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Research of Surfactant-Polymer Flooding Response Characteristic and Mobility Optimization of J Oilfield in Bohai Bay

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Abstract

Surfactant-polymer flooding technology which used in J oilfield is still the first time in Bohai bay, the reference materials are very seldom for its response characteristic and project optimization. Since there's no blank water flooding stage between polymer flooding and surfactant-polymer flooding in J oilfield, it's difficult to accurately judge the response characteristic of production wells and injection wells by the conventional method; on the other side, as surfactant-polymer flooding gradually entered the end stage, the effect of decrease water and increase oil became worse, there's urgently need to improve the effect of chemical flooding. Thus, the research of response characteristic and mobility optimization are conducted in this article. The water cut funnel method is used for the first time to recognize the response of the production wells in J oilfield, and to use the Hall curve method to recognize the response of the injection wells. Meanwhile, based on the idea of mobility control, the minimum polymer concentration which is needed to control the mobility of surfactant-polymer flooding is studied, and establish the mobility control template, the effect of the surfactant-polymer flooding is improved effectively by use of the template to guide the optimization of the polymer concentration, and daily production increase about 15% of J oilfield. The research can be used to guide and refer to other similar offshore oilfield development.

Key words: Surfactant-polymer flooding; Response characteristic; Mobility optimization; Polymer concentration; Offshore oilfield

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INTRODUCTION

As an enhanced oil recovery technology, surfactant-polymer flooding can effectively improve the viscosity of the displacement phase and reduce the interfacial tension of oil and water, thus improve the sweep efficiency and oil displacement effect,[1] it had been popularized and applied in China's onshore oilfields such as Daqing and Shengli oilfield, and achieved better effects of increasing oil and decreasing water.[2-4] However, few surfactant-polymer flooding technology have been carried out in offshore oilfield, on the impact of well pattern, well distance and development investment, There is big difference between offshore oilfield and onshore oilfield carry out chemical flooding,[5-6] in aspect of response characteristic evaluation, water flooding derivative curve method is commonly used in onshore oilfield,[7-8] however, the polymer flooding turn into surfactant-polymer flooding directly without blank water flooding in J oilfield, water flooding derivative curve method is invalid in judge the surfactant- polymer response time, so it's hard to evaluate chemical flooding effect, in addition, there's also few researches on response of the surfactant-polymer injection wells. On the other side, with the surfactant-polymer flooding gradually reaches the end stage, chemical flooding became poor efficiency because of gradually forming of channeling path, measures such as times profile control and water shutoff can ease the futile cycle of chemical flooding to a certain extent, but this will increase the development investment greatly, and the period of measures validity are very short commonly.[9-10] This article takes research of response characteristic and mobility optimization, so to offer an important guide to offshore surfactant-polymer flooding oilfield.

1. OILFIELD SURVEY

J oilfield main block reservoir is mainly belongs to lacustrine delta front sedimentary facies, and the upper Dongying Formation is the main oil-bearing series, the average porosity is 27% and the average permeability is 1,250 mD, the formation crude oil viscosity is 10.0～26.0 mPa·s. Polymer flooding was carried out in 2007 and took preferable effect in decreasing water and increase oil. In order to enhance the effect of chemical flooding and improve oil recovery further, conducted the first surfactant-polymer flooding field test in offshore oilfields in China in 2011. The project designs surfactant concentration is 0.12% and polymer concentration is 1,200 mg/L, the injection slug size is 0.3 PV.

2. RESPONSE CHARACTERISTIC ANALYSIS

2.1 Production Well Response Characteristic

For the polymer flooding oilfield, the response time is judged by the method of water flooding derivative curve which often used in onshore oilfield, and has achieved satisfactory results, but it almost take no effect on judge the response time of surfactant-polymer flooding in J oilfield, as shown in figure 1, there’s no inflection point in the derivative curve when injection method turn into surfactant-polymer flooding. This mainly because of polymer flooding turn into surfactant-polymer flooding directly in J oilfield, the function that improve oil displacement effect is not obvious, this is quite different from the response characteristic of production well when turn into surfactant-polymer flooding after blank water flooding, there’s no obvious decline of water cut, just restraint the velocity of water cut increase. So the method of judge the response time needs to be reanalyzed.

