Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Reservoir and petroleum engineering

NEW WATERFLOODING EFFICIENCY EVALUATION METHOD (ON THE EXAMPLE OF 9th HORIZON OF THE GUNESHLI FIELD)

M. A. Jamalbayov*, Kh.M. Ibrahimov
«OilGasScientificResearchProject» Institute, SOCAR, Baku, Azerbaijan

ABSTRACT
The purpose of the research in the article is to develop a method for evaluating the efficiency of the water injection process. For this purpose, a number of computer studies are carried out. In view of this, a computer simulation of water injection process is applied. Using oil parameters from IX horizon of Guneshli field as PVT-properties of oil in reservoir conditions, the process of oil displacement by water injection in various technological modes is studied, the correlation between the injection rate and the amount of incremental oil production is determined. For this purpose the process of oil displacement in a hypothetical field is modeled on the basis of the idea of «enlarged well» at different injection rates, such as 10, 20, 30, 40, 50, 60, 70. and 75 m^3/day. Water injection is carried out in the area of external reservoir boundary. In addition, the reservoir development process in the depletion regime is predicted for comparison. In both cases, the formation radius is considered as a circular layer equivalent to the real layer. Analysis of the obtained results determines the criteria for minimizing economic risks during water injection process. It is shown that at low rates of water injection, the numerical value of this parameter decreases with an increase of water volume injected per day. However, after a certain value of the injection rate, the efficiency factor increases with an increase of the water injected volume per day.

KEYWORDS:
Displacement;
Waterflooding;
Waterflooding efficiency;
Enlarged well.

***e-mail:** mehemmed.camalbeyov@socar.az
https://doi.org/10.53404/Sci.Petro.20230100039

It is known that if reservoir pressure is not maintained during the oil field, the initial reservoir energy is depleted in a short time, and as a result, well flow rates and total production fall sharply. In this case, however, most of the field's reserves remain in the undeveloped reservoir. Secondary production methods are used to increase current oil production, the most common of which is displacement of oil by water injection. The water flooding process is also widely used in oil fields in Azerbaijan. However, the efficiency of waterflood process depends on the proper selection of the injection mode for the reservoir in question, as well as the flow rate and the total volume of water injected. This is confirmed by a large number of studies dedicated to the water injection process [2-5]. Injected water not only builds-up reservoir pressure, but also provides oil displacement to the wells. However, water injection is an expensive process and, therefore, carries economic risks due to the increased cost of oil. For this reason, it is important to evaluate the efficiency of waterflooding and improve it. The main objective of this work is to study a methodology for evaluating the efficiency of waterflood processes. For this purpose, a computer model of the annular reservoir development process with a central well has been developed on the basis of computational algorithms proposed in [1] and according to the Herst-van Everdingen's theory of enlarged well [6]. Waterflooding is carried out along the external reservoir boundary. By applying this simulator, studies were conducted to find the factor determining the efficiency of water-oil displacement, and the relationship between the injected water rate and the amount of produced oil was investigated. For this purpose, PVT analysis of oil from horizon IX of Guneshli field (well No. 238) was carried out and the relations of gas factor, oil volume factor, density and the coefficient of dynamic viscosity of oil on pressure were determined. These relations are shown in the following graphs (fig. 1).

This information was approximated to include oil properties in the PVT model, and the following expressions were obtained:

Oil dynamic viscosity:

$0 < p < 150$ atm:

$$\mu = -0.000000089p^3 + 0.00013p^2 - 0.042p + 5.8,$$

$150 \le p < 300$ atm:

$$\mu = -0.000000036p^3 + 0.000053p^2 - 0.023p + 4.4;$$

Solution gas-oil ratio:

$$f = 0.3892p + 0.9231$$

Formation volume factor:

$$B = 0.000000001p^3 - 0.0000008p^2 + 0.0013p + 1.0274$$

Oil density:

$$\rho = -0.000002p^3 + 0.0019p^2 - 0.9722p + 839.07$$

Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Reservoir and petroleum engineering

