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Choosing the Optimum Water Injection Pattern in Mishrif Formation Nasiriyah Oilfield

***Sarah Taboor Wali*[1], *Hussain Ali Baqer*[2]**

[1]*Department of Petroleum Engineering, University of Baghdad, Iraq, t.wsarah@yahoo.com*

[2]*Department of Petroleum Engineering, University of Almaaqal,hussain.baker@almaaqal.edu.iq*

**Corresponding author: Sarah Taboor Wali, t.wsarah@yahoo.com*

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Abstract— A process of water injection into Mishrif reservoir in Nasiriyah oilfield south of Iraq was performed in this study depending on 3D reservoir simulation model. The main purpose of this research was to earn the maximum oil recovery and pressure maintenance through increasing reservoir energy by injecting water into Mishrif formation representing the main production reservoir in Nasiriyah oilfield. Depending on fourteen vertical oil wells data, 3D numerical reservoir simulation model has been performed to initiate water injection recovery strategy to increase field production for a long period. Basically the reservoir was modeled employing PETREL&ECLIPSE-100 softwares, where the model boundary was defined according to the geostatistical geological model boundary. Five water injection patterns have been used involving (peripheral, direct line drive, staggered line drive, inverted-5 spot and inverted-9 spot pattern). Subsequently, four of the suggested patterns were combined with peripheral injection wells for the pressure optimization support from reservoir flanks. The estimated initial oil in-place was about 7945 MSTB.The study results elucidate that the optimum injection pattern was inverted 9-spot, with the longest oil production rate (20 year) achieving maximum oil recovery factor (11.04%) and increasing reservoir pressure to be (175.5 bar) till the end of the prediction interval.

Keywords— Water Injection, Injection Patterns, Reservoir Simulation, Nasiriyah Oilfield

1. Introduction

As a consequence, to consider oil and gas are the most demanding energy sources in the world, therefore it is a significant need to obtain high productivity from the oil fields economically with the maintaining of the oil reservoir pressure. In primary recoveries including gas expansion or gravity drainage, pressure depletion through which the reservoir produces naturally, there will be large unproductive amount of remaining hydrocarbon [3]. Observing the behavior of dynamic fluid and estimating the relevant parameters of a reservoir is difficult, also to predict the performance of a reservoir has its own large degree of uncertainty attached. Numerical simulation is usually applied to quantify this uncertainty [4].

It is necessary to define the formation properties and to predict the field production ability with the view to establish the economic restriction in the oil exploration [1]. To guide a recovery strategy, reservoir simulation study must be conducted, basically it is consisting of a geological model that describe the properties of porous rock formation and a flow model to fluid flow in porous medium which are important aspects to achieve satisfactory secondary recovery. The accurate estimation of petrophysical properties is the most challenging part of building a geological model and has a great influence on fluid contact identification. Thereby it is essential to use the reservoir simulation to predict reservoir performance under different hydrocarbon recovery scenarios and optimizing the future reservoir development schemes [1]. Modelling of quantitative geological processes is vital in reservoir assessment to understand the subsurface structures spatial distribution, which represent the base of numerical simulation for hydrocarbon exploration and production. Subsurface modelling in three dimensions represents a mean to improve the interpretation of data by visualizing and confronting these data simultaneously with the created model. Geostatistics can be defined as a numerical techniques collection dealing with the spatial attributes characterization, applying foremost random models in a manner similar to the way where the analysis of time series identifies temporal data [5]. Geostatistical modelling preferred to be used in describing the spatial distribution and variation of reservoir properties involving porosity and water saturation [2]. Water injection represent one of the lowest cost and widely used recovery methods of enhancing oil reservoirs, the main reasons to the commonly use of this method is the availability of water, the highly distribution of water through the oil zones and also water characteristics that will efficiently swept the trapped oil [6]. The purpose of this paper is to conduct development plane involved using five water injection patterns (peripheral, direct line drive, staggered line drive, inverted-5 spot and inverted-9 spot pattern) compined with peripheral wells and then choosing the optimum pattern among them to be applied into Nasiriyah oilfield.