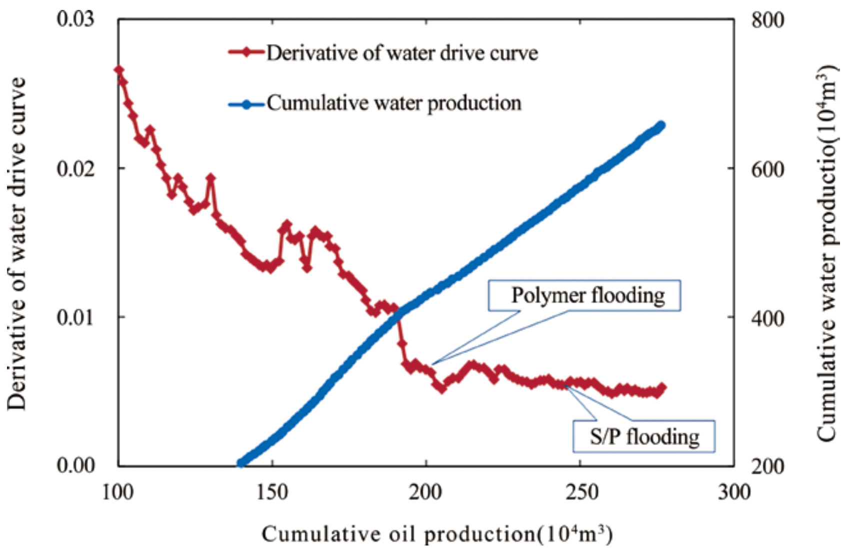

Figure 1
Water Flooding Derivative Curve of Typical Well Group

Based on the mechanism of chemical flooding, the response time should be the opportunity when surfactant and polymer engender synergetic effect. In order to establish the response time distinguish model, to define the water cut declines funnel as:

$$\triangle f_w = f_{w,fit} - f_{w,real}\,. \tag{1}$$

In the formula, $f_{w,real}$ is the water cut of actual polymer flooding, %; $f_{w,fit}$ is the water cut of simulate water flooding, %; and the method which used forecast the simulate water flooding is to use the Logistic water cut forecast model.[11] as shown in Figure 2, polymer flooding water cut decline funnel belong to growth curve, the curve rises from zero to the maximum and then decreases, form a shape similar to a buckle funnel. To determine the trend of polymer flooding water cut decline funnel curve change, 4 characteristic parameters must be confirmed: (a) Initial water cut decline time t_{w0}; (b) corresponding maximum water cut decline funnel time t_{wmax}; (c) end time of water cut decline funnel action t_w; (d) maximum water cut decline funnel Δf_{wmax}. Polymer flooding water cut decline curve is usually presents asymmetrical, To describe this asymmetry, Introduction the parameter of funnel width skewness B, define, it’s better curve symmetry when B tends to 1, otherwise asymmetric enhanced of curves.

According to the establish principle of polymer flooding performance curve quantitative characterization model, a quantitative characterization model of polymer flooding increase oil curve is proposed, the expression is:

