case 1:2, only three cases were subjected to comparison (the base case, cyclic injection scenario 2:1, and cyclic injection scenario 1:1).

The Simulation results showed that there was no large difference in field pressure for all the cases where the total water injection was similar. Therefore, pressure versus time curve was not included. The key criteria used for comparison were; cumulative oil production, recovery, water cut, and water cut versus recovery curves. Some of these results were exported from Eclipse into Graphic 3 software.

Table 2: Cyclic Water Injection Scenarios.

Injection / No injection, (time ratio)	Water Injection Rate, (m^3/d)		
	UN11	UN32	UN33
2:1	1054.5	3191.3	1631.7
1:1	1405.9	4255.0	2175.6
1:2	2108.9	6382.59	3263.4
Constant Case	703.0	2127.5	1087.8

Table 3: Water injection rate for case 1:2

	Water injection rate, m^3/d		
Injected wells	Average	minimum	maximum
UN11	1355.4	646.2	1545.9
UN32	5313.7	1984.7	5935.8
UN33	2563.1	1005.4	2883.4

Cumulative Oil Production and Recovery:
The most important factor in developing oil field is to increase its production, so the main criteria used in the comparison was the cumulative oil production. In this part; the total time period for simulation run, is all the 14 years including the field history and the forecasting time. The Simulation results showed that the cumulative oil production and recovery factor were high in cyclic injection cases where the recovery factor for cyclic case 2:1 increased by 0.7 which represent an increase of 2.54% more than that of the base case as shown in Table 4 and Figures 1 and 2.

Water Cut: The simulation results showed that the water cut in the base case was more than that in cyclic water injection scenarios See Figure 3.

Water Cut Versus Recovery Curve: Water fraction versus recovery was also subjected to comparison. The simulation results showed that using the cyclic injection scenarios, water cut within the produced oil was less than that in the base case. From Figure 4 it is clear that, the water fraction in cyclic injection scenarios 2:1 and 1:1 is approximately the same.

The results obtained were in good agreement with most of the results reported in the literature. The recovery factor was increased and water cut was decreased in most cases depending on the degree of heterogeneity.

However, permeability represents the main factor that causes the differences. Also, the time factor where cyclic injection may be applied agreed with the finding of other workers since water saturation depends on time [7].

Table 4: Comparison between different scenarios

Scenarios Cases	Cumulative Oil Production		Recovery	
	(10^6 M^3)	The increment compared with the base case (%)	%	The increment compared with the base case (%)
The base case	9.6432	-	27.52	-
Cyclic water injection 2:1	9.8364	2.0	28.22	2.54
Cyclic water injection 1:1	9.7583	1.2	27.92	1.45

