

# Feasibility study on cyclic water flooding of high saturation sandstone reservoir in late development stage - A case study of C30 fault block in Chaheji oilfield

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**Abstract.** There are some problems of high saturation sandstone reservoir in late development stage, such as low reservoir pressure level, low oil production volume and high water content ratio. At present, the conventional treatment measures are poor to improve the reservoir development efficiency. Through extensive investigation and comprehensive analysis, the cyclic water flooding method can effectively improve the reservoir development efficiency. This study is based on the theory of cyclic water flooding method to replace remaining oil. The numerical simulation of cyclic water flooding is carried out by establishing geological model of actual blocks. By analysing the influence of injection-production ratio, injection-production method and liquid production volume on the cyclic water flooding development efficiency, the cyclic water flooding scheme of high saturation sandstone reservoir in the late development stage is optimized.

## 1. Preface

Artificial water flooding is one of the main methods to improve recovery of oilfield. The conventional water flooding development methods are mostly stable water flooding. But for serious heterogeneous reservoirs, if the conventional stable water flooding development method is adopted, the injection water advances along the high permeability layer rapidly, then the oil well will water breakthrough soon. In the low permeability layer, the injection water is slow to advance because of the large seepage resistance of injection water. When the oil well water breakthrough, a large amount of crude oil has not been produced in the low permeability layer, thus greatly reduces the oil recovery rate <sup>[1]</sup>.

Taking the C30 fault block of Chaheji oilfield as an example. The reservoir is shallow water delta facies sedimentary environment, which is dominated by underwater distributary channel. The plane and vertical heterogeneity of the reservoir are serious. The average porosity of reservoir is 19% and the air permeability of reservoir is 111mD. The reservoir is of middle permeability and middle porosity. The C30 fault block is a typical high saturation reservoir, which original reservoir pressure is 29.5MPa and saturation pressure is 21.2MPa. Now the reservoir has entered the late development stage, the reservoir pressure is 18.2MPa, the average single well daily oil production is 1.1t/d, the comprehensive water content ratio is 91.3% and the reservoir recovery degree is 19.1%. On the whole, the reservoir is in situation of low oil production and high water content. And the reservoir pressure maintenance level and reservoir recovery degree are both low. Now it is difficult to improve the recovery degree of reservoir by using conventional treatment methods. In view of the problems existing in the development, the cyclic water flooding method is used to develop C30 fault block. The



C203 well field is taken as the research object in this study. The influence of injection-production ratio, injection-production method and liquid production volume on the development of cyclic water flooding method is studied. Finally the cyclic water flooding project of high saturation reservoir in the late development stage is optimized.

## **2. Oil displacement theory of cyclic water flooding**

The cyclic water flooding method produces unstable pressure field in the formation by changing the water injection volume and oil production volume periodically, so that the fluid can be continuously redistributed in the formation. Under the action of elastic force and capillary force in reservoir, the interactive infiltration of injection water between high permeability zone and low permeability zone is achieved. So as to increase the sweep efficiency of injection water and the efficiency of oil washing, the purpose of improving reservoir recovery ratio is achieved <sup>[2, 3]</sup>.

### *2.1. Oil displacement theory of elastic force*

During the process of cyclic water flooding, when the reservoir begins to inject water, the water absorption of the high permeability area is large, the pressure rises fast and the pressure is high. While the water absorption of the low permeability area is small, the pressure rises slowly and the pressure is low. An additional positive pressure difference is formed between high and low permeability zone. Under the action of this pressure difference, oil and water are driven from the high permeability zone to the low permeability zone. Because of the high water saturation in high permeability zone, there is more water and less oil entering into low permeability zone. When the injection is stopped, the discharge volume of high permeability zone is large, the pressure drops fast and the pressure is low. While the discharge volume of low permeability zone is small, the pressure drops slowly and the pressure is high. Then the oil and water are driven from low permeability zone to high permeability zone. Due to the low water saturation of low permeability zone, there is more oil and less water entering into high permeability zone. In this way, the residual oil in the low permeability zone is extracted, which is the cyclic water flooding oil displacement theory of elastic force <sup>[4, 5]</sup>.