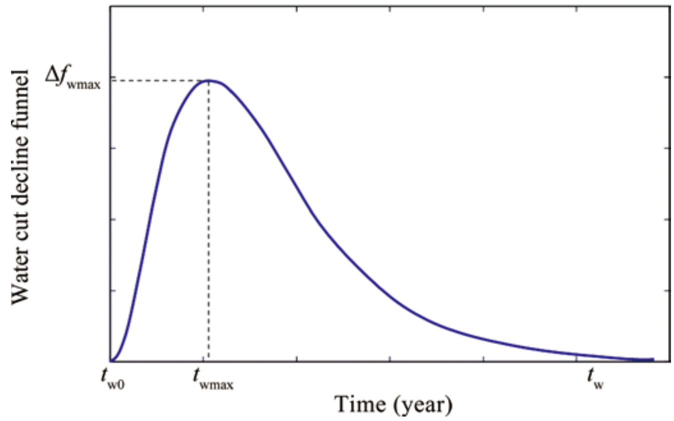

Figure 2
Polymer Flooding Water Cut Decline Curve

$$\Delta f_w = \Delta f_{wmax}\left[\frac{t-t_{w0}}{t_{wmax}-t_{w0}}\right]^b \exp\left[b\left(1-\frac{t-t_{w0}}{t_{wmax}-t_{w0}}\right)\right]. \quad (2)$$

In the formula, Δf_w is the monthly water cut decline funnel; t is the producing time; Δf_{wmax}, t_{w0} and t_{wmax} is the undetermined parameters; define b as the asymmetry coefficient of increase oil curve, it's related with the ending time. The model has obvious characteristics:

(a) when $t = t_{w0}$, $\Delta f_w = 0$;

(b) when $t = t_{wmax}$, $\frac{d\Delta f_w}{dt}=0$, the funnel curve reaches extreme value, that is $\Delta f_w = \Delta f_{wmax}$;

(c) there's a better correlation between asymmetry coefficient b and funnel width skewness B, the regression relation is:

$$\log b = 0.1896(\log B)^2 - 1.5706\log B + 1.2232 . \quad (3)$$

In order to verify the accuracy of the model, the actual production data of J oilfield was imported into the model, as shown in Figure 3, the early discrete points are the monthly data of water cut decline funnel curve in polymer flooding stage, and the late discrete points are the monthly data of water cut decline funnel curve in surfactant-polymer (short for S/ P) flooding stage. According to the research results above, the response time of surfactant-polymer flooding should be at the inflection point of the curve, according to the funnel curve shape that in the stage of polymer flooding and early surfactant-polymer stage, theoretical polymer flooding water cut funnel curve was conducted, to contrast the curve trend difference between theoretical polymer flooding and actual surfactant-polymer flooding, to judge the response time at the inflection point of the curve, that is one and a half years after surfactant-polymer flooding. At the same time, to take the numerical simulation as aided validation method, the response opportunity is the time when the water cut difference greater than 1%, and the result of numerical simulation method is also one and a half years, the results of the two methods are relative consistent.

