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Determination Method of Horizontal Well Polymer Injection Rate

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Abstract: In the middle and later periods of the oilfield development, with horizontal well technology being applied by some oilfields in order to improve the entirety development effect of the reservoir, thus the irregular pattern of the horizontal well and the original vertical wells is formed. In this paper, for the irregular pattern which shows in the middle and later periods of the oilfield development, the distribution function of reservoir pressure field in the irregular pattern which combines horizontal well dual pipe polymer injection with vertical wells oil extraction was derived, basing on complex potential theory and the superposition principles, and the determination method of the rational polymer injection rate of the outer and inner pipe of horizontal well in the irregular pattern was put forward. The determination method of horizontal well rational polymer injection rate in the irregular pattern was applied to waterflood Gao 246 Block in Liaohe Oilfield, the rational polymer injection rate of horizontal well which was determined according to the method mentioned above was consistent with the result of the reference[7], which show that the determination method of the rational polymer injection rate of the outer and inner pipe of horizontal well for the irregular pattern which combines horizontal well dual pipe polymer injection with vertical wells oil extraction is correct.

Key words: Horizontal well; Vertical wells; irregular pattern; Polymer injection rate of horizontal well; Rational polymer injection rate.

Introduction

Using horizontal well to develop oil and gas field is a promising measure to increase production. The advantage of horizontal well is to improve the recovery efficiency of the polymer flooding and economic benefits [1,2]. At present, the research of the determination method of horizontal well rational polymer injection rate in the irregular pattern of horizontal well and vertical wells is mostly based on water flooding, therefore it is necessary to further study the determination method of the rational polymer injection rate.

In this paper, for the irregular pattern which shows in the middle and later periods of the oilfield development, the distribution function of reservoir pressure field in the irregular pattern which combines horizontal well dual pipe polymer injection with vertical wells oil extraction was derived, basing on complex potential theory and the superposition principles, and the determination method of the rational polymer injection rate of the outer and inner pipe of horizontal well in the irregular pattern was put forward. And the determination method of horizontal well rational polymer injection rate in the irregular pattern was applied to waterflood Gao 246 Block in Liaohe Oilfield.

1. Mathematical model

1.1 *Assumed conditions*

There is a polymer injection horizontal well of the irregular pattern in the infinite formation, and there are also n oil extraction vertical wells surrounding the horizontal well. The pressure at the supply boundary is P_e, the horizontal segment length of the polymer injection horizontal well is $2l$, the distance between the i vertical well and the horizontal segment midpoint of the polymer injection horizontal well is r_i, and the radius of the i vertical well is r_{wi}.

1.2 *The shear viscosity of polymer solution*

Based on power law fluid, the relational expression between $\dot{\gamma}$ and υ is as follows [3]:

$$\dot{\gamma} = \frac{3n+1}{n+1} \frac{\upsilon}{\sqrt{8c' k_r \phi}} \tag{1}$$

And the approximate linear relational expression between flow rate and seepage velocity is as follows [3]:

$$\upsilon = \frac{QB}{2\pi rh} \tag{2}$$

The shear viscosity of polymer solution flowing in the formation is as follows [3]:

$$\mu_s = k\left[L_c \cdot \frac{QB}{2\pi h}\right]^{n-1} r^{1-n} \tag{3}$$

where

$$L_c = \frac{3n+1}{n+1} \frac{1}{\sqrt{8c' k_r \phi}} \tag{4}$$

In the above formulae, $\dot{\gamma}$ is the shear rate, s^{-1}; n the liquidity index, non-dimension; υ the seepage rate, $\mathrm{m/s}$; c' the coefficient associated with capillary tortuosity, the range is 25/12 ~ 2.5; k_r the permeability, m^2; ϕ the formation porosity, non-dimension; Q the flow rate, m^3/s; B the volume factor, non-dimension; r the distance between the vertical well and the horizontal segment midpoint of the horizontal well, m; h the reservoir thickness, m; k the consistency coefficient, $\mathrm{Pa \cdot s^n}$.

