

Fluid flow characteristics during polymer flooding

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Abstract. At present the main problems of polymer flooding is the high injection pressure which could not guarantee the later injection. In this paper the analyses of polymer's physical properties and its solution's variable movement characteristics in porous media reveal the inevitable trend of decrease in injection capacity and liquid production due to the increase of fluid viscosity and flow rate with more flow resistance. The injection rate makes the primary contribution to the active viscosity of the polymer solution in porous media. The higher injection rate, the greater shearing degradation and the more the viscosity loss. Besides the quantitative variation, the rate also changes qualitatively as that the injection rate demonstrates composite change of injection intensity and density. Due to the different adjustment function of the polymer solution on its injection profile, there should be different adjustment model of rates in such stages. Here in combination of the on-site recognitions, several conclusions and recommendations are made based on the study of the injection pattern adjustment during polymer flooding to improve the pressure distribution system, which would be a meaningful reference for extensive polymer flooding in the petroleum industry.

Key words: fluid flow law; Injection rate.

1. Introduction

Polymer solution is a kind of typical non-newtonian fluid due to not only its non-newtonian viscosity, but also the strong viscoelasticity of flowing in porous media [1]. In the process of field development by water drive, the mixture of oil and water can be described as a Newtonian fluid. But for polymer flooding development, because of shearing degradation, dilution, adsorption and retention etc. the fluid property of polymer flooding is more complex than that of water flooding.

2. Formation fluid characteristics during polymer flooding

2.1. Water solubility of polymers

The polymer molecules have charged groups which is able to react intensively with polar molecules through hydrogen bonds. So that water is a good solvent for polymer while oil is not. After the polymer solution flows into the formation, dipole water molecules form surrounding macromolecule of polymer a solvation layer as bound water by adsorption or hydrogen bond. At the same time due to the electrostatic repulsion of charged groups between the polymer molecules, the coil volume increases to enhance the internal friction of active molecules, then to improve the water viscosity. But herein oil phase flowing is not affected [2].



2.2. Rheological properties of polymer solutions in porous media

The polymer solution is a kind of typical non-Newtonian fluid, of which the flow behavior can describe by the law of power exponent.

$$\mu = \tau / r = H r^{n-1}$$

(μ -viscosity, τ -shearing stress, r -shearing rate, H -consistency coefficient, n - index of power exponent law.)

The working viscosity of polymer solution in the pay zone is mainly affected by the shearing rate. From several methods of calculation, the shearing rate is mainly related to the injection rate and pore throat size, such as the Pang Cheng equation.

$$r = (3n+1) Q / A \sqrt{8k\phi}$$

(Q -injection volumetric rate; A -infiltration area; K -effective permeability; ϕ -porosity.)

For the same core, the faster the injection rate, the quicker the degradation of the polymer and the greater the loss of viscosity. For cores with different permeability, under the same injection rate, the viscosity loss of polymer solution in high permeability reservoir is small, and the viscosity loss of polymer in low permeability reservoir is large.

3. Fluid flowing and its dynamic characteristics during polymer flooding

After the polymer solution is injected into the porous medium, the change of fluid flowing is mainly demonstrated in two aspects [3]:

3.1. Influence of fluid flowing rate variation on dynamic characteristics

For non-Newtonian fluids, the modified Darcy's law shows the effect of the change of fluid viscosity on various parameters.

$$v = Q/F = K\Delta P / \mu L$$

(v -infiltration rate; Q - volumetric rate; F - cross section area of fluid flowing; ΔP -fluid pressure difference; μ -fluid viscosity; K - permeability; L -length.)

From the equation above, the fluid infiltration rate (V) is directly proportional to injection strength (Q/F), permeability (K) and fluid pressure (P), but inversely proportional to the fluid viscosity (μ). With the injection of polymer solution, the viscosity of fluid in the formation is increasing, which will inevitably lead to the decline of fluid infiltration rate, the increase of infiltration resistance and the decrease of injection rate and production rate. This is the main reason why it is difficult to enhance the liquid production in the later stage of polymer flooding, although the pressure of the formation is high. From the dynamic characteristics, after polymer injection the pressure rise in injectors while the flowing pressure drops in producers with significant reduction of both water absorption index and production index (Table 1). For example, in the Block N- II by polymer flooding, water absorption index decreased by 22.58%, liquid production the index decreased by 43.15%.