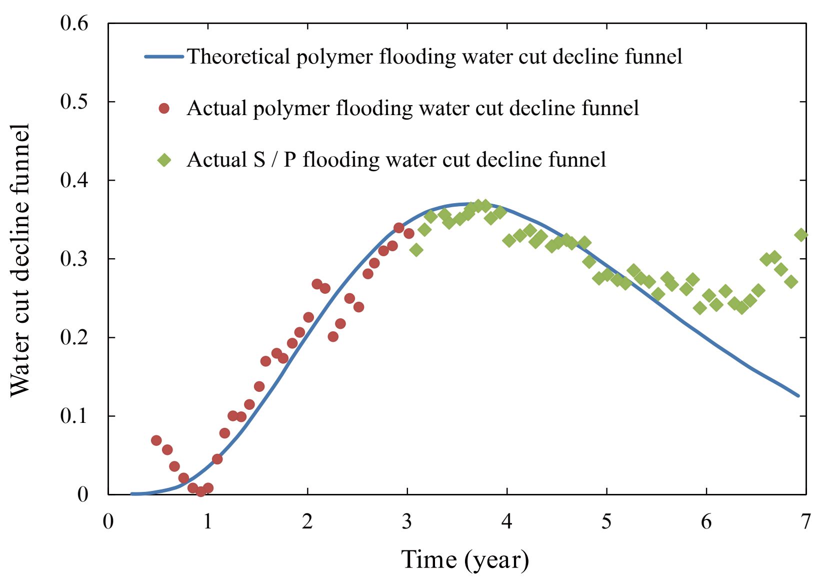

Figure 3
Theoretical and Actual Water Cut Decline Funnel Curve

2.2 Injection Well Response Characteristic

When the development model that of water flooding turn into polymer flooding, because of the effect of increase displacing phase viscosity, seepage resistance of injection water was increased, as shown in Figure 4, the slope of Hall curve increase after polymer flooding, average resistance coefficient of injection well is 1.55. When polymer flooding turn into surfactant-polymer (short for S/P) flooding, the slope of Hall curve decrease, this mainly because of the reduction of interfacial tension, lead to the increase in capillary number, Oil and water will be miscible gradually and decreasing the residual oil saturation, the seepage capacity of oil and water is also enhanced, average resistance coefficient of injection well dipped to 1.39, but the resistance coefficient can be uptrend again with the polymer concentration increase.

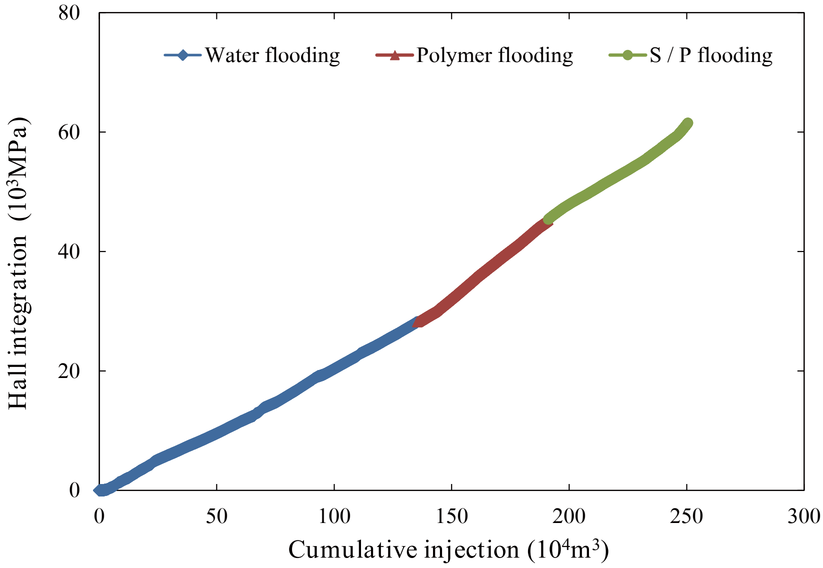

Figure 4
Average Injection Well Hall Curve of J Oil Field

As shown in Table 1, when water flooding turn into polymer flooding, average injection well apparent injectivity index dropped by 16.3 $m^3/(d{\cdot}MPa)$, the extent of decline is approximately 30%. When polymer flooding turn into surfactant-polymer flooding, due to the seepage resistance decreased, average injection well apparent injectivity index increased by 3.8 $m^3/(d{\cdot}MPa)$, the extent of increase is approximately 11%.

Table 1
The Change of Apparent Injectivity Index Under Different Development Model

Injection well	Apparent injectivity index [$m^3/(d{\cdot}MPa)$]					
	Polymer flooding stage			Surfactant-polymer flooding stage		
	Before	After	Change	Before	After	Change
W4-2	50.3	40.0	-10.3	31.8	34.1	2.2
W4-4	61.2	47.0	-14.2	35.1	40.2	5.1
W5-3S1	62.7	29.9	-32.9	26.6	29.1	2.5
W6-4	46.3	33.7	-12.6	46.2	53.9	7.7
W6-6	50.2	36.8	-13.3	42.0	44.8	2.9
W7-3	52.2	36.5	-15.7	22.0	25.4	3.4
W8-4	54.2	39.6	-14.6	47.2	50.3	3.1
W8-6	51.2	34.1	-17.1	28.3	31.9	3.7
average	53.5	37.2	-16.3	34.9	38.7	3.8