1.3 *The distribution function of reservoir pressure field*

1.3.1 Basic relations

The horizontal segment length of the horizontal well outer pipe is $2l_o$, and the horizontal segment length of the inner pipe is $2l_i$.

$$2l_o + 2l_i = 2l \tag{5}$$

The rectangular coordinate system (x_o, y_o) with the horizontal axis of the horizontal well outer pipe as the x_o axis and the horizontal segment midpoint as the origin of coordinate is set up in the Z_o plane. The conformal transformations $Z_o = l_o \mathrm{ch} W_o$ are as follows [4]:

$$x_o = l_o \mathrm{ch}\xi_o \cos\eta_o \tag{6}$$

$$y_o = l_o \mathrm{sh}\xi_o \sin\eta_o \tag{7}$$

In the above formulae, $Z_o = x_o + iy_o$, $W_o = \xi_o + i\eta_o$.

Based on the formulae (6) and (7), the flow domain in the Z_o plane is transformed into the flow domain with the form of an infinite half strip ($\xi_o \ge 0$, $\eta_o = \pi$) in the W_o plane; the horizontal segment ($x_o \in [-l, l]$, $y_o = 0$) of the polymer injection horizontal well in the Z_o plane is transformed into the supply boundary ($\xi_o = 0$, $\eta_o \in [0, \pi]$) on the η_o axis in the W_o plane; the rectangular coordinate (x_{oi}, y_{oi}) of the i producing well ($i = 1, 2, \cdots, n$) in the Z_o plane is transformed into the rectangular coordinate (ξ_{oi}, η_{oi}) in the W_o plane, as shown in Fig.1.

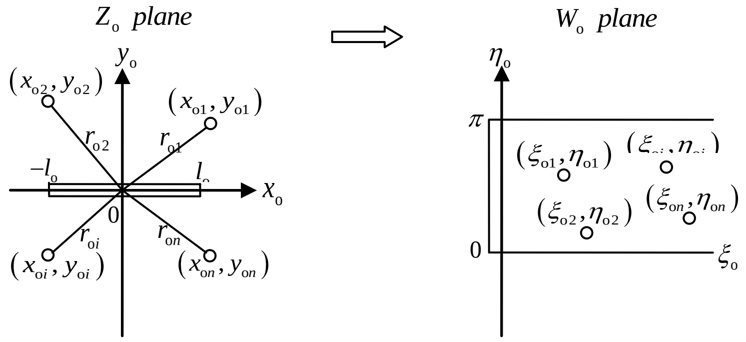

Fig.1 The flow domain transformation in the well group of horizontal well outer pipe polymer injection and vertical wells oil extraction

The coordinate transformation of the i producing well in the Z_o plane and W_o plane are as follows [4]:

$$\xi_{oi} = \ln\left[\sqrt{\frac{\left(x_{oi}^2 + y_{oi}^2 + l_o^2\right) + \sqrt{(x_{oi}^2 + y_{oi}^2 - l_o^2)^2 + 4y_{oi}^2 l_o^2}}{2l_o^2}} + \sqrt{\frac{\left(x_{oi}^2 + y_{oi}^2 - l_o^2\right) + \sqrt{(x_{oi}^2 + y_{oi}^2 - l_o^2)^2 + 4y_{oi}^2 l_o^2}}{2l_o^2}}\right] \tag{8}$$

$$\eta_{oi} = \arctan\sqrt{\frac{-\left(x_{oi}^2 + y_{oi}^2 - l_o^2\right) + \sqrt{(x_{oi}^2 + y_{oi}^2 - l_o^2)^2 + 4y_{oi}^2 l_o^2}}{\left(x_{oi}^2 + y_{oi}^2 + l_o^2\right) - \sqrt{(x_{oi}^2 + y_{oi}^2 - l_o^2)^2 + 4y_{oi}^2 l_o^2}}} \tag{9}$$

The rectangular coordinate system (x_i, y_i) with the horizontal axis of the horizontal well inner pipe as the x_i axis and the horizontal segment midpoint as the origin of coordinate is set up in the Z_i plane. The coordinate transformation of the i producing well in the Z_o plane and Z_i plane are as follows:

$$x_{ii} = x_{oi} - l \tag{10}$$

$$y_{ii} = y_{oi} \tag{11}$$

Similarly, the flow system in the W_i plane (the image plane) is transformed from the Z_i plane (the real plane) with the conformal transformations.