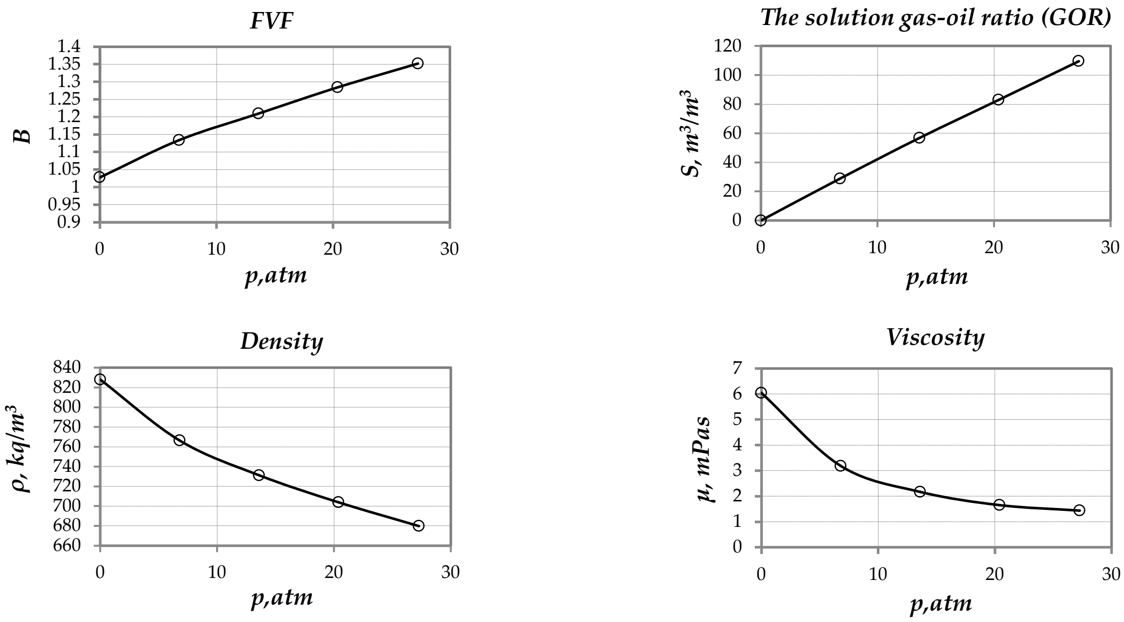

Fig. 1. PVT data of oil from IX horizon of Guneshli field (well № 238)

These expressions were used in the calculations. In this case, the processing was carried out at a constant value of depression equal to 8 atm and based on the following initial data:

Initial formation pressure $p_0 = 125$ atm;
Initial oil-water contact radius $r_{k0} = 500$ m;
Radius of the water basin $R_k = 1000$ m;
Well radius $r_w = 0.1$ m;
Formation permeability $k = 0.102 \cdot 10^{-12}$ m^2;
Porosity $m = 0.2$;
Formation thickness $h = 20.0$ m;

It should be noted that the purpose of computer studies is to investigate the displacement process in different injection modes and to determine parameters characterizing this process. Therefore, the development process was simulated at different injected water flow rates: 10, 20, 30, 40, 50, 60, 70 and 75 m^3/day. In addition, the depletion mode is predicted for comparison. The results of computer calculations performed in these variants are shown in figures 2-7 (in the figures, «0» curves refer to the depletion mode).

Figure 2 shows formation - pressure dynamics in the considered variants over time. As can be seen from the curves, injecting water into the formation ensures that the current pressure is maintained at higher values, which is natural. Note that in all cases, the calculation process stops when the formation pressure drops below 25 atm or the water-oil contact reaches the well. In this regard, it is noteworthy that the development time increases as the waterflood rate increases up to a certain value (in this case it is 40 m^3/day), and then the development time decreases as the water injection rate increases. If we look at the time history plots of oil recovery factor in the considered variants (fig. 5), we see that starting from the same rate of water injection (i.e., 30 m^3/day), there is no significant difference in the value of ultimate oil recovery factor. However, it takes less time to reach this value of ultimate oil recovery factor. This is due to the fact that the well flow rate increases sharply at higher injection rates and remains constant (see fig. 3).

Another noteworthy fact is that, as shown in Figure 4, the amount of additional oil produced per 1 m^3 of injected water is higher at lower injection rates. At the same time, the situation seems to change inversely as the injection rate increases - the curves for higher injection rates run higher.

The analysis of the curves in figures 4 and 5 shows how important it is to study the process in advance to achieve waterflood efficiency and predict economic as well as technological risks. To confirm this, the injected water flow rate corresponding to 25 years of development, the amount of additional oil produced per cubic meter of injected water and the current oil recovery factor prices were noted. This information is presented in table. The last column of the table shows the value of the parameter A_S - the product of the amount of additional oil produced per cubic meter of water by the current oil recovery factor.