3. MOBILITY DESIGN IN SURFACTANT-POLYMER FLOODING

3.1 Mobility Control Equation

Mobility control is an important part of chemical flooding project optimize, chemical flooding channel could be generated without mobility control, based on the idea of mobility control, the mobility design model for chemical flooding is established to form a quantitative method for mobility design, The total mobility of the oil-water mixing zone is expressed as:

$$\lambda_m = \frac{KK_{rw}}{\mu_w} + \frac{KK_{ro}}{\mu_o} . \quad (4)$$

In the formula, λ_m is the mobility of the oil-water mixing zone, mD/(mPa·s); K is absolute permeability, mD; K_{rw} and K_{ro} are relative permeability of water and oil respectively; μ_w and μ_o are viscosity of water and oil respectively, mPa·s.

In order to prevent viscous fingering phenomenon, the mobility ratio of surfactant-polymer flooding slug to the oil-water mixing zone should be less than 1, considering the change of relative permeability curve after oil-water miscible, the expression of mobility control is:[12]

$$\frac{\frac{KK_{rw}}{R_k\mu_{sp}}}{\frac{KK_{rw}}{\mu_w}+\frac{KK_{ro}}{\mu_o}}=\frac{(1-M_w)K_{rwi}(S_{wi})+M_wK_{rwm}(S_{wm})}{R_k\,\mu_{sp}\lambda_m}<1\,. \tag{5}$$

In the formula, R_k is the permeability reduction factor; μ_{sp} is the reservoir viscosity of surfactant-polymer slug; M_w is the water phase miscibility coefficient; K_{rwi} is immiscible relative permeability of water; K_{rwm} is miscible relative permeability of water, S_{wi} is immiscible water saturation; S_{wm} is miscible water saturation. Transform the Formula (5):

$$R_k\,\mu_{sp}>\frac{(1-M_w)K_{rwi}(S_{wi})+M_wK_{rwm}(S_{wm})}{\lambda_{mmin}}. \tag{6}$$

The relationship between polymer concentration and permeability reduction factor was determined experimentally:[13-14]

$$R_k=1+\frac{(R_{kmax}-1)b_{rk}\cdot C_p}{1+b_{rk}\cdot C_p}. \tag{7}$$

In the formula, R_{kmax} is the maximum permeability reduction factor; C_p is the polymer concentration; mg/L; b_{rk} is the parameter that was determined by experiment.

The influence of surfactant on displacing plug viscosity is very small, so the viscosity of surfactant-polymer μ_{sp} and polymer μ_p are approximately equal, the relationship between polymer concentration and shear rate as below:

$$\mu_p(\gamma)=\mu_w+\frac{\left(\mu_p^0-\mu_w\right)}{1+\left(\frac{\gamma}{\gamma_{1/2}}\right)^{pown-1}}. \tag{8}$$

In the formula, γ is the shear rate, s^{-1}; $\gamma_{1/2}$ is the shear rate which viscosity of polymer solution is reduces to the half of original, s^{-1}; *pown* is the parameter that was determined by experiment.

Put Formula (7) and Formula (8) into Formula (6):

$$\left[1+\frac{(R_{kmax}-1)b_{rk}C_p}{1+b_{rk}C_p}\right]\left[\mu_w+\frac{\mu_p^0-\mu_w}{1+(\gamma/\gamma_{1/2})^{pown-1}}\right]>\frac{(1-M_w)K_{rwi}(S_{wi})+M_wK_{rwm}(S_{wm})}{\lambda_{mmin}}. \tag{9}$$

