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Research on Injection Capacity of Polymer Flooding in Sublayers in Daqing Oilfield

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Abstract
According to the application of numerical simulation method, this paper firstly analyzed the single factor including the reservoir parameters, chemical agent parameters, injection parameters and well spacing. And established the single factor regression formula of polymer injection pressure, then designed the orthogonal test scheme of different parameters. The paper also calculated the injection pressure increment of different scheme by the numerical simulation method, and established the multi factor quantitative formula between pressure increment and the factors based on multiple regression analysis. Through the application of field examples, the error between the calculation result of model and the actual result is within the allowable range of project. After Verifying the reliability of injection capacity model, it could provide theoretical support for injection capacity analysis of polymer flooding and injection scheme design.

Key words: Numerical simulation method; Polymer flooding; Orthogonal test scheme; Injection pressure increment; Multiple regression analysis

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INTRODUCTION

The basic principle of polymer flooding technology is adjusting the mobility ratio of oil-water two-phase and reducing the permeability of water phase to expand the sweep volume by increment the injected fluid viscosity[1] polymer flooding in sub-layers has get the stage of industrialization promotion[2]. Because of low permeability of the reservoir, small development scale of sand body and the physical property of reservoir which is significantly worse than the major reservoir, The injection pressure of polymer flooding in sub-layers was obvious higher than that of the major reservoir[3-4]. What's more, The injection pressure relate to reservoir sweep status, and be limited by formation breakdown pressure and injection capacity of injection equipment[5-6]. So it is necessary to carry on the injection ability analysis of polymer flooding and injection scheme optimization. The actual field and theoretical studies indicate that the average permeability, viscosity of polymer injection, residual resistance factor, Injection of polymer slug size, polymer injection rate and well spacing play the main role among all influence parameters of polymer flooding pressure increment in sub-layers. By studying on the effect that the parameters have on injection pressure in polymer flooding process of sub-layers, this paper build the relationship between the injection pressure increment of sub-layers and all parameters. It is significant for injection capacity analysis of polymer flooding, Injection scheme design, reasonable control of injection pressure and enhanced recovery.

1. THE ESTABLISHMENT OF TYPICAL NUMERICAL SIMULATION CONCEPT MODEL

Apply the Eclipse numerical simulation software to establish numerical simulation model. The model uses Cartesian grid, and length and width of the reservoir are both 927.5 m. It is divided into 53 × 53 grid system on the plane, and the size of every block is 17.5 × 17.5 m. It is divided into five layers longitudinally, among them the 2nd and the 4th layers are interlayers. The model is positive rhythm reservoir, and the porosity values f upper, middle and lower layers are respectively 0.2, 0.25 and 0.3. The thickness of each layer is 4 m. The reservoir model uses line well pattern for production.

The Tables 1 and 2 show the main basic data used in the model. The Figure 1 is the three-dimensional figure of the reservoir geological model.

Table 1
Basic Data of the Reservoir Geological Model

Reservoir parameters	Values	Reservoir parameters	Values
Depths of top faces/m	1,000	Underground oil viscosity /mPa·s	10
Average permeability /10^{-3}μm^2	400	Underground oil density /kg/m^3	890
Average porosity	0.25	Underground water viscosity /mPa·s	0.5
Kv/Kh	0.01	Crude oil volume factor	1.1
Initial reservoir pressure/MPa	10	Variation coefficient of permeability	0.7

Table 2
Main Parameters Used for the Base Program of Polymer Flooding

Parameter name	Values	Parameter name	Values
Water cut before polymer injection (%)	90	Injection rate of polymer (PV/a)	0.2
Inaccessible pore volume	0.2	Residual resistance factors	2
Maximum adsorbance (ug/g)	110	Polymer slug (mg/L·PV)	1,000