To visualize the data in the table, their injection rate curves are shown in figure 7 and figure 6. Figure 7 shows the dependence of EOR values on injection rate,

Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Reservoir and petroleum engineering

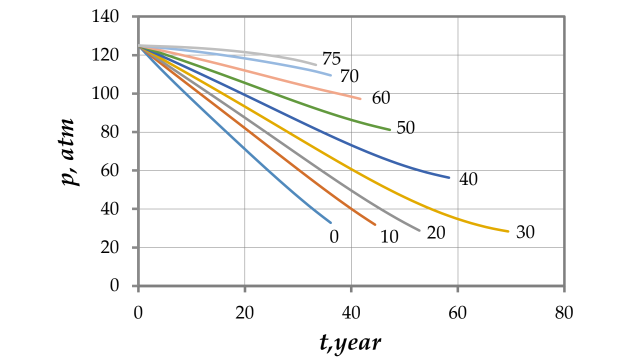

Fig. 2. Formation-pressure dynamics at different water injection rates (10-75 m³/day). 0 - depletion mode

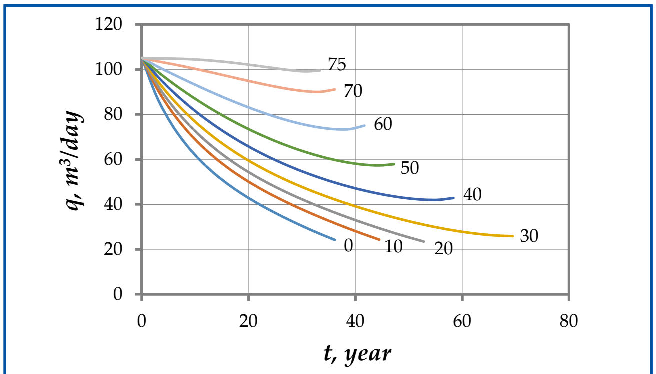

Fig. 3. Production performance at different water injection rates (10-75 m³/day).0- depletion mode

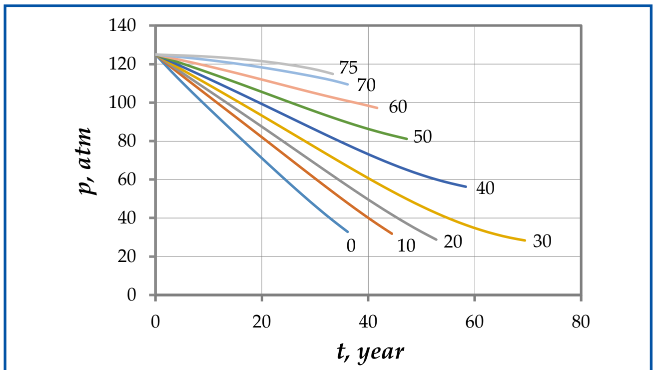

Fig. 4. Additional oil amount produced per 1 m³ of water versus the oil recovery factor (labels similar to the above chart)

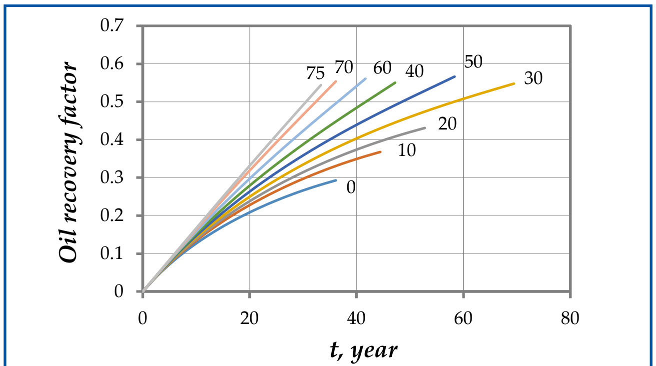

Fig. 5. Current oil recovery factor performance at different water injection rates (10-75 m³/day). 0 - depletion mode