2. Study Area

Nasiriyah oilfield is located south of Iraq, about 38 km northwest of Thi Qar city, (Fig-1). The structure direction is Northwest-South east and its corresponds with the general axis structures in the southern region of Iraq. Mishrif formation is the major reservoir in the field with an average thickness 180m, 45 vertical oil well have been drilled in the field. This paper was based on 14 well that all penetrated in Mishrif formation. Fig-2 shows the chosen well locations in this study.

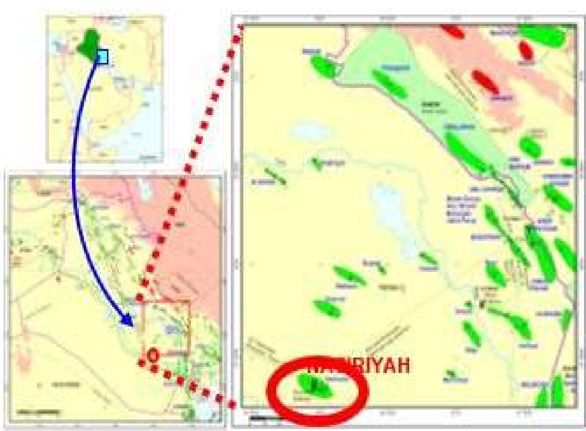

Figure 1: Geographical location of Nasiriyah oil field [7]

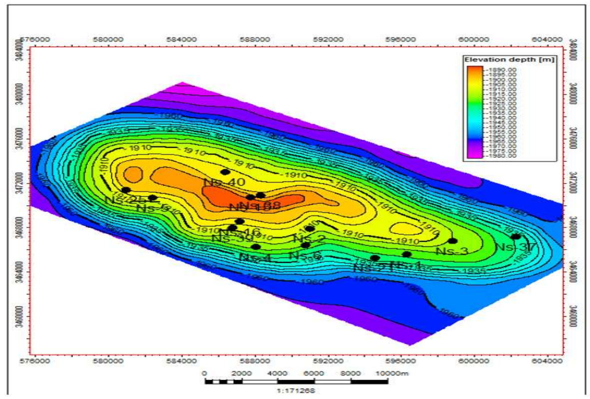

Figure 2: Wells distribution in Nasiriyah oilfield

3. Reservoir Simulation Model

This study was conducted starting with building CPI (Computer Processing Interpretation) utilizing well log data involving density, neutron, sonic, gamma ray, self-potential, caliper and resistivity that were interpreted and environmentally corrected by ***Techlog v.2015*** software and calibrated using special core analysis data. The static model was constructed to represent the entire stratigraphic framework of Mishrif formation and to reflect the distribution of reservoir properties in 3D space under the condition of the currently available data employing ***Petrelv.2016.3*** software using 200mx200m cells dimensions (Fig-3 and Fig-4). The generated grid cells were 184 along the X-axis ,117 at the Y-axis and 34 at the Z-axis. Mishrif formation units (Mishrif Top, MA, Shale bed, MB1, MB2) were divided into several sublayers according to their petrophysical properties. Reservoir properties (porosity, permeability, water saturation and net gross) geostatistical calculation involved; variogram analysis and petrophysical properties calculation utilizing geostatistic method which was Sequential Gaussian Simulation method. The resulted initial oil in place was about 7945 MSTB.

3D black oil reservoir model was run applying ECLIPSE-100, which have been used to carry out all the simulations. The single porosity approach was adopted in the dynamic model conducted in this research. Basically the reservoir was modeled with a regular gridding (200mX200m), where the 3D reservoir property distribution and the vertical layering of the dynamic model was performed in the geostatistical geological model and the model boundary was defined accordingly; grid blocks outside of the model boundary were defined as inactive. No aquifer was specified neither in static nor in the dynamic model.

The resulted Sw distribution in the simulation model was calculated based on the Swi distribution and the scaled capillary pressure values at each grid block. O.W. Cs was located previously in static model applying (oil down to) method.