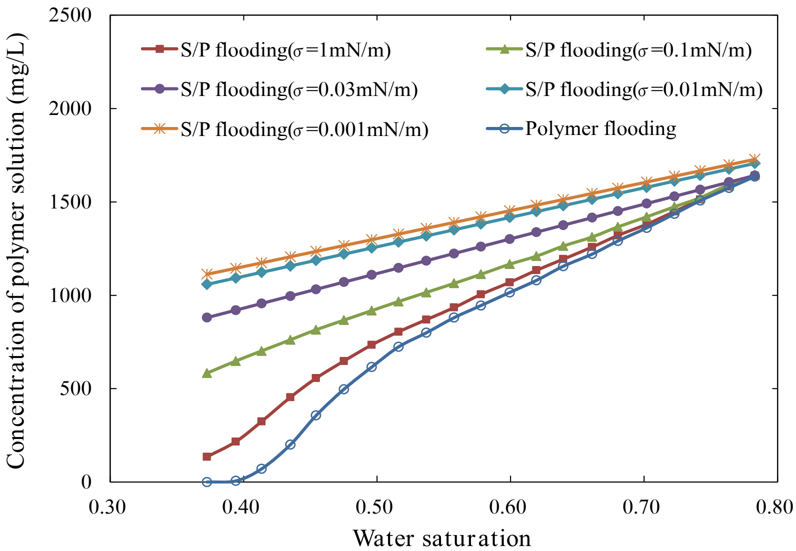

Figure 5
Mobility Control Optimization Template of J Oilfield

The minimum polymer concentration which satisfies the mobility control need can be calculated from Formula (9).

3.2 Mobility Optimization Template

The mobility control equation is applied to the actual production of J oilfield. To choose four orders of magnitude interfacial tension include 10^{-3}, 10^{-2}, 3×10^{-2}, $10^{1}$and 10^{0} mN/m, the mobility optimization template of J oil field is drawn up, as shown in Figure 5, under the same interfacial tension, the minimum polymer concentration which satisfies the mobility control need increase with water saturation increase; under the same water saturation, polymer concentration which satisfies the mobility control need increase with interfacial tension decrease. So it should be considered for the two elements include interfacial tension and water saturation for mobility control optimization.

3.3 Practical Field Application

Through test of surfactant-polymer solution from injection well head of J oilfield, the orders of magnitude of interfacial tension is 10^{-3} mN/m, consideration of surfactant dilution and adsorptive loss from rock in reservoir, the orders of magnitude of interfacial tension should be in the range of 10^{-2}~10^{-3} mN/m, It can be seen from the template, water saturation corresponding to water cut at present in J oilfield, the polymer concentration should be greater than 1,500 mg/L, but the actual polymer concentration is 1,200 mg/L at that time, that didn't meet the mobility control demand. Raise the actual polymer concentration to 1,500 mg/L, it can be seen from Figure 6, water cut decreased by 1.7% and peak daily oil production increased by 15% in J oilfield, there's a significant effect of decrease water and increase oil through mobility optimization.

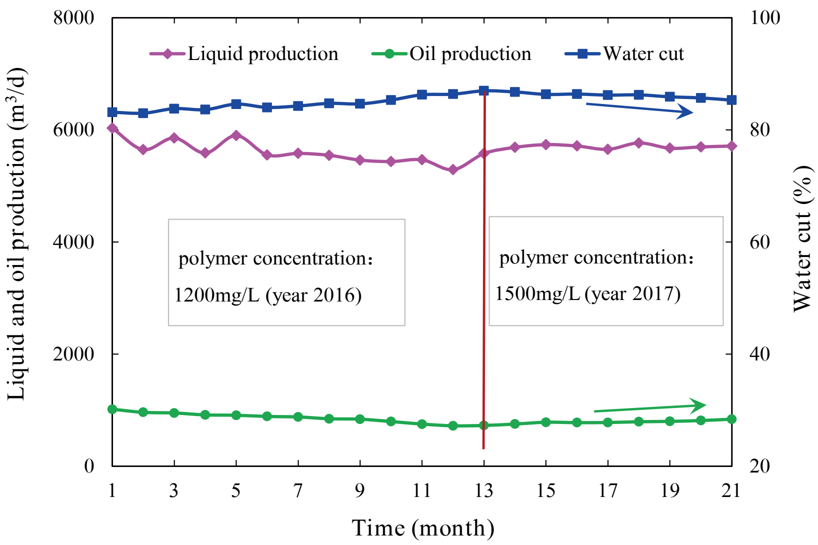

Figure 6
Effect of Mobility Optimization in J Oilfield

CONCLUSION

(a) The polymer flooding turned into surfactant-polymer flooding directly in J oilfield, water flooding derivative curve method can't judge the response time effectively, derivation and establishes of water cut decline curve model can efficiently judge the response time.