### *2.2. Oil displacement theory of capillary force*

Capillary force can cause oil-water reverse seepage exchange between high and low permeability zones. In the stage of water injection, the effect of capillary force is not obvious. In the early stage of stopping injection, the additional pressure difference caused by elastic force leads to the same direction channeling of oil and water between high and low permeability zones. With the release of elastic energy, the function of elastic force disappears quickly. The reverse channeling of oil and water caused by the function of capillary force will gradually occupy a dominant position. Because of the low water saturation in low permeability zone, there is more oil and less water entering into high permeability zone. In this way, under the effect of additional pressure difference, some oil in high permeability zone is taken out. Under the effect of repetitive pressure pulse action, the oil flows from low water saturation region to high water saturation region, while the water flows from high water saturation region to low water saturation region <sup>[6-10]</sup>.

## **3. Numerical simulation research of cyclic water flooding**

### *3.1. The research path of cyclic water flooding*

The reasonable water injection timing for the high saturation reservoir of C30 fault block is 3 months after the oil wells is put into operation. However, the water injection measures lag for one year in the actual production process. As a result, the degassing of reservoir is serious and the development efficiency is poor. At present, the reservoir pressure level and recovery degree are relatively low, the water content ratio is relatively high. Comprehensive adjustment measures should be based on improving reservoir pressure level and water drive utilization degree. Firstly, logistic cycle model and material balance principle are used to calculate the reservoir pressure recovery rate of different

injection-production ratios. According to the calculation results, the reasonable injection production ratio of reservoir to maintain current pressure level is 1.05. Subsequently, the cyclic water flooding projects of various injection-production ratios, injection-production methods and liquid production volumes are designed. Finally according to the results of numerical simulation, the best cyclic water flooding project is determined.

The injection-production methods mainly include three means of conventional injection-production, cyclic water injection continuous production and cyclic water injection cyclic production. A total of 192 prediction projects are designed and compared according to the injection-production methods of different injection-production ratios, injection-production cycles and liquid production volumes. According to the actual production process of C30 fault block, the water injection response time is about 1~2 months. So the designed injection-production cycle are 30 days and 60 days respectively. The specific scheme is shown as Table 1.

Table 1. Numerical simulation scheme of C30 fault block

Injection-production method	Injection-production cycle	Injection-production ratio	Liquid production (t)
Conventional injection-production	Continuous injection continuous production		
Cyclic water injection continuous production	①Water wells start for 30 days and off for 30 days	0.8	15
	②Water wells start for 30 days and off for 60 days	1.05	
	③Water wells start for 60 days and off for 30 days		
	④Water wells start for 60 days and off for 60 days	1.2	
Cyclic water injection cyclic production	①Water wells start for 30 days and off for 30 days, while oil wells off for 30 days and start for 30 days	1.5	20
	②Water wells start for 30 days and off for 60 days, while oil wells off for 30 days and start for 60 days	2.1	25
	③Water wells start for 60 days and off for 30 days, while oil wells off for 60 days and start for 30 days	2.5	
	④Water wells start for 60 days and off for 60 days, while oil wells off for 60 days and start for 60 days		

### 3.2. The establishment of numerical simulation model

Firstly, the C203 well field with condition of relatively complete structure and relatively high production is selected. Then the 3D geological model is established by software. Subsequently, the daily liquid production, daily oil production, daily water production, comprehensive water content ratio and cumulative oil production of C203 well field are matched with historical data as shown in Figure 1. On the basis of historical matching, the predictions of cyclic water flooding numerical simulation projects are carried out. Finally the cyclic water flooding numerical simulation projects are optimized.