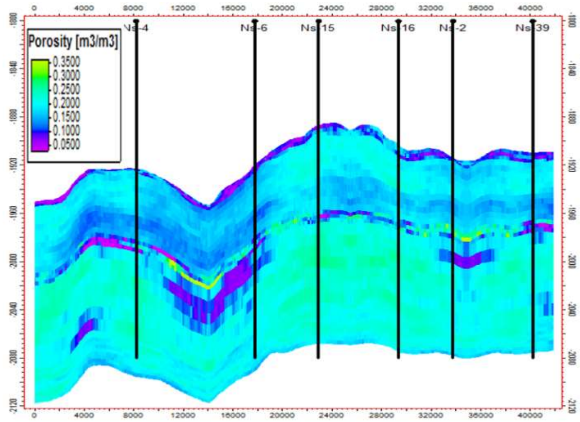

Figure 3: Cross-section in W-E Direction of Porosity Distribution for Mishrif Formation in Nasiriyah oilfield

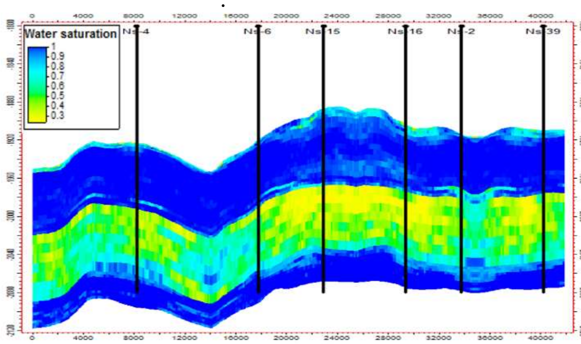

Figure 4: Cross-section in W-E Direction of Water Saturation Distribution for Mishrif Formation in Nasiriyah Oilfield

3.1 *Water Injection Patterns Simulation*

The study efforts were to run three phase reservoir (single porosity) simulation model using Petrel & Eclipse software for designing and choosing the optimum injection pattern under different operating scenarios. Five water injection patterns have been chosen to be applied in the study area which are, peripheral, direct line drive, staggered line drive, inverted-5 spot and inverted-9 spot. These patterns are the most commonly used as water injection patterns in Iraqi oil fields. Subsequently, four of the suggested patterns were combined with peripheral injection wells for the pressure optimization support from reservoir flanks.

The recovery strategy included drilling new vertical wells for the purpose of increasing oil recovery and maintaining pressure above bubble point pressure for the suggested injection patterns. The original production wells distribution that are drilled in the study area allows to use different injection patterns thus, to change the location of the new drilled suggested wells. The well spacing of the original production wells was almost 1500m, while the distance between the production wells (original and suggested) and the injection wells, depends on the suggested patterns which ranged from 500 to 1000m. There were some wells with well spacing to other wells smaller than 500m (about 450m) due to dense well patterns. The simulation of water injection scenarios starts on January 2019 and the used injection rate for the field was 180,000 STB/D. The recovery strategy was performed for twenty years starting from January 2019 till the end of 2038.

Three production plateaus were suggested as the main constrain for recovery potential assessment for each pattern proposed for the field as follows:

Case (1,1A) Target oil rate @ plateau 25437.96 m3/d 160,000 STB/D

Case (2, 2B) Target oil rate @ plateau 23848.08 m3/d 150,000 STB/D

Case (3, 3C) Target oil rate @ plateau 22258.22 m3/d 140,000 STB/D

Where the cases (1A,1B and 1C) are combined with peripheral wells

The operational conditions for the producer's wells were controlled by the bottom hole pressure (BHP ≥ Pb)

4. Results and discussion

4.1 *Recovery Factor*

The primary energy of Mishrif reservoir produces only 1.96% of the initial oil in-place based on the field production potential that was identified in this research. All patterns scenarios results (except 9-spot pattern) combined with peripheral wells were nearly the same as without peripheral wells, where there was very slight rise in recovery factor in scenarios that were incorporated with peripheral wells. The inverted 9-spot pattern demonstrated the maximum recovery factor (11.04%), followed by peripheral pattern (10.65) and inverted-5spot pattern (10.19). The minimal performing pattern was the direct line drive with a recovery factor (9.79). Figure (5) illustrate the results of recovery factor for the suggested patterns. It should be noted that peripheral pattern provides the same means for sweeping oil towards producers and prevent entrapment. Theoretically, extra injector wells, as in the direct line and staggered line patterns should maximize oil recovery factor, but in this study it leads to earlier water breakthrough and high water cut. Thus, oil production resulting from these pattern was limited due to the fact that some injectors were located in non-vital regions.