The coordinate transformation of the i producing well in the Z_i plane and W_i plane are as follows [4]:

$$\xi_{ii} = \ln\left[\sqrt{\frac{\left(x_{ii}^2 + y_{ii}^2 + l_i^2\right) + \sqrt{(x_{ii}^2 + y_{ii}^2 - l_i^2)^2 + 4y_{ii}^2 l_i^2}}{2l_i^2}} + \sqrt{\frac{\left(x_{ii}^2 + y_{ii}^2 - l_i^2\right) + \sqrt{(x_{ii}^2 + y_{ii}^2 - l_i^2)^2 + 4y_{ii}^2 l_i^2}}{2l_i^2}}\right] \tag{12}$$

$$\eta_{ii} = \arctan\sqrt{\frac{-\left(x_{ii}^2 + y_{ii}^2 - l_i^2\right) + \sqrt{(x_{ii}^2 + y_{ii}^2 - l_i^2)^2 + 4y_{ii}^2 l_i^2}}{\left(x_{ii}^2 + y_{ii}^2 + l_i^2\right) - \sqrt{(x_{ii}^2 + y_{ii}^2 - l_i^2)^2 + 4y_{ii}^2 l_i^2}}} \tag{13}$$

1.3.2 The distribution function of reservoir pressure field

Based on complex potential theory and the superposition principles, the reservoir potential function (Φ) of the irregular pattern which combines horizontal well with vertical wells is as follows [5]:

$$\Phi = \sum_{i=1}^{n} \frac{Q_{oi}}{4\pi h} \ln\left\{\frac{\left[\mathrm{ch}(\xi_o - \xi_{oi}) - \cos(\eta_o - \eta_{oi})\right]\left[\mathrm{ch}(\xi_o - \xi_{oi}) - \cos(\eta_o + \eta_{oi})\right]}{\left[\mathrm{ch}(\xi_o + \xi_{oi}) - \cos(\eta_o - \eta_{oi})\right]\left[\mathrm{ch}(\xi_o + \xi_{oi}) - \cos(\eta_o + \eta_{oi})\right]}\right\}$$
$$+ \sum_{i=1}^{n} \frac{Q_{ii}}{4\pi h} \ln\left\{\frac{\left[\mathrm{ch}(\xi_i - \xi_{ii}) - \cos(\eta_i - \eta_{ii})\right]\left[\mathrm{ch}(\xi_i - \xi_{ii}) - \cos(\eta_i + \eta_{ii})\right]}{\left[\mathrm{ch}(\xi_i + \xi_{ii}) - \cos(\eta_i - \eta_{ii})\right]\left[\mathrm{ch}(\xi_i + \xi_{ii}) - \cos(\eta_i + \eta_{ii})\right]}\right\} + C \tag{14}$$

In the above formula, Q_{oi} is the production of the i producing well which is displaced by horizontal well outer pipe polymer injection, $\mathrm{m^3 \cdot s^{-1}}$; Q_{ii} is the production of the i producing well which is displaced by horizontal well inner pipe polymer injection, $\mathrm{m^3 \cdot s^{-1}}$; h the effective thickness of the reservoir, m; C the constant which can be determined by the potential of the supply boundary, $\mathrm{m^2 \cdot s^{-1}}$.

The formula $\Phi = \frac{k}{\mu} p$ and the shear viscosity μ_s which is determined by the formula (3) are substituted into the formula (14). The distribution function of reservoir pressure field in the irregular pattern which combines horizontal well with vertical wells is given as follows:

$$p = \sum_{i=1}^{n} \frac{\mu_s Q_{oi}}{4\pi K h} \ln \left\{ \frac{[\mathrm{ch}(\xi_o - \xi_{oi}) - \cos(\eta_o - \eta_{oi})]}{[\mathrm{ch}(\xi_o + \xi_{oi}) - \cos(\eta_o - \eta_{oi})]} \frac{[\mathrm{ch}(\xi_o - \xi_{oi}) - \cos(\eta_o + \eta_{oi})]}{[\mathrm{ch}(\xi_o + \xi_{oi}) - \cos(\eta_o + \eta_{oi})]} \right\}$$
$$+ \sum_{i=1}^{n} \frac{\mu_s Q_{ii}}{4\pi K h} \ln \left\{ \frac{[\mathrm{ch}(\xi_i - \xi_{ii}) - \cos(\eta_i - \eta_{ii})]}{[\mathrm{ch}(\xi_i + \xi_{ii}) - \cos(\eta_i - \eta_{ii})]} \frac{[\mathrm{ch}(\xi_i - \xi_{ii}) - \cos(\eta_i + \eta_{ii})]}{[\mathrm{ch}(\xi_i + \xi_{ii}) - \cos(\eta_i + \eta_{ii})]} \right\} + C_1 \quad (15)$$

In the above formula, μ_s is the shear viscosity of polymer solution flowing in the formation, $\mathrm{Pa \cdot s}$; K the formation permeability, m^2.