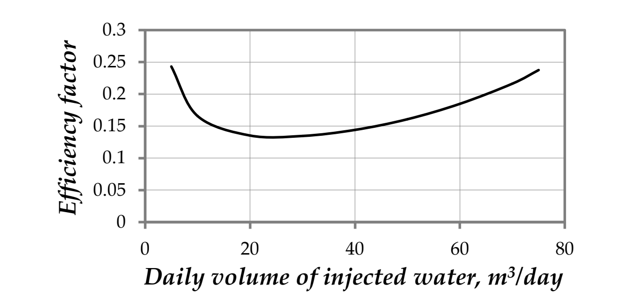

Fig. 6. Efficiency factor versus water injected volumes

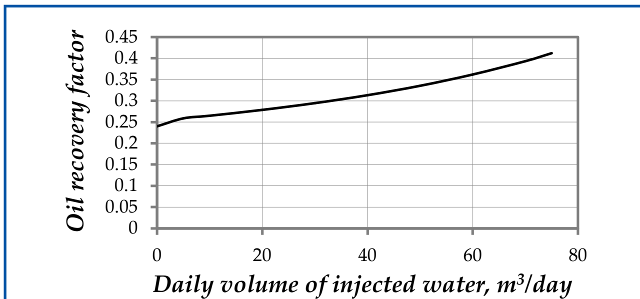

Fig. 7. Current oil recovery factor versus water injected volumes

and Figure 6 shows the curve of dependence of A_S on injection rate. The above analysis is confirmed by this curve. It turns out that dependence of the parameter A_S on injection rate is ambiguous. Thus, water injection rate decreases until a certain value, and increases after a certain value. This fact has an important practical value. We can thus say that there is a certain minimum injection rate, and if we do not take into account all the other factors, the waterflood must be carried out at a higher rate than this value. In this case, the minimum parameter corresponds to water injection rate of 35 m³/day (see table). If we look at the physical nature of the parameter, it is easy to see that this parameter indicates the effectiveness of waterflood process. Thus, its maximum is ensured not only by the maximum amount of additional oil production per cubic meter of water, but also by the maximum oil recovery factor. Therefore, the parameter may be called the «Efficiency Factor» of waterflooding.

The result is of great practical importance. Thus, when designing the injection process, it is necessary to determine the optimal technological mode taking into account the minimum parameters for the field under consideration.

Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Reservoir and petroleum engineering

Table

Values of reservoir parameters at different water injection rates (q_w) in the 25th year of development

q_w, m³/day	Volume of additional oil production per 1 m³ of injected water, m³/m³	Current oil recovery factor	A_e
0	-	0.24	-
5	0.93	0.26	0.24
10	0.62	0.26	0.16
20	0.48	0.28	0.13
30	0.46	0.29	0.13
40	0.46	0.31	0.14
50	0.48	0.33	0.16
60	0.51	0.36	0.18
70	0.55	0.39	0.22
75	0.58	0.41	0.24

References

1. Aliev, F. A., Jamalbayov, M. A., Hasanov, I. R., et al. (2018). Mathematical modeling of the nonlinear filtration process of volatile oils to a well in a compacting formation. In: *Proceedings of the 6th International Conference on Control and Optimization with Industrial Applications.*

2. Wu, X., Wu, H., Bu, Z., et al. (2017). An innovative EOR method for waterflooding heterogeneous oil-field-graded diversion-flooding technology and verification by field comparison tests. SPE-187845-MS. In: *SPE Russian Petroleum Technology Conference. Society of Petroleum Engineers.*

3. de Bento, H., Moreno, R. B. (2016). Evaluation of heavy oil recovery factor by water flooding and polymer flooding at different temperatures. SPE-181193-MS. In: *SPE Latin America and Caribbean Heavy and Extra Heavy Oil Conference. Society of Petroleum Engineers.*

4. Wu, X., Zhang, J., Liang, W., et al. (2017). Technical and economic evaluation of EOR technology in low-oil-price period a new polymerflooding case study from China. SPE-185375-MS. In: *SPE Oil and Gas India Conference and Exhibition. Society of Petroleum Engineers.*

5. Udie, C., Faithpraise, F., Anuka, A. (2021). Enhanced oil recovery improvement using augmented water-flooding to induce fluids flow orientation in a reservoir. SPE-207108-MS. In: *SPE Nigeria Annual International Conference and Exhibition. Society of Petroleum Engineers.*

6. Onuka, A. U., Okoro, F. (2019). Prediction of oil reservoir performance and original-oil-in-place applying schilthuis and hurst-van everdingen modified water influx models. SPE-198714-MS. In: *SPE Nigeria Annual International Conference and Exhibition. Society of Petroleum Engineers.*

7. Aliev, F. A., Dzhamalbekov, M. A., Veliev, N. A., et al. (2019). Computer simulation of crude oil extraction using a sucker rod pumping unit in the oil well–resevoir system. *International Applied Mechanics*, 55(3), 332-341.

8. Jamalbayov, M. A., Veliyev, N. A. (2017). The technique of early determination of reservoir drive of gas condensate and velotail oil deposits on the basis of new diagnosis indicators. *TWMS Journal Pure and Applied Mathematics*, 8(2), 236-250.

9. Guliyev, A. M., Jamalbayov, M. A. (2017). The prediction of the development indicators of creeping reservoirs of light oils. *SOCAR Proceedings*, 3, 51-57.

10. Jamalbayov, M. A., Valiyev, N. A., Mahamat Zene, M. T. (2021). Imitation modelling of pump-well-reservoir systems equipped with submersible rodless pumps. *Automation, Telemechanization and Communication in Oil Industry*, 2(571), 49-54.