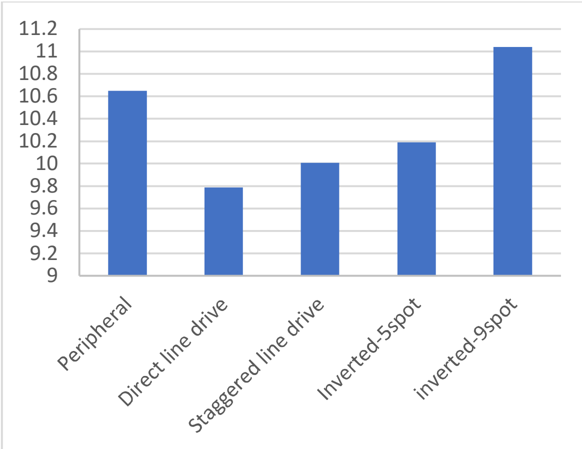

Figure 5: Recovery Factor for the Suggested Patterns

4.2 *Field Water Cut (W.C.)*

Generally, field water cut for all the proposed scenarios ranged between 32-48 at the end of prediction interval. In peripheral pattern, field water cut was mainly around 32% (case-3) after which the inverted 9-spot pattern where the W.C. value was 38.9% case-3C hence the W.C outcomes of these two patterns were the minimum among all the patterns scenarios due to the fact they were contained the least number of injection wells. Subsequently, the highest field W.C. value resulted from direct line pattern (47.9) case-3C, followed by staggered line drive pattern W.C. 46.11%, case-1. The inverted 5-spot pattern with field W.C. 46.4% case-1, this is because of the injection wells placements at certain position regarding to producers which permit the water front to move faster in respect to producers and thus earlier water breakthrough and increased water production.

4.3 *Reservoir Pressure*

Over all the reservoir pressure was maintained around 157-167 bar at the end of 2038. Peripheral and inverted 9-spot patterns involved the maximum reservoir pressure value (167 bar, case-3 and 164 bar, case-3C respectively) providing the suitable support for the field pressure. For direct line drive, Staggered line drive, and the inverted 5-spot patterns, the resulted reservoir pressure was 159.21, 157.61,158.64 and 157.87 bar respectively (all in case-3C) at the end of prediction interval.

4.4 *Field Production Rate*

Based on the water injection scenarios results, case-3C was the optimum one for the proposed patterns with long-term plateaus and the highest recovery factor. For peripheral pattern the oil production rate plateau was 11.92 year at the end of 2038 (case-3). The longest oil production rate was obtained from inverted 9-spot pattern which last till the end of prediction interval (140 MSTB/D for 20 year), while the minimum production period outcomes from the staggered line drive pattern (140 MSTB/D for 8.58 year) after which direct line drive (140 MSTB/D for 9 years) and the inverted-5spot (140 MSTB/D for 11.33 years). The analysis result for the optimum cases of each suggested water injection pattern are summarized in table (1).

Table 1: Results of Optimum Cases for each Water Injection Pattern.