3.2. Effect of fluid flow direction on dynamic characteristics

For water drive development, due to the great heterogeneity between different pay zones, inside different layers and at different surface locations, the infiltration rate of the injection fluid along the high permeability layer (mainstream line) is faster so that the middle and low permeability (non mainstream) oil layer is inhibited. Because of polymer's solubility in water, the polymer solution into the reservoir of high permeability (the main line) firstly increase the fluid viscosity herein to increase flow resistance, then to reduce the infiltration rate, so as to change fluid flow direction to the low permeability reservoir (non mainstream line). However, after the entrance of polymer solution into the middle & low permeability reservoir (non mainstream line), the increase of fluid viscosity will decrease the infiltration rate of low permeability layer (non mainstream line), and then speed up the infiltration rate of high permeability reservoir (mainstream line). Hence in the polymer flooding

process, the profile adjustment would affect the development effect of polymer flooding. At different stages of polymer flooding, the reservoirs injection profile changes. The suction capacity of high permeability declines to the highest extent during the low value period and rises continuously along with the decrease of suction capacity of low & middle permeability layers during the recovery period. From injection pressure changes of polymer flooding blocks, the initial injection pressure increased rapidly and in the water cut decline period, due to the great increase of infiltration area, low permeability layer flow more and more rapid while pressure incremental amount becomes small. Therefore, it is necessary to limit the injection pressure rise of the polymer flooding to ensure the later normal injection [4].

Table 1. Variation of absorption and liquid production index during polymer flooding at Sabei Development Zone.

Blocks	Water absorption index			liquid production index			
	Before polymer injection (m ³ /d.MPa)	After polymer injection (m ³ /d.MPa)	Reduction extent (%)	Before polymer injection (t/d.MPa)	After polymer injection (t/d.MPa)	Reduction extent (%)	Reduction difference (%)
Block N-II WE	32.29	25.00	22.58	63.45	36.07	43.15	20.57
Block N-II WW	26.07	20.50	21.37	42.46	28.49	32.9	11.53
Block N-III WE	19.90	19.69	1.06	37.63	26.22	30.32	29.26
Block N-III WW	21.80	16.36	24.95	28.74	19.42	32.43	7.47

The polymer fluid movement changes firstly surrounding the injection well. Due to the different profile adjustments by polymer at different stages, the injection production method should be adjusted (see Table 2), especially during the initial period when the profile is adjusted at low rate with displacement at high rate to control the decrease amount of both injection and liquid production capacity [5].

And the improved pressure system will guarantee the later normal injection. At the early stage of polymer injection, the main purpose is to reduce the infiltration capacity of high permeability layer (main line) through formation of slugs surrounding injection well. To reduce the degradation of the polymer, it is necessary to reduce injection intensity, to improve concentration to control the pressure rising rate, so as to provide favorable conditions for late injection concentration adjustment. At the declining period of water cut, because of the incremental of infiltration area, the increase of injection intensity and reduction of concentration at this time will not cause significant increase of injection pressure. At the same time due to the increase of amount, the working viscosity of polymer in high permeability layer (main line) will not be affected and the decrease of concentration will accelerate the decline of polymer degradation in middle & low permeability layers (non mainstream line) without plugging the surrounding area of wellbore [6]. When it comes into the low water cut period, in order to reduce water flow rate and improve oil flow rate inside layers, the injection concentration should be enhanced on the basis of injection intensity. At the same time, due to the most obvious profile control effect of the high permeability layer (main line), the relative permeability of the high permeability layer (main line) will decline with the largest amount. When it comes into the water cut recovery period, with the recovery of suction capacity in high permeability layers, deep profile adjustment could be adopted to decrease the injection intensity by improvement of polymer concentration to inhibit liquid breakthrough of fluid along the high permeability layer. For wells with obvious

contradiction the stratified injection method could be used to tap the low permeability layer (non mainstream line) potential.

Table 2. Adjustment of injection and production methods at different stage of polymer injection.

Stages	Adjustments of Injection & Production	Purposes	Characteristics of Injectors and Producers
Initial	1.Adjust profile fundamentally	Plug pay zones of high permeability (old water channel)	1.Injection pressure rises by great amount and flowing pressure of producer declines 2.Suction capacity declines in high permeability layers
	2.Reduce injection intensity and improve its concentration	Form plugs inside pay zones of high permeability surrounding wellbores	
Declining	1.Improve injection intensity and reduce its concentration	Inhibit the incremental of infiltration resistance inside pay zones of middle & low permeability surrounding wellbores and increase the infiltration rate (non-mainstream line)	1.Injection pressure keep stable and flowing pressure of producer recovers 2.Suction capacity rises with great amount in middle & low permeability layers
Low value	1. Maintain injection intensity and improve its concentration	Reduce water flow rate inside pay zones and increase oil flow rate	1.Injection pressure rises a bit 2.Suction capacity keeps relatively stable in middle & low permeability layers 3.Liquid production volume declines
	2.Stimulate reservoirs	Narrow differences inside, between layers and at horizontal locations	
Recovery	1.Adjust profile fundamentally	Inhibit the breakthrough of injected liquid along layers of high permeability	1.Injection pressure rises by great amount 2.Suction capacity rises in high permeability layers
	2. Subdivide layers	Release inter-layers contradiction	
	3.Reduce injection intensity and improve its concentration	Form plugs inside pay zones of high permeability surrounding wellbores	

