The Quantitative Characterization and Evaluation of Water Flooding Efficiency of D Oilfield

Yugui Liu
No.6 Oil Production Factory,Daqing Oilfield Limited Company,Daqing,163318, China
Email: 1525841456@qq.com

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Abstract: Eastern D pure oil zone has entered the phase of extra high water cut. In order to reduce the decline rate, control rising speed of water cut, study on the efficiency of water injection and reasonable injection and production rate for target block, in this way determine limit of controlling water injection and increasing efficiency, and increase the efficiency of water injection. This paper makes a technical evaluation of the water injection efficiency of the target block from the storage ratio of injected water, water consumption ratio, and water drive index. The relationship curve of storage ratio of injected water versus degree of reserve recovery in the east of D pure oil zone compares with theoretical diagram, and the work of controlling water injection such as water plugging is suggested to strengthen. The relationship curve of water consumption ratio versus degree of reserve recovery in the target zone compares with theoretical diagram, the water injection utilization ratio of the zone in recent years is poor, which belong to three types of level. In order to increase the efficiency of water injection, adjustment measures are urgent needed. The real relationship curve of water drive index versus water cut in the target zone compares with theoretical diagram, it is confirmed that the development effect is better in early stage of development, exist a underground deficit phenomenon in middle stage of development and water drive index could not be used to evaluate the development effect of water flooding in later stage of development.

1 INTRODUCTION

The evaluation of oilfield efficiency of water injection is often through compared various indexes (such as reserve control degree, reserve employ degree, production decline rate, water content escalating rate, and recovery ratio)with the standards of oil and gas profession index. According to contrast results, oilfield water drive efficiency is evaluated. At the same time, the evaluation of oilfield efficiency of water injection is also obtained through comparing various indexes with the standards of same oilfield development index. According to contrast results, better or worse of oilfield water flooding efficiency is concluded. The contrast method is used in the process of single index evaluation (the line in real data is compared with the line in theory). Aiming at the situation of curve deviation, remedial measures are adopted. This has guiding significance (Lu, 2015)

Sun Jiwei, Chen Bo (Sun et al., 1998;Chen et al., 2012) et al developed the relational expression between degree of reserve recovery and water consumption ratio (according to the relationship between degree of reserve recovery and water consumption index). Fu Ming, Liao Maolin (Fu et al., 2017) et al already adopted water drive reservoir injection-production empirical formula in the process of oilfield treating rightful injection-production ratio. In this way, injection-production empirical formula was combined with storage ratio of injected water, water drive index in oilfield. The line in theory was compared with the production curve in practice, and the effect of water flooding in target block was evaluated. Wang Zuoqian, Huang Shunv (Wang, 2011) et al applied the relational expression between water drive index in theory and water content ratio, the fitness and effect of water flooding were evaluated. Yuan Dong, Ge Lizhen (Yuan et al., 2008) et al used the material balance method to solve the water influx in the target block

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and obtain the water influx different stages of the target block. According to the generalized storage ratio of injected water and the generalized water drive index in the way of oil flooding in oilfield, a new method for water flooding oilfield evaluation was created. In special oilfield, the water flooding effect of oilfield containing edge water was evaluated. Jiang Yuanzheng, Jin Shuanlian (Jiang et al., 2009) et al conducted research and analysis on two formation indexes (such as formation storage ratio of injected water and water drive index), the effect of water injection development in target block was evaluated. Sun Wei, Ma Jing, Wang Mingfang, Fang Yuliang (Sun, 2017;Ma et al., 2016;Pang and Wang, 2005;Wang et al., 2004) et al established ideal state chart of change of water content in the water flooding mode. The theoretical was compared with the actual change curve.

In order to tap the remaining potential effectively, increase the ultimate recovery, we must speed up the pace of researching of water flooding fine tapping potential technology in extra high water cut period. This article makes a technical evaluation to the water injection efficiency of the entire area of the target block from the three aspects of water retention rate, water consumption rate and water flooding index.

2 BLOCK OVERVIEW

The oil-bearing area of the D oil field is 7.5 km^2, and the geological reserves are 2418.8×10^4 tons. The variation range of reservoir lithology and physical properties are larger in the demonstration area, the heterogeneity is stronger. There are three oil layers in the whole area, subdivided into 72 deposition units. The target block has fully entered the higher water cut development stage, there are many well pattern in the layer system and the objects to be mined are complex and the reservoir heterogeneity is serious, the effect of water control tap potential measures has gradually deteriorated. However, from a macroscopic point of view, although the overall recovery degree is over 45%, the combined water content is over 93%, the remaining geological reserves of underground are still large, reaching 14 million tons.