The bottom hole flowing pressure p_{wfi} of the i producing well is given as follows:

$$p_{wfi} = \sum_{\substack{j=1 \\ j \neq i}}^{n} \frac{\mu_s Q_{oj}}{4\pi K h} \ln \left\{ \frac{[\mathrm{ch}(\xi_{oi} - \rho_{owi} - \xi_{oj}) - \cos(\eta_{oi} - \eta_{oj})]}{[\mathrm{ch}(\xi_{oi} - \rho_{owi} + \xi_{oj}) - \cos(\eta_{oi} - \eta_{oj})]} \frac{[\mathrm{ch}(\xi_{oi} - \rho_{owi} - \xi_{oj}) - \cos(\eta_{oi} + \eta_{oj})]}{[\mathrm{ch}(\xi_{oi} - \rho_{owi} + \xi_{oj}) - \cos(\eta_{oi} + \eta_{oj})]} \right\}$$
$$+ \frac{\mu_s Q_{oi}}{4\pi K h} \ln \left\{ \frac{[\mathrm{ch}(\rho_{owi}) - 1]}{[\mathrm{ch}(2\xi_{oi} - \rho_{owi}) - 1]} \frac{[\mathrm{ch}(\rho_{owi}) - \cos(2\eta_{oi})]}{[\mathrm{ch}(2\xi_{oi} - \rho_{owi}) - \cos(2\eta_{oi})]} \right\}$$
$$+ \sum_{\substack{j=1 \\ j \neq i}}^{n} \frac{\mu_s Q_{ij}}{4\pi K h} \ln \left\{ \frac{[\mathrm{ch}(\xi_{ii} - \rho_{iwi} - \xi_{ij}) - \cos(\eta_{ii} - \eta_{ij})]}{[\mathrm{ch}(\xi_{ii} - \rho_{iwi} + \xi_{ij}) - \cos(\eta_{ii} - \eta_{ij})]} \frac{[\mathrm{ch}(\xi_{ii} - \rho_{iwi} - \xi_{ij}) - \cos(\eta_{ii} + \eta_{ij})]}{[\mathrm{ch}(\xi_{ii} - \rho_{iwi} + \xi_{ij}) - \cos(\eta_{ii} + \eta_{ij})]} \right\}$$
$$+ \frac{\mu_s Q_{ii}}{4\pi K h} \ln \left\{ \frac{[\mathrm{ch}(\rho_{iwi}) - 1]}{[\mathrm{ch}(2\xi_{ii} - \rho_{iwi}) - 1]} \frac{[\mathrm{ch}(\rho_{iwi}) - \cos(2\eta_{ii})]}{[\mathrm{ch}(2\xi_{ii} - \rho_{iwi}) - \cos(2\eta_{ii})]} \right\} + C_1 \quad (16)$$

where
$$\rho_{owi} = \left| \frac{\mathrm{d}W_o}{\mathrm{d}Z_o} \right| r_{wi} = \frac{r_{wi}}{l_o \sqrt{(\mathrm{ch}^2 \xi_{oi} - \cos^2 \eta_{oi})}} \quad (17)$$

$$\rho_{iwi} = \left| \frac{\mathrm{d}W_i}{\mathrm{d}Z_i} \right| r_{wi} = \frac{r_{wi}}{l_i \sqrt{(\mathrm{ch}^2 \xi_{ii} - \cos^2 \eta_{ii})}} \quad (18)$$

In order to solve the problem of using inequality of the dual pipe horizontal segment of polymer injection horizontal well, the velocity of dual pipe polymer injection is ensured to be the same [5]:

$$v_{\xi_{oi}} = v_{\xi_{ii}} \quad (19)$$

where
$$v_{\xi_{oi}} = \frac{\mathrm{d}\Phi(\xi_o, \eta_{oi})}{\mathrm{d}\xi_o} \quad (20)$$

$$v_{\xi_{ii}} = \frac{\mathrm{d}\Phi(\xi_i, \eta_{ii})}{\mathrm{d}\xi_i} \quad (21)$$

In the above formulae, $v_{\xi_{oi}}$ is the seepage velocity of the horizontal well outer pipe to the i producing well, $\mathrm{m \cdot s^{-1}}$; $v_{\xi_{ii}}$ is the seepage velocity of the horizontal well inner pipe to the i producing well, $\mathrm{m \cdot s^{-1}}$.