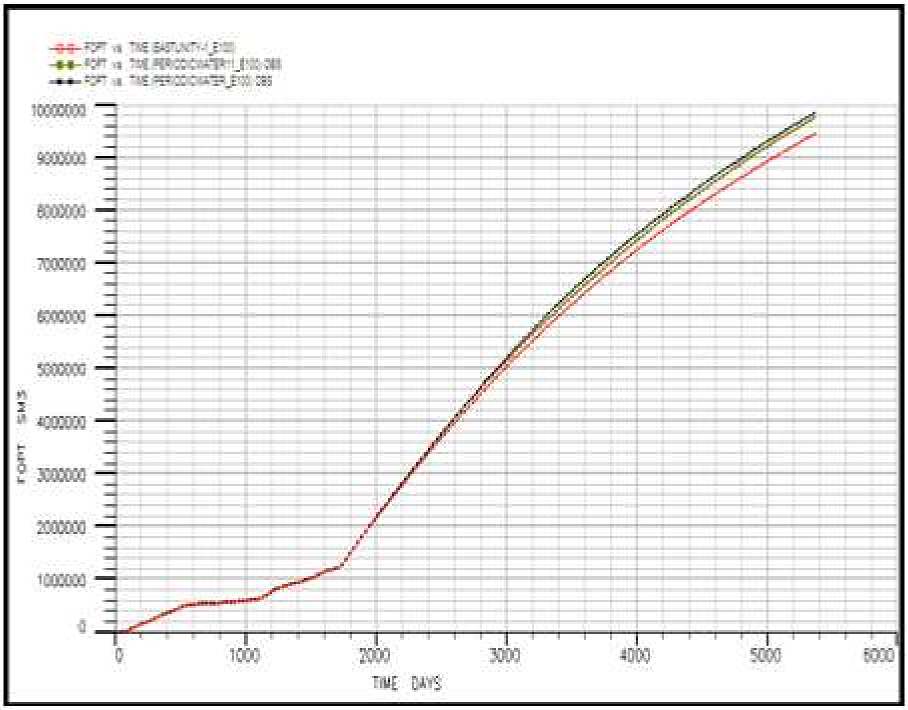

Figure 1: Cumulative oil production for different scenarios

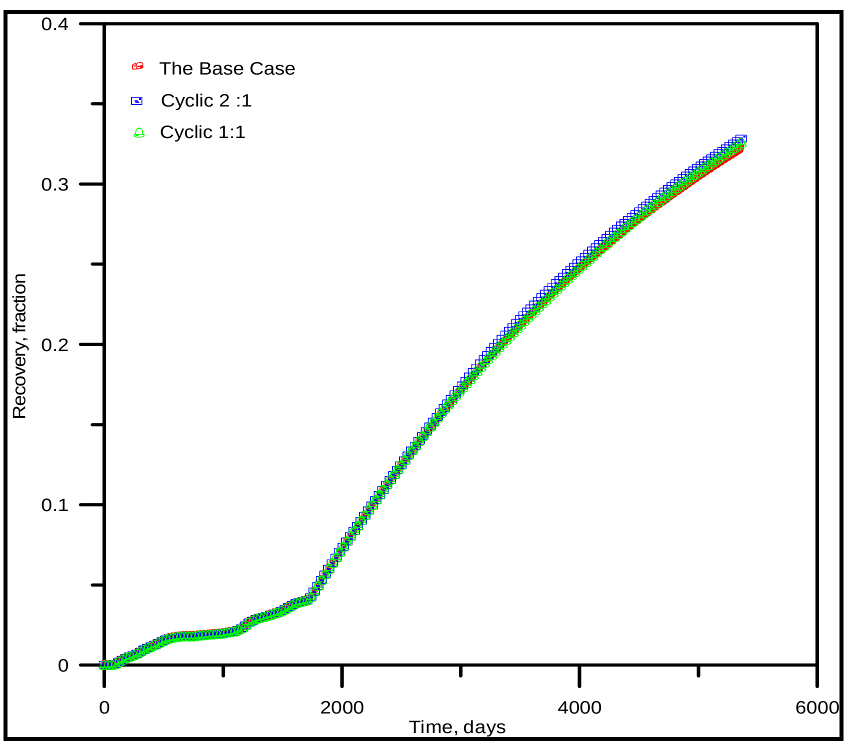

Figure 2: Recovery for different scenarios

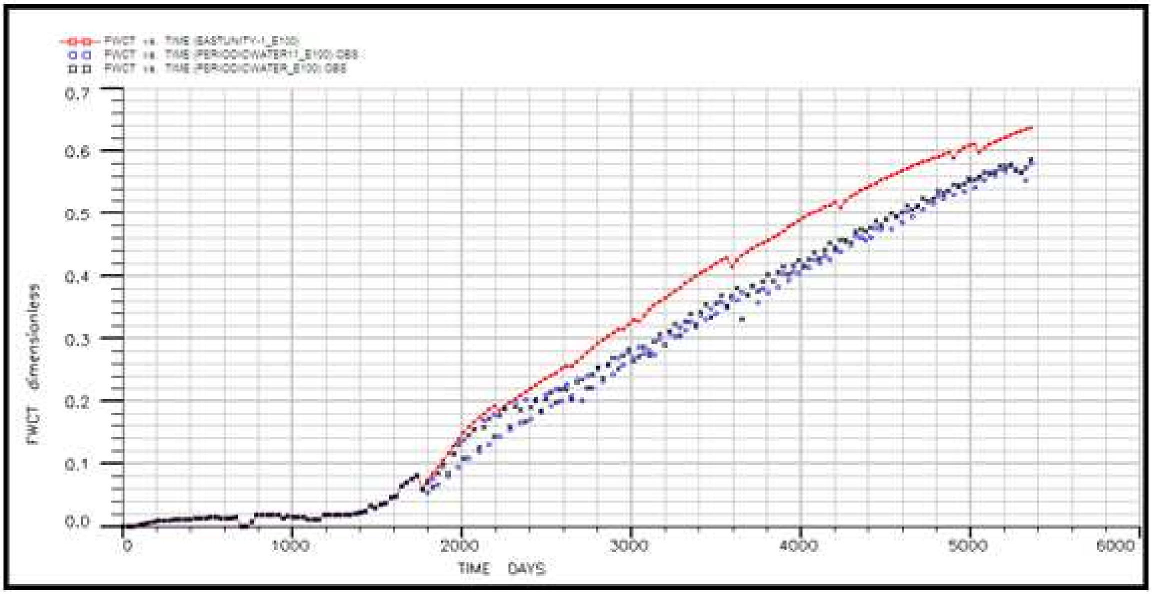

Figure 3: Water cut for different scenarios

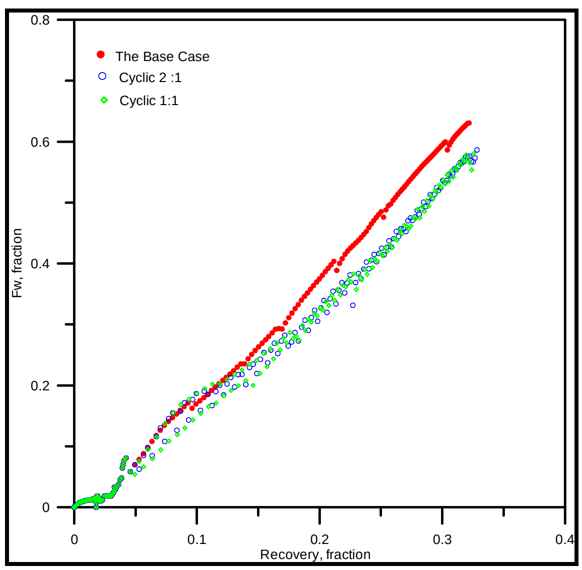

Figure 4: Water cut vs. recovery for different scenarios

Conclusions and Recommendations:

- The cyclic water injection was evaluated for sandstone, highly heterogeneous with high permeability contrasts (Aradeiba formations at East Unity oil field). Several scenarios were simulated to evaluate the potential of cyclic waterflooding. The results obtained showed that oil recovery from layers AA, AB and AC will display an increase of 2% after ten years of production.
- Under cyclic water injection in wells UN11, UN32 and UN33 with 2:1 injection / no injection cycles, the oil production from the eight production wells can be increased by 193.194 × 10 m3 after 10 years accompanied by 10% reduction in water-cut.
- Using cyclic water injection scenario 2:1; it was found that 28.22 % of the oil in place can be produced during ten years, although 27.52% can be recovered using continuous water flooding for the same period.
- The cumulative water that can be produced using cyclic water injection scenarios will be less than that in continuous water injection by 15-18%.
- Using cyclic water injection scenarios 1:1 or 2:1, the injection duration can be reduced to 6 - 8 months per year, and this will reduce the number of employees needed and consequently reduces the cost of production and maintenance. However, this method is not recommended for East Unity field because the water cut is already exceed 92% from most wells and it cannot be reduced by this method of water injection. This method can be applied to any other field having similar properties to East Unity field.

References:

1. Alpak F. O., et al, (2002). "Numerical Sensitivity Studies for the Joint Inversion of Pressure and DC Resistivity Measurments Acquired with In-Situ Permanent Sensors", SPE 77621, Annual Technical Conference and Exhibition, San Antonio, Texas, USA.
2. Gorbunov, A. T., Surguchev, M., Tsinkova, O. E., (1977). Cyclic Waterflooding of Oil Reservoirs, Moscow, VNIOENG publication, 1977.
3. L. Surguchev, et al, (2002). "Cyclic water injection: improved oil recovery at zero cost", Petroleum Geosciences, 8: 89-95.
4. Elkins, et al, (1963). “Cyclic Water Flooding the Spraberry Utilizes "End Effects" to Increase Oil Production Rate”, JPT 545-PA, 15: no. 8, p. 877-884.
5. M.T. Stirpe, et al, (2004). “Cyclic Water Injection Simulations for Evaluations of its Potential in Lagocinco Field”, SPE 89378, SPE/DOE Symposium on Improved Oil Recovery, Tulsa, Oklahoma.
6. 6.. Shchipanov A. A and L.M. Surguchev, (2008). Improved Oil Recovery by Cyclic Injection and Production (Russian). SPE Russian Oil and Gas Technical Conference and Exhibition, Moscow, Russia.
7. Lei Deng, et al, (2010). Mechanism of imbibtion process in cyclic water injection, Journal of Southwest Petroleum University (Science and Technology).
8. Ahmed Abd Elaziz Ibrahim, (2001). A Comprehensive Mathematical Model Optimizing Hole Cleaning-Cutting Transport in the Oil Drilling Engineering, M. ENG. Thesis China

University of Geosciences, Wuhan, China.

9. RIPED, (1998). "Unity field development plan of Sudan-Reservoir Geology", Report, Beijing, China.
10. RIPED, (1998). "Unity field development plan of Sudan-Reservoir Engineering", Report, Beijing, China.
11. Tagwa A M, et al, (2005). "Optimization of Field Development Scheduling, East Unity Oil Field, Sudan", American Journal of Environmental Sciences. 1: 29-33.
12. Reza Tavakoli, Albart C. Reynolds, (2009). History Matching with Parameterization Based on the SVD of a Dimensionless Sensitivity Matrix", SPE Reservoir Simulation Symposium, Texas, USA.