3 EVALUATION OF STORAGE RATIO OF INJECTED WATER

In the process of oilfield development, crude oil is continuously produced. The gradual increase of oil production during oil recovery in oilfield will inevitably lead to a continuous increase in the composite water cut. At the same time, injection water will also be gradually produced. As the water content of oilfield increases, the amount of crude oil produced will increase, the storage ratio of injection water of oilfield will decline slowly, and the result will inevitably lead to a change from good to poor in the way the oilfield adopts water flooding oil at this stage. Therefore, the reservoir storage ratio of injection water can be applied, to score the development effect of water flooding oil in oilfield.

Usually, there are two forms of storage ratio of injection water, the one is the accumulative storage ratio of injection water, and the other one is the period storage ratio of injection water. The accumulative storage ratio of injection water is the ratio of the water injection of having not been produced to the water injection. In the process of oilfield development, it is not only an important index of the water injection status of water flooding development oilfield, but also a benchmark for measuring the development effect of reservoir water flooding development oilfield, it has a grade distinction; The period storage ratio of injection water is the ratio of the period water injection of having not been produced to the period water injection. In the process of oilfield development, it not only measures an important factor in the utilization ratio of injection water in a certain stage of the oilfield, but also a benchmark for measuring the development effect of the way of water flooding development in all stages of water injection development oilfield, it has a grade distinction. And it is also suitable for evaluating the development effect of the way of water flooding for the stage oilfield. The higher storage ratio of injection water of oilfield in a certain stage, the greater utilization ratio of injection water at this stage in oilfield, the development effect of the way of water flooding of oilfield will also increase.

According to formula 1-1, the formula of storage ratio of injection water under the different degree of reserve recovery can be deduced.

$$E_i = 1 - \frac{\Delta Q_w}{\Delta Q_i} = 1 - \frac{1}{Z\left(\frac{\Delta Q_o gV}{\Delta Q_w} + 1\right)} \quad (1\text{-}1)$$

In the formula: ΔQ_o——stage of oil recovery,$10^4 m^3$;

V——crude oil reduction factor;

Z——injection-production ratio.

After finishing

$$\ln(1 - E_i) = A_s + B_s R \quad (1\text{-}2)$$

In the formula: $\left(\frac{W_p}{W_i}\right)$——drainage ratio, decimal;

R——degree of reserve recovery,%;

E_i——storage ratio of injection water;

W_p——cumulative water production,million tons;

W_i——cumulative water injection,million tons;

A_s,B_s——statistical constant.

When $\frac{W_p}{W_i}$ value is closer to 1, B_s can be expressed as:

$$B_s = \frac{D_s}{E_R} \quad (1\text{-}3)$$

$$A_s = \ln(1 - E_s) - D_s \frac{R}{E_R} \quad (1\text{-}4)$$

In the process of oilfield development, for different geological oilfields, they have different ways of water injection development. In the same situation in oilfield development stage, there is a close relationship between storage ratio of injection water and oil-water viscosity, the storage ratio of injection water will decrease as the increasing of oil-water viscosity ratio. Therefore, the curves of D_s, A_s and μ_R are regressed from a large number of oilfield related data. Derive the relevant formulas between them, the results are finished:

$$E_s = 1 - e^{\left(A_s + D_s \frac{R}{E_R}\right)} \quad (1\text{-}5)$$

The same types of geological oilfield in a certain degree of reserve recovery, the value of storage ratio of injection water of oilfield shows a positive correlation relation with the value of water flooding recovery ratio in the way of the oilfield uses water flooding oil. Therefore, it is possible to judge the development effect of the way of oilfield water flooding oil by the value of the storage ratio of injection water in oilfield.

In order to evaluate the development effect of water injection of the way of water flooding oil on the eastern block of the D pure oil area, according to the value of oil-water viscosity ratio of the target block and the relational formulas, it can calculate the values of D_s and A_s separately, according to the data of calculating results, a curve that can describe the relation between the storage ratio of injection water of oilfield and the degree of recovery of oilfield, this is a set of curves describing the relationship of oilfield under different water flooding recovery (E_R). The evaluation criteria for the underground storage ratio of injection water in oilfield are shown in table 1.