The injection-production ratio of the pattern is assumed to be 1, and under the condition of the bottom hole flowing pressure p_{wfi} of each producing well is known, then the production of each producing well can be calculated by the formulae (16) and (19). The injection rate Q_{ho} of the polymer injection horizontal well outer pipe can be obtained as $Q_{ho} = \sum_{i=1}^{n} Q_{oi}$ and the injection rate Q_{hi} of the polymer injection horizontal well inner pipe can be obtained as $Q_{hi} = \sum_{i=1}^{n} Q_{ii}$.

1.4 *The oil displacement efficiency*

In the mainstream line from the polymer injection horizontal well outer pipe to the producing well in the Z_o plane, the seepage velocity of any point in the y_o direction is as follows [6,7]:

$$v_{y_o} = \frac{\partial \Phi}{\partial y_o}\Big|_{\eta_o = \eta_{oi}} \tag{22}$$

Along the mainstream line, the time t_{oi} for polymer flowing from the wall $(y_o = 0)$ of the polymer injection horizontal well outer pipe to the bottom hole $(y_o = y_{oi})$ of the i producing well is given as follows:

$$t_{oi} = \int_0^{y_{oi}-\rho_{owi}} \frac{dy_o}{v_{y_o}} \tag{23}$$

In the mainstream line from the polymer injection horizontal well inner pipe to the producing well in the Z_i plane, the seepage velocity of any point in the y_i direction is as follows [6,7]:

$$v_{y_i} = \frac{\partial \Phi}{\partial y_i}\Big|_{\eta_i = \eta_{ii}} \tag{24}$$

Along the mainstream line, the time t_{ii} for polymer flowing from the wall $(y_i = 0)$ of the polymer injection horizontal well inner pipe to the bottom hole $(y_i = y_{ii})$ of the i producing well is given as follows:

$$t_{ii} = \int_0^{y_{ii}-\rho_{iwi}} \frac{dy_i}{v_{y_i}} \tag{25}$$

The oil displacement efficiency E_a is given as follows:

$$E_a = \frac{\sum_{i=1}^{n}\left(Q_{oi}t_{oi} + Q_{ii}t_{ii}\right)}{\phi A h} \tag{26}$$

In the above formula, A is the pattern area, m^2.

1.5 *The rational bottom hole flowing pressure*

1.5.1 The maximum rational bottom hole flowing pressure of the polymer injection well is as follows [8,9]:

$$p_{iwfmax} = p_f\left(1 - X\right) \tag{27}$$

where $$p_f = H_m Y \tag{28}$$

In the above formula, p_{iwfmax} is the maximum rational bottom hole flowing pressure of the polymer injection well, MPa; p_f the formation fracture pressure, MPa; X the fracture probability, non-dimension; H_m the midpoint of pay zone, m; Y the fracture pressure gradient, $MPa \cdot m^{-1}$.

1.5.2 The minimum rational bottom hole flowing pressure of the producing well is as follows [8,9]:

$$p_{wfmin} = p_p + 0.01\gamma_m\left(H_m - H_p\right) \tag{29}$$

In the above formula, p_{wfmin} is the minimum rational bottom hole flowing pressure of the producing well, MPa; p_p the rational pump inlet pressure, MPa; γ_m the relative density of mixture in the production well bore, non-dimension; H_p the pump setting depth, m.

Calculation method

The determination method of the rational polymer injection rate of the outer and inner pipe of horizontal well in the irregular pattern which combines horizontal well with vertical wells are as follows [7]:

(1) According to the consistency coefficient k, the liquidity index n, the permeability k_r, the formation porosity ϕ, the volume factor B, the reservoir thickness h, and the distance r between the oil extraction vertical wells and the horizontal segment midpoint of the horizontal well, the shear viscosity μ_s of polymer solution flowing in the formation is calculated through the formula (3).