11. Aliev, F. A., Jamalbayov, M. A., Nasibov, S. M. (2010). Mathematical modeling of the well-bed system under the gaslift operation. *TWMS Journal of Pure and Applied Mathematics*, 1(1), 5-14.

Scientific Petroleum
journal home page: http://scientificpetroleum.com/

Reservoir and petroleum engineering

Новый метод оценки эффективности в процессе вытеснения нефти водой (на примере IX горизонта месторождения Гюнешли)

М. А. Джамалбеков, Х. М. Ибрагимов
НИПИ «Нефтегаз», SOCAR, Баку, Азербайджан

Реферат

Целью проведенного в статье исследования является разработка методики оценки эффективности процесса заводнения пласта при вытеснении нефти водой. С этой целью проводится ряд компьютерных исследований. Для этого используется компьютерное моделирование процесса заводнения нефтяного пласта. В пластовых условиях с использованием параметров нефти IX горизонта месторождения Гюнешли, таких как PVT нефти, процесс вытеснения нефти водой исследуется в различных технологических режимах, изучается взаимосвязь между темпами закачки и количеством добываемой нефти. Для этого процесс вытеснения нефти в скважину водой на гипотетическом месторождении моделируется на основе идеи «укрупненной скважины» при различных расходах закачиваемой воды - 10, 20, 30, 40, 50, 60, 70 и 75 м^3/сут. Закачка осуществляется в контуре питания залежи. Кроме того, для сравнения также прогнозируется и процесс разработки пласта в режиме истощения. В обоих случаях радиус пласта представляется как круговой пласт, эквивалентный реальному пласта. На основе анализа полученных результатов устанавливается критерий минимизации экономических рисков в процессе вытеснения нефти водой. Показано, что при малых значениях темпа заводнения цифровая оценка этого параметра снижается с увеличением объема воды, закачиваемой в пласт каждые сутки. Но после определенного значения темпа закачки наблюдается повышение коэффициента эффективности с увеличением объема закачиваемой воды в сутки.

Ключевые слова: вытеснение; заводнение; эффективность вытеснения водой; укрупненная скважина.

Neftin su ilə sıxışdırılma prosesində səmərəliliyinin qiymətləndirilməsi üçün yeni üsul (Günəşli yatağının IX horizontu timsalında)

M. A. Camalbəyov, X. M. İbrahimov
«Neftqazelmitədiqiatlayihə» İnstitutu SOCAR, Bakı, Azərbaycan

Xülasə

Məqalədə aparılan tədqiqatın məqsədi neftin su ilə sıxışdırılması zamanı laya suvurma prosesinin səmərəliliyinin qiymətləndirilməsi üçün metodikanın işlənməsidir. Bu məqsədlə bir sıra kompüter tədiqatları aparılır. Bunun üçün neft layında suvurma prosesinin kompüter simulyasiyasından istifadə edilir. Lay şəraitində neftin PVT xüsusiyyətləri kimi Günəşli yatağı IX horizontu neftinin parametrlərindən istifadə etməklə neftin su ilə sıxışdırılması prosesi müx-təlif texnoloji rejimlərdə tədqiq edilir, suvurma tempi ilə hasil edilən əlavə neftin miqdarı ara-sında əlaqə öyrənilir. Bunun üçün, hipotetik yataqda neftin su ilə quyuya sıxışdırılması prosesi vurulan suyun 10, 20, 30, 40, 50, 60, 70 və 75 m^3/sut kimi müxtəlif sərflərində «iriləşdirilmiş quyu» ideyası əsasında modelləşdirilir. Suvurma yatağın qidalanma konturunda həyata keçirilir. Bundan başqa, müqayisə üçün layın tükənmə rejimində işlənməsi prosesi də proqnozlaşdırılır. Hər iki halda lay radiusu real laya ekvivalent olan dairəvi lay kimi təsəvvür edilir. Alınan nəticələrin təhlili ilə neftin su ilə sıxışdırılma prosesində iqtisadi risklərin minimallaşdırılması üçün meyar təyin edilir. Göstərilir ki, suvurma tempinin kiçik qiymətlərində laya hər sutkada vurulan suyun həcminin artırılması ilə bu parametrin ədədi qiyməti aşağı düşür. Lakin suvurma tempinin müəyyən qiymətindən sonra sutkada vurulan su həcminin artırılması ilə səmərəlilik amilinin yüksəlməsi müşahidə olunur.

Açar sözlər: sıxışdırma; sulaşma; su ilə sıxışdırmanın səmərəliliyi; iriləşdirilmiş quyu.