Table 1: Evaluation standard of underground storage ratio of injection water.

degree of reserve recovery classify	I	II	III
degree of reserve recovery＜50	≥60%	＜ 60%~≥50%	＜50%
degree of reserve recovery≥50	≥80%	＜ 80%~≥70%	＜70%

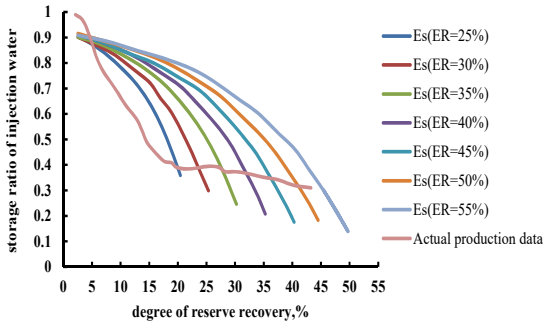

Figure 1: Relationship curve between storage ratio of injection water and degree of reserve recovery in the east of D oilfield.

The formula 1-4 can be used to calculate the storage ratio of injection water (E_s) corresponds to a certain degree of recovery(R) under the water flooding recovery (E_R) of oilfield. According to the result of the calculation of formula 1-4, to make the

E_S~R curve. Among them, when the oilfield water flooding recovery rates are 25%, 30%, 35%, 40%, 45%, 50% and 55%, the corresponding E_S~R curve is its standard curve. We need to storage ratio of injection water of target block and the actual data points with the degree of recovery are plotted in the ideal case of the plate, and connect these data points, form a curve, as shown in Figure 1.

Evaluation of the effects of oilfield development from Figure 1, get the following conclusion. At present, the oil field is gradually changing from the traditional recovery scheme to the recovery scheme of water injection development. In the initial period of oilfield development of taking natural energy mining into production, the declined speed of storage ratio of injection water of oilfield is slowly, however, the water injection utilization of oilfield is highly. In this stage, the development effect of oil recovery is relatively good in oilfield. However, due to the accumulation of the contradiction between layers, the oilfield is becoming prominent increasingly, this led to the value of storage ratio of injection water beginning to show a decreasing trend, and have not been able to take remedial measures to control water timely, and this makes the value of water injection utilization of oilfield become low. At this stage of the process, the development effect of oilfield water injection development methods is deteriorated. When the oilfield is undergoing comprehensive improvement and governance, the value of the storage ratio of injection water has some room for growth. At this stage of the process, the theoretical curve value of oil field above 50% of recovery, the oilfield water injection efficiency has been effectively improved, the development effect of oilfield water injection development methods began to gradually increase, in present, we can get the conclusion from the current overall trend of storage ratio of injection water, it is recommended that when implementing various measures on the oilfield of stable oil, in order to make the injected water use reasonably, the water control work (such as water shutoff, etc.) should be emphasized, to maintain the sustainable development of each major oilfield.

4 EVALUATION OF WATER CONSUMPTION RATIO

In the field of oilfield professional knowledge, the water consumption ratio refers to the amount of water production per ton of crude oil produced by using the method of water injection development in oilfield. The water injection utilization is mainly evaluated. The water consumption ratio of water flooding oilfield is reduced, and the water injection utilization will increase, thus reducing the amount of injected water for water flooding development and reducing the cost. The specific relational expression is shown in formula 2-1.

$$h = \frac{Q_i}{Q_o} \tag{2-1}$$

The formula of injection-production ratio is expressed by formula 2-2:

$$Q_{\mathrm{i}} = IPR \cdot \left(Q_{\mathrm{w}} + \frac{B_{\mathrm{o}}}{\rho_{\mathrm{o}}} \cdot Q_{\mathrm{o}} \right) \tag{2-2}$$

From the injection-production ratio formula and water consumption ratio formula, that is:

$$\frac{Q_{\mathrm{w}}}{Q_{\mathrm{o}}} = \frac{f_{\mathrm{w}}}{1 - f_{\mathrm{w}}} \tag{2-3}$$

Combine and organize to get:

$$h = IPR \cdot \left[\left(\frac{B_o}{\rho_o} \right) + \frac{f_{\mathrm{w}}}{1 - f_{\mathrm{w}}} \right] \tag{2-4}$$

According to the formula of water drive curve, the mathematical expression of water consumption index is obtained under the condition of the same degree of reserve recovery.

$$Z = \frac{B_{\mathrm{o}}}{\rho_{\mathrm{o}}} + 10^{7.5(R - E_R) + 1.69} \tag{2-5}$$

The volume factors of B_o=1.115 and ρ_o=0.851 in the eastern part of the D pure oil region are substituted and calculated to obtain the results of different water flooding yields under the water flooding index, and the water consumption index theory chart for different water flooding recovery is produced. The rate evaluation criteria are shown in Table 2.

Table 2: Evaluation standard of underground storage ratio of injection water.