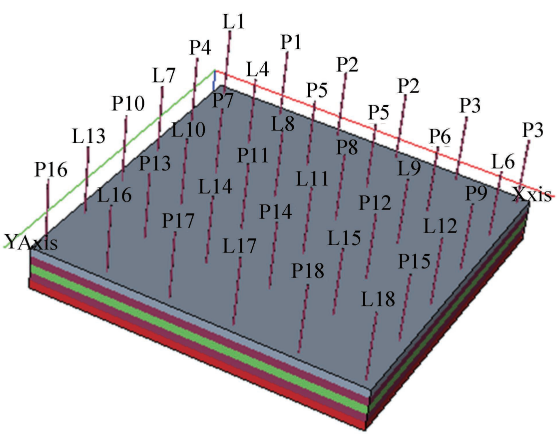

Figure 1
Three-Dimensional Figure of the Reservoir Geological Model

2. ANALYSIS OF INFLUENCING FACTORS ABOUT INJECTION CAPACITY OF THE POLYMER FLOODING

In order to study the effect of various parameters on the injection pressure, we apply univariate analysis to the influencing parameters of injection pressure. Under the premise of other parameters which are constant, we respectively study these parameters that is the average permeability, viscosity of polymer solution, residual resistance coefficient, slug size, injection rate of the polymer and well spacing have an influence on injection pressure[7-9]. The influence result of different parameters on injection pressure of polymer flooding for sub-layers are shown in Figures 2-7.