Injection Pattern	peripheral	Direct line	Staggered line	Inverted-5	Inverted-9
Case No.	Case-3C				
No. of production wells	82	87	96	108	86
No. of injection wells	17	90	83	97	35
Prod. Plateau MSTB/D	140				
Plateau length (year)	11.92	9	8.58	11.33	20
Cum. oil MSTB	1032	942.8	968.7	978.2	1065
R.F %	10.65	9.79	10.01	10.19	11.04
Res. Pressure.(bar)	167.67	159.21	157.61	157.87	175.5
W.C. %	32.5	47.9	44.3	46.4	38.9

5. Conclusion

The study was performed to increase oil recovery factor and to maintain reservoir pressure for Mishrif formation in Nasiriyah oilfield located south of Iraq, the study concluded that:

1. The analysis result for the optimum cases of each suggested water injection pattern identified that the inverted-9 spot pattern with peripheral wells (case-3C) represent the optimum injection case for Mishrif formation in Nasiriyah field with an oil production rate (140 MSTB/D) continue till the end of prediction interval (20 year) and the reservoir pressure was maintained higher than bubble point pressure followed by peripheral pattern with 10.65% recovery factor

2. The water cuts of the field for the suggested patterns increased sharply when starting to apply water injection process. As a result, the recovery factor was limited for some cases because of the high water production rate.

3. The effect of adding peripheral wells to the proposed pattern was very slight due to the placement of these injection wells in non-vital positions.

4. It is considered that enough water was injected to Mishrif reservoir (180 MSTB) where more water could be injected to replace 100% of its production voidage It is expected to increase oil recovery in case if enough water source (<180Mstb) was secured for Nasiriyah Mishrif reservoir.

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Abbreviations Nomenclature

OOIP	Initial Oil inplace
O.W.Cs	Oil Water Contacts
W.C.	Water Cut
BHP	Bottom Hole Pressure
Pb	Bubble Point Pressure
STB	Stock Tank Barrel
Cum.	cumulative
Prod.	Production
Res.	Reservoir
No.	Number

أختيار نمط الحقن المائي الأمثل لتكوين المشرف في حقل الناصرية النفطي جنوب العراق

سارة طابور والي[1]، حسين علي باقر[2]،

[1] *قسم هندسة النفط ، جامعة بغدادة، العراق، t.wsarah@yahoo.com*

[2] *قسم هندسة النفط، جامعة المعقل، العراق، hussain.baker@almaaqal.edu.iq*

[*] *الباحث الممثل: سارة طابور والي، t.wsarah@yahoo.com*

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الخلاصة – تم اجراء عملية الحقن المائي لتكوين المشرف في حقل الناصرية الواقع جنوب العراق. ان الهدف الرئيسي من هذه الدراسه هو الحصول على اعلى معامل استخلاص نفطي والمحافظه على ضغط المكمن بالأعتماد على موديل محاكاة مكمني ثلاثي الأبعاد .أن الهدف من هذا البحث هو الحصول على اعلى أستخلاص نفطي وللمحافظه على الضغط عبر زيادة طاقة المكمن بتطبيق الحقن المائي لتكوين المشرف والذي يعتبر المكمن المنتج الرئيسي في حقل الناصريه. بالأعتماد على 14 بئر نفطي عمودي تم انشاء موديل محاكاة مكمني ثلاثي الابعاد من اجل استراتيجية الحقن المائي لغرض زيادة انتاج المكمن لفترة طويله .مبدئيا تم نمذجة الموديل بأستخدام 200 m x200 grids بالاعتماد على برنامج PETREL&ECLIPSE-100 حيث ان حدود الموديل تم تعريفها استنادا الى الموديل الجيولوجي الجيوستاتيكي تم استخدام خمس انماط للحقن المائي والتي تضمنت (peripheral, direct line drive, staggered line drive, inverted-5spot and inverted-9 spot pattern) أربعة من انماط الحقن المقترحه تم اقرانها مع آبار محيطيه وذلك لدعم الضغط في جوانب المكمن. أن الأحتياطي النفطي المحسوب في هذه الدراسه (7945 MSTB) وقد بينت الدراسة بأن افضل انماط الحقن هو النمط inverted-9 spot بأطول فترة انتاج (20 سنة)واعلى معامل استخلاص نفطي (11.04%) ولزيادة ضغط المكمن حتى (175.5bar) والمحافظه عليه حتى نهاية فترة التنبؤ .

الكلمات الرئيسية – حقن مائي, انماط الحقن المائي, المحاكاة المكمنية, حقل الناصريه النفطي