Development phase	Leveling		
	I	II	III
Low phase of water content	≤0.2	0.2-0.5	＞0.5
Middle phase of water content	≤2	2-4	＞4
High phase of water content	≤5	5-8	＞8
Extra high phase of water content	≤9	9-12	＞12

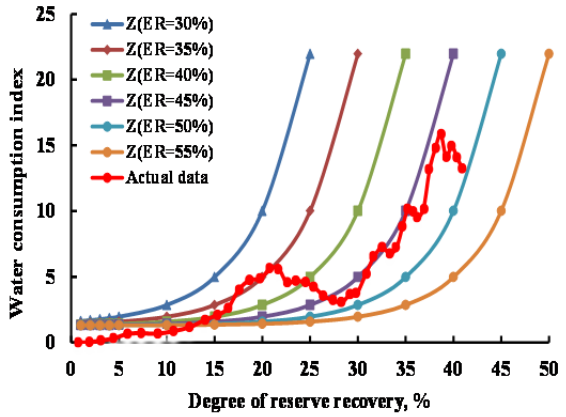

Figure 2: Relationship between curve water consumption ratio and the degree of Recovery theory diagram.

Combined with the evaluation standards of water consumption ratio, the actual water consumption ratio in east of D pure oil area can be concluded as follows: In the early stage of water flooding development, the water consumption ratio is small. Water consumption ratio is less than 0.2 that be into the low phase of water content, and it is belonged to first level. During 1981-1984, water consumption ratio increases, which be into the high phase of water content. It is belonged to second level. However, water consumption ratio increases rapidly in the high phase of water content. The average level is 5.13, and the highest level is 7.995, which is belonged to the second level. The oilfield entered a special period that has extra high water cut period in 2003. At the same time, water consumption ratio remains high level, which average is 12.683, and it gets the peak of water consumption ratio in 2011 that is 15.814. The utilization ratio of oilfield water injection is not high and it fall into three levels. The target block is in urgent need of various adjustments and various measures are taken to improve the water injection efficiency so as to maintain the cyclic development of the oil field. The theoretical chart of the relation curve between the water consumption index and degree of reserve recovery curve and the actual data in the east of D pure oil area are shown in Figure 2.

In the early stage of oilfield development, natural energy was sufficient. However, at that time, the number of injection wells was small, and the injection volume of each well was also small. So it leaded to water consumption ratio was low in the oilfield of water injection development. However, the water consumption index showed an upward trend and the rate of increase accelerated about in the 1981. After 1989, the water consumption rate showed a downward trend, the final recovery ratio was from the original 35% to 40%. After, along the curve of 45% recovery ratio upward, and utilization of injected water was increased. It improved the development effect of oilfield water injection development methods and increased oil recovery ratio. After the measures were improved in 2011, the water consumption ratio of the oilfield fell again. It made the sliding result closer to the curve that final recovery ratio was 50%.

5 EVALUATION OF WATER DRIVE INDEX

Water drive index refers to withdraw water storage of underground $1m^3$ crude oil, expression with the formula is:

$$R_{wo}=(Q_i-Q_w)/(Q_o\times B_o) \tag{3-1}$$

In the formula: R_{wo}——water drive index, $10^4m^3/10^4m^3$;

Q_i——water injection in the period, 10^4m^3;

Q_w——water production in the period, 10^4m^3;

Q_o——oil production in the period, 10^4m^3

Put the formula of injection and production ratio

$$Z=Q_i/(Q_w+Q_oB_o) \tag{3-2}$$

The formula of water cut

$$f_w=Q_w/(Q_w+Q_o) \tag{3-2}$$

Substitute formula 3-1, after finishing:

$$R_{wo}=(Z-1)\frac{f_w}{B_o(1-f_w)}+Z \tag{3-4}$$

The actual water drive index and water cut data in the eastern part of the D pure oil zone are plotted on the theoretical chart of the relation between water drive index and water cut, as shown in Figure 3.

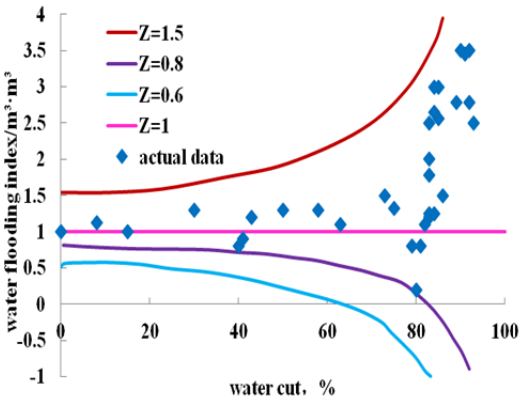

Figure 3: Relationship curve between water flooding index and water cut.