(b) The seepage resistance increases when water flooding turned into polymer flooding, so the slope of Hall curve increase; but when polymer flooding turned into surfactant-polymer flooding, the slope of Hall curve decrease.

(c) Based on the idea of mobility control, the mobility optimization template of J oilfield was studied for surfactant-polymer flooding, and the effect of chemical flooding was enhanced availably through mobility optimization.

REFERENCES

[1] Song, H. B. (2014). Research of surfactant-polymer flooding response characteristics and influencing factors-case of Gudong Oilfield. *Natural Gas Geoscience, 25*(S1), 98-106.

[2] Xia, H. F., Huang, Q. J., & Ma, W. G., et al. (2010). The effect of polymer/ betaine surfactant compound system on residual oil after polymer flooding in Daqing oilfield. *Oilfield Chemistry, 27*(2), 162-165.

[3] Xia, H. F., Jia, Y., & Wang, G. (2010). Study on enhancing the recovery factor of residual oil by polymer/ surfactant compound system after polymer flooding. *Journal of Xi'an Shiyou University (Natural Science Edition), 25*(1), 45-49.

[4] Wang, R. J., Lu, X. G., & Niu, L. W., et al. (2009). Study on surfactant/ polymer flooding technology for under-productive oil layers in development zone of the north Saertu of Daqing Oilfield. *Offshore Oil, 29*(3), 57-62.

[5] Zhou, S. W., Han, M., & Zhang, J. (2007). Study on polymer for chemical flooding in offshore oilfield of China. *China Offshore Oil & Gas, 19*(1), 25-29.

[6] Zhang, X. S., Sun, F. J., & Feng, G. Z. (2007). A research on influence factors of polymer flooding and its field testing in Bohai heavy oil fields. *China Offshore Oil & Gas, 19*(1), 30-34.

[7] Jiang, H. Q., Liu, R., & Zhang, X. S. (2009). An application of Type C water-drive curve to evaluation of early plymer flooding effects in offshore fields. *China Offshore Oil & Gas, 21*(6), 383-387.

[8] Zhou, F. J., Zhang, L. F., & Wang, H. J. (2010). Experimental study on relative permeability curve of polymer flooding. *Petroleum Geology & Engineering, 24*(6), 117-119.

[9] Wang, F., Ren, S., & Dai, C. L. (2005). Study on profile control by water injection wells in offshore oilfields at middle-water-cut stage. *Petroleum Drilling Techniques, 33*(3), 58-60.

[10] Zhao, F. L., Dai, C. L., & Wang, Y. F. (2006). Water control technique of enhanced oil recovery for offshore oil field. *Journal of China University of Petroleum, 30*(2), 53-58.

[11] Yang, R. F., & Yang, L. (2012). Study on new forecasting model of water cut in water-flood reservoirs. *Chinese Journal of Hydrodynamics, 27*(11), 713-718.

[12] Zhao, M., Zhao, W., & Liu, H. C. (2011). Study on the mobility design method for combination flooding. *Journal of Southwest Petroleum University (Science & Technology Edition), 33*(6), 131-134.

[13] Zhu, W. Y. (1996). A compositional simulator for channeling-control and oil-displacement with cross-linking polymer. *Petroleum Exploration & Development, 23*(1), 43-46.

[14] Hou, J., Wang, Y. D., & Chen, Y. M. (2002). A streamline method for studying mathematical mode of polymer drive. *Journal of Hydrodynamics, 17*(3), 343-351.

[15] Shao, Z. B., Chen, G., & Sun, G. (2008). A new mathematical model for polymer flooding. *Acta Petrolei Sinica, 29*(3), 409-413.