(2) The rectangular coordinate (x_{oi}, y_{oi}) of the vertical wells in the Z_o plane are transformed into the corresponding rectangular coordinate (ξ_{oi}, η_{oi}) in the W_o plane through the formulae (8) and (9). The corresponding rectangular coordinate (x_{ii}, y_{ii}) of the vertical wells in the Z_i plane are calculated through the formulae (10) and (11). According to the rectangular coordinate (x_{ii}, y_{ii}), the corresponding rectangular coordinate (ξ_{ii}, η_{ii}) of the vertical wells in the W_i plane are calculated through the formulae (12) and (13).

(3) According to the average formation permeability K, the reservoir thickness h and the shear viscosity

μ_s, the distribution function of reservoir pressure field in the irregular pattern which combines horizontal well with vertical wells is calculated through the formula (15).

(4) According to the midpoint of pay zone H_m, the pump setting depth H_p, the relative density γ_m of mixture in the production well bore, the formation fracture pressure p_f, the fracture probability X and the fracture pressure gradient Y, the maximum rational bottom hole flowing pressure p_{iwfmax} of the polymer injection horizontal well is calculated through the formula (27) and the minimum rational bottom hole flowing pressure p_{wfimin} of oil extraction vertical wells are calculated through the formula (29).

(5) The production Q_{oi} and Q_{ii} of each producing well and the injection rate Q_{ho} of the outer pipe and the injection rate Q_{hi} of the inner pipe of the polymer injection horizontal well are calculated through the formulae (16) and (19). The oil displacement efficiency E_{a} is calculated through the formula (26).

(6) According to the above steps, different injection rate Q_{ho} of the outer pipe and injection rate Q_{hi} of the inner pipe of the polymer injection horizontal well and oil displacement efficiency E_{a} are calculated, when the oil displacement efficiency reaches maximum, then the corresponding injection rates are the rational polymer injection of the outer pipe Q_{oo} and the rational polymer injection of the inner pipe Q_{io} of the polymer injection horizontal well.

Calculation example

The determination method of the rational polymer injection rate of the outer and inner pipe of horizontal well in the irregular pattern which combines horizontal well with vertical wells was applied to waterflood Gao 246 Block in Liaohe Oilfield.

In order to improve development effect of water injection, the pilot test of horizontal well water injection was carried out by waterflood Gao 246 Block in Liaohe Oilfield. There are 10 vertical wells around the Gao 246 Block G2-H16 water injection horizontal well, as shown in Fig.2. The midpoint of pay zone H_m of the Gao 246 Block is $1560\,\text{m}$, the average effective thickness of reservoir h is $57.74\,\text{m}$, the formation porosity ϕ is 0.218, the oil-bearing area A is $2.39\,\text{km}^2$, the average permeability k of main oil layer is $1.748\,\mu\text{m}^2$, the outer pipe horizontal segment length of the G2-H16 water injection horizontal well $2l_{\text{o}}$ is $120.98\,\text{m}$, and the horizontal segment length of the inner pipe $2l_{\text{i}}$ is $222.12\,\text{m}$.

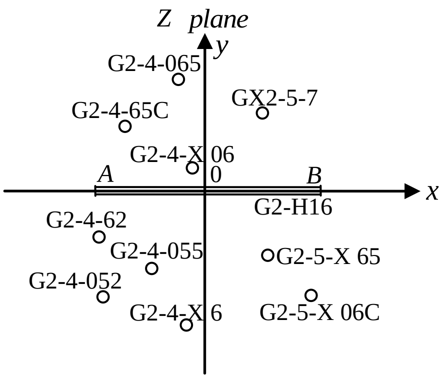

Fig.2 The location of the Gao 246 Block G2-H16 horizontal well

The relationship between water injection rate of the outer and inner pipe and oil displacement efficiency of the waterflood Gao 246 Block G2-H16 horizontal well in Liaohe Oilfield is shown in Fig.3. Figure 3 presents when the average daily water injection rate of the outer pipe is about $27\,\text{m}^3/\text{d}$, and the average daily water injection rate of the inner pipe is about $46\,\text{m}^3/\text{d}$, the oil displacement efficiency reaches maximum, which is consistent with the result of the reference [7]. Thus the determination method of the rational polymer injection rate of the outer and inner pipe of horizontal well in the irregular pattern which combines horizontal well dual pipe polymer injection with vertical wells oil extraction is correct.