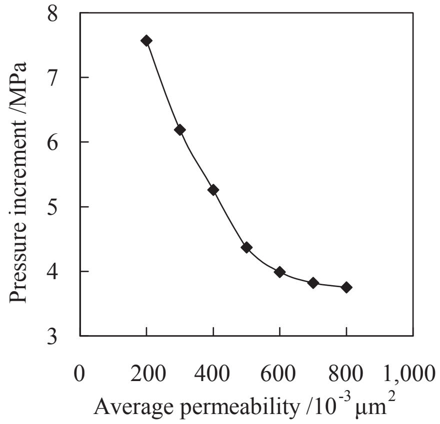

Figure 2
Effect of Average Permeability

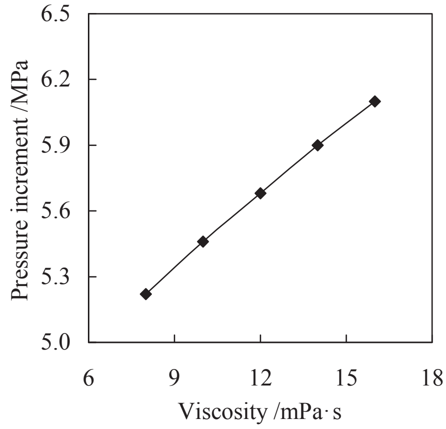

Figure 3
Effect of Viscosity

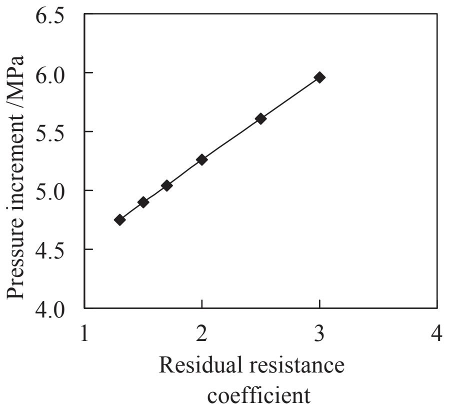

Figure 4
Effect of Residual Resistance Coefficient

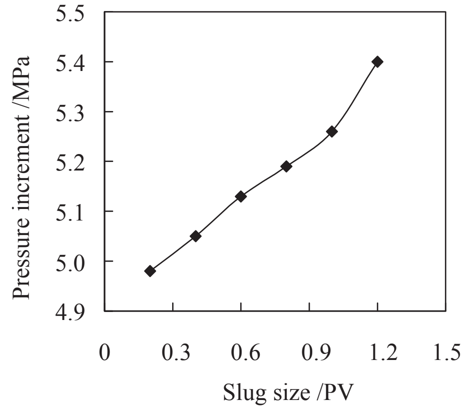

Figure 5
Effect of Slug Size

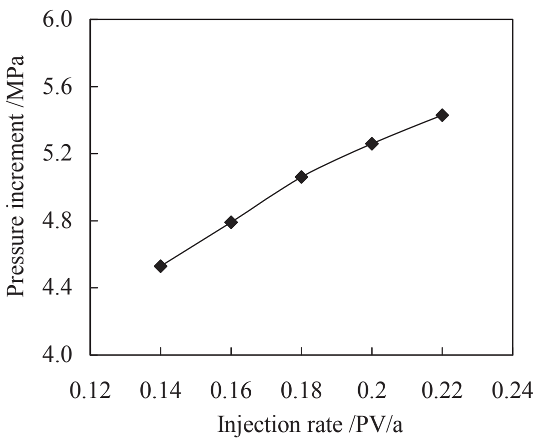

Figure 6
Effect of Injection Rate

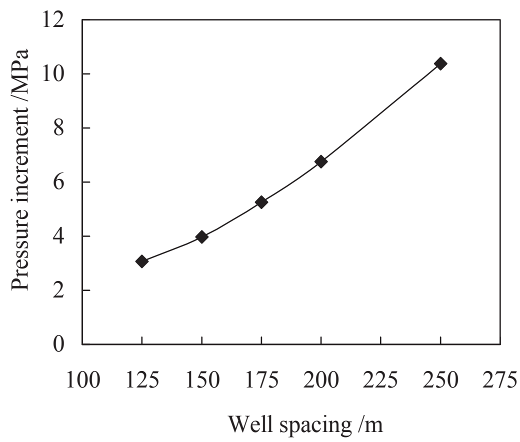

Figure 7
Effect of Well Spacing

From Figure 2 to 7, you can see that the permeability have a significant influence on the injection pressure of polymer flooding. With the decrease of the permeability, the injection pressure of polymer flooding increases significantly .With the increase of viscosity, it is linear relationship between pressure increment and viscosity. By Darcy's law, under the same injection rate, the relationship between pressure difference and viscosity is linear. As a result, the relationship between pressure increment and the viscosity is roughly linear .Under the same adsorption quantity, if the corresponding residual resistance coefficient increases, the injection pressure increases significantly. That is because the bigger the residual resistance coefficient is, the smaller the water phase permeability is, the greater resistance of the displace slug flow is, the greater the pressure increment of injection well. The pressure increases with the increase of slug length which is caused by the big chemical dosage, the broader slug spreading, the greater resistance. With the increase of injection rate, the pressure increment increases significantly. According to the Darcy's law, the pressure difference is proportional to the water injection rate, so the injection pressure increases gradually. Under the same rate of injection-production and reservoir conditions, with the increase of well spacing, pressure increases quickly after polymer flooding. This is because the longer the spacing, the greater the flow resistance of displacing agent, so the pressure increment is bigger.

3. POLYMER FLOODING INJECTION CAPACITY MODEL AND ITS VERIFICATION

As can be seen from the research of polymer flooding in this paper, because of the existence of the polymer, the viscosity of the injected water increases and the water phase permeability reduces, which lead to the increase of percolation resistance and injection pressure. The injection pressure increment is affected by various factors, before the implementation of polymer flooding project, it is necessary to take various factors into account and design the injection and production parameters reasonably to prevent the well bottom hole pressure of injection well exceeding the reservoir fracturing pressure[10].

Through the single factor analysis of polymer flooding in this paper, by means of data analysis software 1st Opt 6.0 to perform regression relationship between the injection pressure increment and various factors.