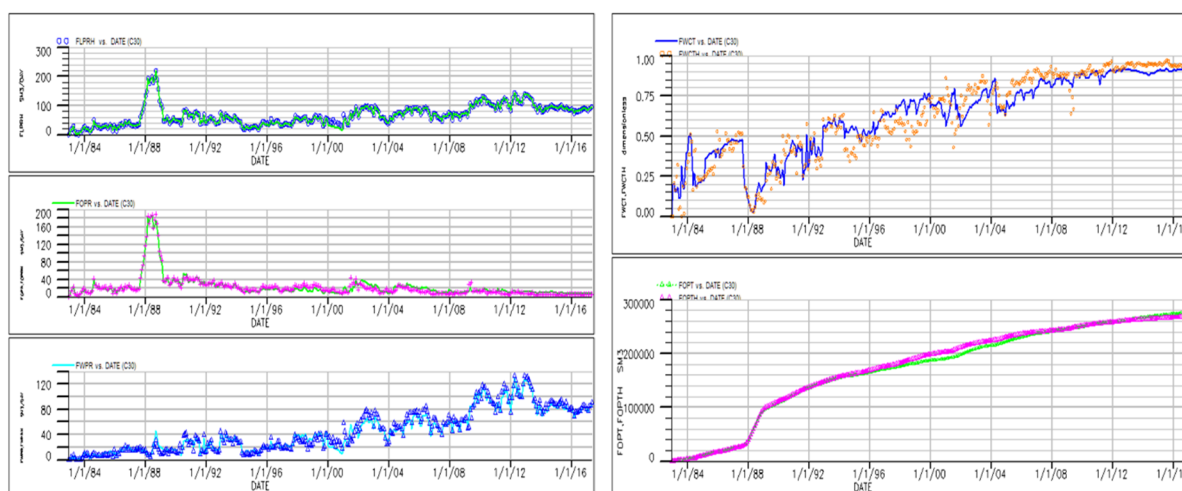


Figure 1. The historical matching curves of C203 well field

### 3.3. The research results of cyclic water flooding numerical simulation

Through the numerical simulation study of cyclic water flooding, the influence of injection-production ratio, injection-production method and liquid production volume on the cyclic water flooding development in C203 well field is analysed. And the cyclic water flooding project of high saturation sandstone reservoir in the late development stage is optimized.

#### 3.3.1. The optimization of injection-production ratio

In the late stage of high saturation reservoir development, the pressure level of reservoir is low. So the adjusting measure of reservoir pressure recovery is considered firstly. According to logistic cycle model and material balance principle, the reasonable injection-production ratio of reservoir to maintain the present pressure level is 1.05. It is shown from Table 2 that the annual pressure recovery rate increases with the increase of annual injection-production ratio.

Table 2. Pressure recovery rate of injection-production ratio

Annual injection-production ratio	0.8	1.05	1.2	1.5	2.1	2.5
Annual pressure recovery rate (MPa/a)	-0.30	0	0.21	0.59	1.35	1.85

Under the condition of conventional water injection method with injection-production ratio of 0.8, 1.05, 1.2, 1.5, 2.1 and 2.5 respectively, the reservoir recovery rate and water content ratio are predicted. As can be seen from Figure 2, when the injection-production ratio is 1.05, the recovery rate of reservoir is highest, the water content ratio is low and the development efficiency of reservoir is the best. When the injection-production ratio is less than 1.05, although the water content ratio of reservoir is low, which cannot maintain the reservoir pressure level. Then the liquid production volume is reduced and the recovery rate of reservoir is low. When the injection-production ratio is larger than 1.05, the water content ratio of reservoir increases rapidly, while the recovery rate of reservoir decreases gradually. Therefore, under the condition of conventional water injection method, the single increase of injection-production ratio has little effect on enhancing reservoir recovery rate. According to the reservoir characteristics of C30 fault block and the theory of cyclic water flooding, the cyclic water flooding method is considered for the subsequent development of reservoir.