During the development of water injection oilfield, when the value of the effective of water drive index is less than 0, the water injection has not played the role of displacing oil. When the value of the effective of water drive index is more than 1.0,the stage belongs to the stage of intensification water injection,and the increasing of net volume of the underground water injection is much greater than the underground volume of the crude oil produced in oilfield. When the value of the effective of water drive index is between 0 and 1, the stage belongs to the development stage of combination drive. The greater the value of the water drive index, the stronger the role played by water flooding.

Comparing the actual relationship between the water drive index and the water content in the eastern stage of D pure oil block with the theoretical chart, the following conclusions can be drawn: in the early period of the development of water injection oilfield, the value of water drive index keeps around 1, and the value of injection-production ratio of the block is also around 1.0. At this stage, the block is in the stage of full water flooding, and this stage has better effect of water injection development. However, in the middle period of development of water injection oilfield, the water drive index is less than 1.0, and the injection-production ratio also trends to 0.8. It is confirmed that there is a phenomenon of underground depletion in the oil field. Therefore, in order to increase the water drive index, the injection-production ratio must be increased. It is advisable to close high capacity channel and other adjustment measures to prevent inefficient circulation and invalid water injection; in the later period of development of water injection oilfield, when the target block has entered the stage of high water content, the value of water drive index has a significant range. The increasing trend has risen to around 2~3.5. However, this cannot be simply considered that the water flooding effect of the target block is getting better and better, as some adjustment measures are often taken in the later period of development of water injection oilfield, and the storage ratio of water injection in oilfield will rapidly fluctuate greatly. Water drive index alone cannot be used to evaluate the effect of water flooding development in oilfield.

6 CONCLUSIONS

This paper makes a technical evaluation of the water injection efficiency of the target block from the storage ratio of injected water, water consumption ratio, and water drive index.

(1) Storage ratio of injected water. The oil field is gradually changing from the traditional mining mode to the mining mode of water injection development. In the initial period of oilfield development of taking natural energy mining into production, the declined speed of storage ratio of injection water of oilfield is slowly, however, the water injection utilization of oilfield is highly. In this stage, the development effect of oil recovery is relatively good in oilfield. However, due to the accumulation of the contradiction between layers, the oilfield is becoming prominent increasingly, and this led to the value of storage ratio of injection water beginning to show a decreasing trend. The development effect of oilfield water injection development methods is deteriorated. When the oilfield is undergoing comprehensive improvement and governance, the value of the storage ratio of injection water has some room for growth. In present, we can get the conclusion from the current overall trend of storage ratio of injection water, it is recommended that when implementing various measures on the oilfield of stable oil, in order to make the injected water use reasonably, the water control work (such as water shutoff, etc.) should be emphasized, to maintain the sustainable development of each major oilfield.

(2) Water consumption ratio. Combined evaluation standards of water consumption ratio, analysis the actual water consumption ratio in east of D pure oil area can be concluded as follows: In the early stage of water flooding development, the water consumption ratio was small. Water

consumption ratio was less than 0.2 that be into the low phase of water content, and it belonged to first level. During 1981-1984, water consumption ratio increased, which be into the high phase of water content. It belonged to second level. However, water consumption ratio increased rapidly in the high phase of water content, which belonged to the second level. The oilfield entered a special period that was extra high water cut period in 2003. At the same time, water consumption ratio remained high level. The utilization ratio of oilfield water injection was not high and it fall into three levels. The target block is in urgent need of various adjustments and various measures are taken to improve the water injection efficiency so as to maintain the cyclic development of the oil field.

(3) Evaluation of water drive index. In the early period of the development of water injection oilfield, the value of water drive index keeps around 1, and the value of injection-production ratio of the block is also around 1.0. At this stage, the block is in the stage of full water flooding, and this stage has better effect of water injection development. However, in the middle period of development of water injection oilfield, the water drive index is less than 1.0, and the injection-production ratio also trends to 0.8. It is confirmed that there is a phenomenon of underground depletion in the oil field. Therefore, in order to increase the water drive index, the injection-production ratio must be increased. It is advisable to close high capacity channel and other adjustment measures to prevent inefficient circulation and invalid water injection; in the later period of development of water injection oilfield, when the target block has entered the stage of high water content, the value of water drive index has a significant range. The increasing trend has risen to around 2~3.5. However, this cannot be simply considered that the water flooding effect of the target block is getting better and better, as some adjustment measures are often taken in the later period of development of water injection oilfield, and the storage ratio of water injection in oilfield will rapidly fluctuate greatly. Water drive index alone cannot be used to evaluate the effect of water flooding development in oilfield.

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