Table 3
The Pressure Increment in Single Factor Regression Type

Influence factor	Pressure increment (MPa)	Correlation coefficient
Well spacing	$\Delta P = (3.9\text{E-}04)r^{1.8439}$	$R^2 = 0.9983$
Permeability	$\Delta P = 128.82K^{-0.5347}$	$R^2 = 0.9985$
Injection rate	$\Delta P = 11.34V+2.971$	$R^2 = 0.9907$
Viscosity	$\Delta P = 0.11\mu+4.352$	$R^2 = 0.9990$
Residual resistance coefficient	$\Delta P = 0.7106R_k+3.8322$	$R^2 = 0.9999$
Slug size	$\Delta P = 0.192SL^2+0.1113SL+4.959$	$R^2 = 0.9995$

It can be seen from Table 3, in the case that all other factors are constant, it is power relationship between well spacing, permeability and the pressure increment; it is linear relationship between injection rate, viscosity, residual resistance coefficient and the pressure increment. And it is secondary heterogeneous type relationship between slug size and the pressure increment. The coefficient of determination between every factor and formula of the pressure increment is close to 1, and goodness of fit is higher. In this paper, by means of orthogonal experimental method and multiple regression analysis, it established multifactor quantitative type between the pressure increase and other factors. Specific methods are as follows.

Considering six factors which are well spacing, injection speed, viscosity, reservoir permeability and residual resistance coefficient and slug size, we use L2556 orthogonal design table. Each factor takes five levels. We designed 25 sets of plan for it to study the water injection pressure of polymer flooding. The factor level tables of various factors are shown in Table 4. The design and the calculation results are shown in Table 5.

Table 4
Levels of Every Factor

Level	Well spacing (m)	Injection rate (PV/a)	Permeability (10^{-3} μm^2)	Viscosity (mPa·s)	Residual resistance coefficient	Slug size (PV)
1	125	0.14	200	8	1.3	0.4
2	150	0.16	300	10	1.5	0.6
3	175	0.18	400	12	1.7	0.8
4	200	0.2	600	14	2	1
5	250	0.22	800	16	2.5	1.2

Table 5
The Experimental Results and Analysis of Variance

Scheme	Well spacing (m)	Injection rate (PV/a)	Permeability (10^{-3} μm^2)	Viscosity (mPa·s)	Residual resistance coefficient	Slug size (PV)	Pressure increment (MPa)
1	1	1	1	1	1	1	3.99
2	1	2	2	2	2	2	3.01
3	1	3	3	3	3	3	2.88
4	1	4	4	4	4	4	2.67
5	1	5	5	5	5	5	2.98
6	2	1	2	3	4	5	4.85

To be continued

Continued

Scheme	Well spacing (m)	Injection rate (PV/a)	Permeability (10^{-3} μm^2)	Viscosity (mPa·s)	Residual resistance coefficient	Slug size (PV)	Pressure increment (MPa)
7	2	2	3	4	5	1	4.15
8	2	3	4	5	1	2	3.05
9	2	4	5	1	2	3	1.95
10	2	5	1	2	3	4	6.57
11	3	1	3	5	2	4	4.98
12	3	2	4	1	3	5	3.62
13	3	3	5	2	4	1	3.36
14	3	4	1	3	5	2	7.94
15	3	5	2	4	1	3	6.19
16	4	1	4	2	5	3	4.88
17	4	2	5	3	1	4	4.34
18	4	3	1	4	2	5	9.46
19	4	4	2	5	3	1	7.82
20	4	5	3	1	4	3	6.72
21	5	1	5	4	3	2	8.60
22	5	2	1	5	4	3	13.11
23	5	3	2	1	5	4	11.09
24	5	4	3	2	1	5	10.14
25	5	5	4	3	2	1	9.32

Take the relationship between the pressure increment with each single factor as reference, establish the relationship between pressure increment and the six factors shown in the orthogonal Table 5 and then carry on the regression fitting. The final expression of pressure increment is as follows:

$$\Delta P = (3.75E-5)\times r^{2.2499} + 109.99\times k^{-0.4947} + 0.1115\times \mu + 0.7106\times R_k + 11.51\times V + 0.1115\times \mu + 0.7106\times R_k + 11.51\times V + 0.2086\times SL^2 + 0.0719\times SL - 9.525. \quad (1)$$

Equation (1) shows a comprehensive consideration of the main factors which influence the injection ability of polymer flooding, and it can be used to quantitatively evaluate the influence of main factors on injection ability of polymer flooding[11].