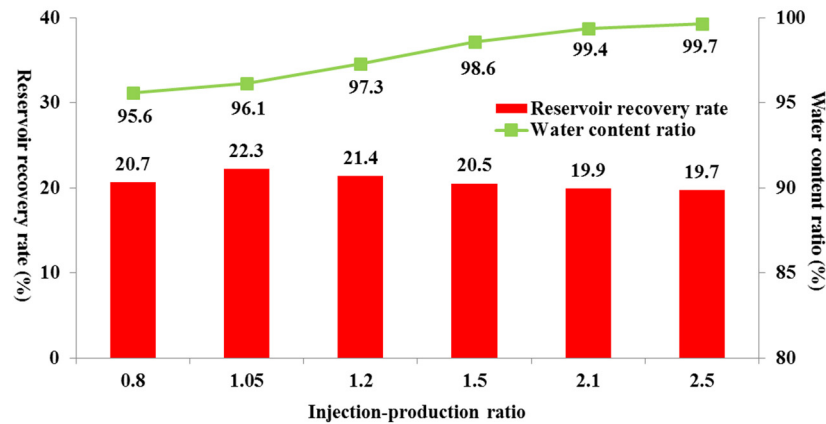


Figure 2. Recovery rate and water content of different injection-production ratios

### 3.3.2. The optimization of injection-production method

By comparing the numerical simulation results of different cyclic injection-production schemes, the optimum injection-production method of C203 well field is selected. When the cyclic injection-production ratio is 1.05, the water wells start for 30 days and off for 30 days is the best scheme in the injection-production scheme of cyclic water injection continuous production. When the cyclic injection-production ratio is 1.05, the water wells start for 30 days and off for 60 days, while oil wells off for 30 days and start for 60 days is the best scheme in the injection-production scheme of cyclic water injection cyclic production. The following conclusions can be drawn by comparing the cyclic injection-production scheme with the conventional injection-production scheme in condition of the same injection-production ratio and the same liquid production volume.

Firstly, the reservoir recovery rate of conventional injection-production scheme is the lowest, the water consumption rate of conventional injection-production is the highest and the development efficiency of conventional injection-production is the worst. Secondly, the scheme of cyclic water injection continuous production, which can not only cause the seepage between high and low permeability zones, but also make the oil production cycle longer. The reservoir recovery rate of this scheme is the highest. Thirdly, the scheme of cyclic water injection cyclic production, which can make the fluid in the high and low permeability zones fully seepage under the action of elastic force and capillary force. The water utilization rate of this scheme is the highest, and the water content ratio and water consumption rate are both low. As can be seen from Figure 3 and Figure 4, the two kinds of cyclic injection production method are better than conventional injection production method.