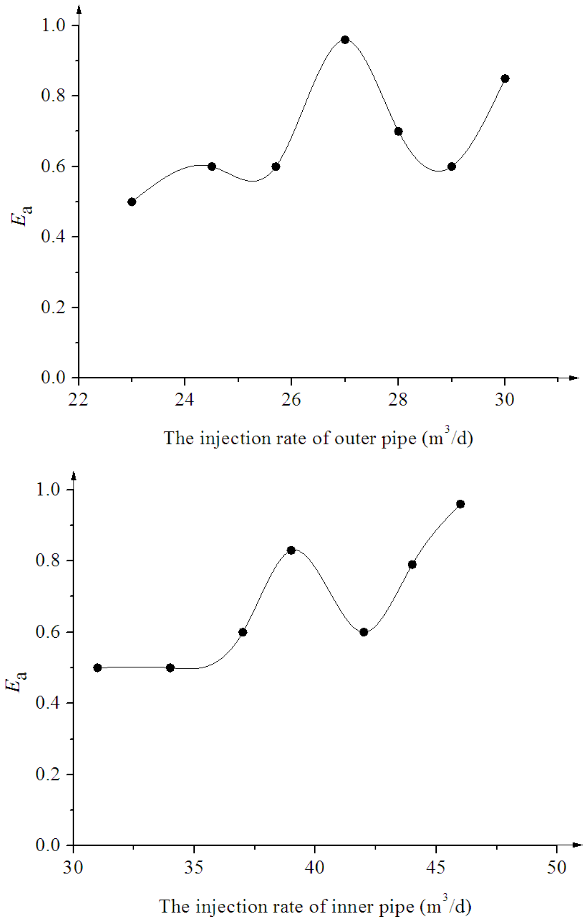

Fig.3 The relationship between water injection rate and oil displacement efficiency of the Gao 246 Block G2-H16 horizontal well

Conclusions

(1) Based on complex potential theory and the superposition principles, the distribution function of reservoir pressure field in the irregular pattern which combines horizontal well with vertical wells was derived.

(2) Based on the distribution function of reservoir pressure field in the irregular pattern which combines horizontal well with vertical wells, the determination method of the rational polymer injection rate of the outer and inner pipe of horizontal well was put forward.

(3) The rational injection rate of the horizontal well outer and inner pipe which was determined by the method applied to waterflood Gao 246 Block in Liaohe Oilfield is consistent with the result of the reference [7]. Thus the determination method of the rational polymer injection rate of the outer and inner pipe of horizontal well in the irregular pattern which combines horizontal well dual pipe polymer injection with vertical wells oil extraction is correct.

References

[1] X. Liu, W. G. Lu, F. An. Horizontal well combination of tertiary oil recovery [J]. Oil-Gasfield Surface Engineering, 2005, 24(12): 23-24.

[2] S. D. Joshi. Cost/Benefit of horizontal wells[C].SPE83621, 2003: 226–230.

[3] S. Y. Zhang, H. Q. Cui. Study on characteristics of oil well inflow performance of ASP flooding [J]. Science Technology and Engineering, 2010, 10(18): 95-100.

[4] D. B. Qu, J. L. Ge, D. M. Wang. The theoretical research of combined area well pattern of horizontal well and vertical wells-the 5-spot well pattern[J]. Petroleum Exploration and Development, 1995, 22(1): 35-38.

[5] J. L. Ge, D. M. Wang, D. B. Qu. The theoretical research of combined area well pattern of horizontal well

and vertical wells-the 7-spot well pattern[J]. Petroleum Exploration and Development, 1995, 22(2): 47-50.

[6] H. Ferreira. Simulation studies of waterflood performance with horizontal wells[C].SPE35208, 1996: 375–383.

[7] B. C. Gao, J. P. Yu, S. Y. Zhang et al. The determination of horizontal well injection in irregular pattern[C]. The 9th national congress on hydrodynamics and proceedings of the 22rd national conference on hydrodynamics, Beijing: Maritime Press. 2009: 569-575.

[8] Y. P. Li. Study on rational pressure level of waterflooding reservoir [J]. Journal of Xinjiang Petroleum Institute, 2003, 15(3): 52-56.

[9] A. M. Abbas. Feasibility of oil chemical flooding through horizontal well[C]. SPE50431, 1998: 326–332.

[10] Z. X. Lang, L. H. Zhang, L. S. Cheng et al. Combined production of vertical and horizontal wells- the 5-spot well pattern [J]. Journal of China University of Petroleum, 1993, 17(6): 50-55.