In order to evaluate the accuracy of the fitting formula, select the 1, 5, 10, 15, 20, 25 scheme in the Table 5, and a comparative study is made on the digital results and calculation results of the fitting formula. Table 6 lists the results of calculation.

The average error of each scheme in Table 6 is 1.59%, the maximum error is 3.46%. From the fitting error can be seen, the average error and the maximum error of the fitting formula are smaller, the prediction accuracy can meet the demand of mine. So we can use the establishment of polymer flooding injection capacity model carry on the design of polymer flooding injection ability.

The fitting of the obtained polymer flooding injection capacity model is applied to the actual sub-layers polymer flooding blocks. Used of the data of calculate the pressure increases is Daqing oilfield reservoir polymer flooding blocks of two kinds of practical. The calculation results of pressure increases forecast and the statistical results of actual as shown in Table 7.

Table 6
Validation of Prediction Models of Polymer Flooding Pressure Increases

Scheme	Calculation (MPa)	Fit (MPa)	Error (%)
1	3.989	3.9213	1.697
5	2.984	2.9416	1.421
10	6.566	6.5611	0.075
15	6.189	6.4033	3.463
20	6.717	6.8268	1.635
25	9.317	9.4339	1.255

Table 7
The Application Instance of Injection Capacity Model

Well name	Practice (MPa)	Fit (MPa)	Error (%)
B1-1-P52	7.29	8.03	10.15
B1-1-P54	7.02	7.62	8.55
B1-1-P58	7.04	7.53	6.96
B1-1-P60	6.11	6.78	10.97
B1-1-P62	6.22	5.63	9.49
B1-1-P68	6.84	6.85	0.15
B1-2-P134	6.62	6.76	2.11
B1-2-P135	7.86	7.29	7.25
B1-2-P136	7.82	7.04	9.97
B1-2-P138	5.7	5.27	7.54
B1-2-P139	6.34	6.94	9.46
B1-2-P140	6.42	6.49	1.09
B1-2-P141	5.11	4.81	5.87
B1-2-P36	6.37	5.81	8.79
B1-2-P39	7.1	6.49	8.59

Select the injection polymer wells of sub-layers of North Row 1 and 2 to verify the accuracy of the results, the selection of polymer injection wells should be satisfied by the conditions of little influence by polymer flooding and injection production system with perfect measure. Some calculated results be listed in Table 7, select the actual parameters of polymer injection wells as calculate the relevant parameters which used to, and polymer injection viscosity as polymer viscosity which pass the shear loss in the reservoir. As can be seen from the table, compared with the pressure increases which calculated by using the injection capacity model and the actual pressure increases, the maximum error is 10.97%, the average error is 7.13%. The calculation results meet engineering requirements, indicating that the injection capacity model of polymer flooding have a good application effect in sub-layers. Therefore, using this polymer injection capacity model can design the injection ability of polymer flooding.

CONCLUSION

In the process of sub-layers polymer flooding, injection pressure was significantly higher than that of the main layer. The pressure increment is greatly affected by the mean permeability, polymer solution viscosity, residual resistance factor, slug size, polymer injection rate, and the well spacing. The pressure increment decreases with the increment of average permeability, but it goes up with the increase of the polymer solution viscosity, residual resistance factor, slug size, polymer injection rate, and the well spacing.

In the case of other factors unchanged, the relationship between pressure increment and the well spacing and permeability is power. The pressure increment with injection rate, viscosity and residual resistance factor is the linear relationship. The pressure increment with slug size is secondary multiphase type relationship. Goodness of fit between the pressure increment formula that is obtained by single factor regression and the numerical analogue result is high. It can be used for trend analysis and prediction of the influences of various factors on the pressure increment.

With the help of orthogonal experimental method and multiple regression analysis, establish the injection capacity model. Through actual example verification, the calculation results of the model meet engineering requirements, using this model can conduct injection capacity analysis and injection scheme design about sub-layers polymer flooding.

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