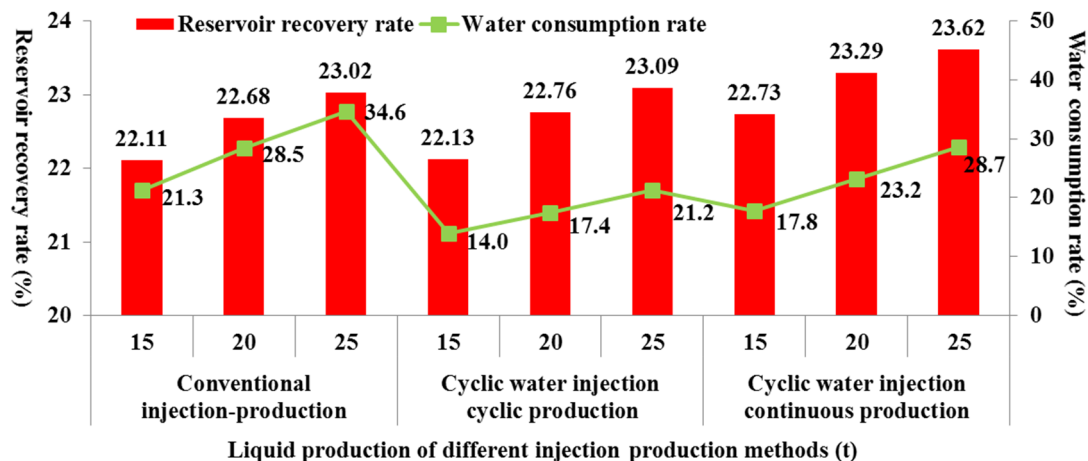


Figure 3. Development index of different injection production methods

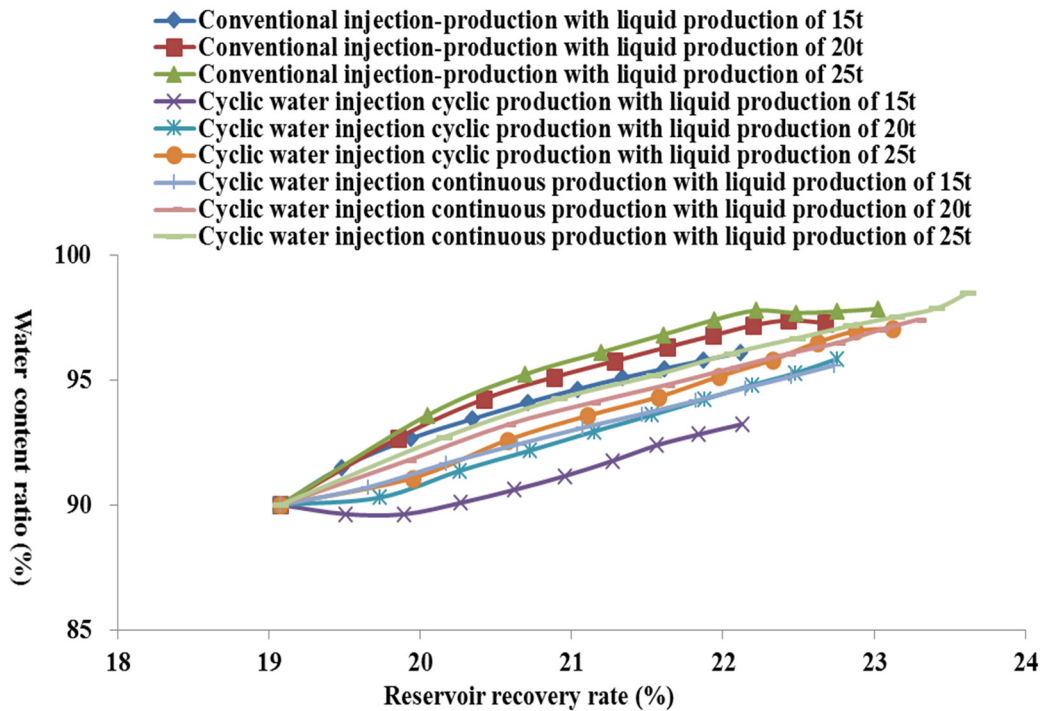


Figure 4. Water content and recovery rate of different injection production methods

### 3.3.3. The optimization of liquid production volume

By comparing the numerical simulation results of different liquid production volume schemes, increasing liquid production volume has obvious effect on improving reservoir recovery rate. With the increase of liquid production volume, the reservoir recovery rate increases, but the water content ratio and water consumption rate also increases. When the liquid production volume is 15 t/d, the water content ratio and reservoir recovery rate of cyclic water injection cyclic production scheme are both low. When the liquid production volume is 25 t/d, the water content ratio and reservoir recovery rate of cyclic water injection continuous production scheme are both high. Consequently, for the well field of high water content, the scheme of cyclic water injection cyclic production is adopted to maintain the current liquid production volume of oil wells and slow down the increase of water content ratio. For the well field of low water content, the scheme of cyclic water injection continuous production is adopted to increase the liquid production volume and the cumulative oil production volume.

## 4. Conclusion

(1) For high saturation reservoir of late development stage, conventional injection production method has little effect on improving reservoir development efficiency by increasing injection production ratio. Under the reasonable injection production ratio, the reservoir development efficiency can be improved by adopting cyclic water flooding method.

(2) In the process of oilfield development, the reasonable injection-production method should be determined according to the actual situation of reservoir. For the well field of high water content, the scheme of cyclic water injection cyclic production is adopted to slow down the increase of water content ratio. For the well field of low water content, the scheme of cyclic water injection continuous production is adopted to increase the cumulative oil production volume.

(3) The measure of raising liquid production volume can effectively increase the output of oil wells, but at the same time cause the increase of water content ratio. Therefore the reasonable liquid production volume should be determined according to the actual production situation of reservoir, so as to improve the development efficiency.

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