Block N- II WE is the fifth polymer flooding block with water cut currently in declining period. Through the adjustment of injection pattern after polymer flooding and grasp best occasions of the effective wells, there appears an obvious characteristic as significant improvement of injection condition based on the polymer flooding effect of the Block. After the polymer injection compared to the same period, the injection pressure was significantly lower than that of other blocks (see Table 3). At the beginning time of effect the injection pressure rised by 2.0MPa with current (16 months after injection) injection pressure of 11.2MPa, while the other blocks of the injection pressure rised by 3.0-4.0MPa. If compared with the performance before polymer injection, the injection pressure rised by 3.0MPa, and the injection pressure is close to 13.0MPa at other blocks. At the beginning of effect the apparent water absorption index of Block N- II WE decreased by 46.28% while the Block N-III WW decreased by 50.56%. The injection pressure control effectively ensured the injection rate improvement after the polymer flooding effect. At present, the injection rate of the Block increased to 0.150PV/a, and the injection rate of other blocks can only stay at 0.12PV/a after a year [7].

Table 3. Comparison of flooding injection status in Sabei Development Zone.

Blocks	Fracturing Pressure (MPa)	Before Polymer Flooding			Effect Time			Currently		
		Injection Pressure (MPa)	Daily Injection (m ³)	Apparent Water absorption index (m ³ /d.MPa)	Injection Pressure (MPa)	Daily Injection (m ³)	Apparent Water absorption index (m ³ /d.MPa)	Injection Pressure (MPa)	Daily Injection (m ³)	Apparent Water absorption index (m ³ /d.MPa)
Block N- II WW	13.7	7.3	108	14.79	11.3	202	17.88	12.5	205	16.40
Block N- II WE	13.2	8.5	220	25.88	11.7	204	17.44	12.8	200	15.63
Block N-III WW	14.1	8.3	106	15.70	11.6	113	9.74	12.8	110	8.59
Block N-III WE	14.1	7.1	105	14.71	11.1	137	12.34	12.1	127	10.50
Block N- II EW	13.6	8.2	94	11.44	10.2	85	8.37	11.2	122	10.92

From the development effects in the above table, the effective time is basically the same. After injection of 5 months, the water cut began to fall. The dosage was 48PV.mg/l which is lower than Block N- II WE by 13PV.mg/l and bigger than Block N-III WW by 5PV.mg/l. In the two Blocks the average single well liquid production is 147t, bigger than that before polymer injection by 29t while the number of the other Blocks after polymer injection declines, to ensure the whole block development effect. The production rate of both geological reserves and recoverable reserves reached 4.20% and 8.22%, respectively while the corresponding recovery degrees reaches 4.10% and 7.04%, respectively which is only lower than the number of Block N- II WE (see Table 4).

Table 4. Comparison of the effect of polymer flooding in Sabei Development Zone.

Blocks	Time	Polymer dosage (PV.mg/l)	Daily liquid Production of one well (t)	Daily oil Production of one well (t)	Water Cut (%)	Production rate (%)		Stage recovery degree(%)		Enhanced oil Production by 1 ton of polymer (t)
						geological reserves	recoverable reserves	geological reserves	recoverable reserves	
Block N- II WE	Before polymer injection		162	17	89.60	2.22	4.3			
	Effective time	61	128	16	87.78	2.07	4.00	1.17	2.37	6
	17months	176	150	45	69.13	5.99	11.60	5.32	10.39	87
Block N- II WW	Before polymer injection		136	10	92.53	2.01	3.90			
	Effective time	81	139	12	92.35	2.28	4.43	0.75	1.46	4
	17months	175	118	21	82.63	4.09	7.95	2.82	4.49	29
Block N-III WW	Before polymer injection		122	8	93.55	1.68	3.00			
	Effective time	43	118	9	92.23	1.91	3.41	0.47	0.90	7
	17months	161	126	23	81.73	4.78	8.55	3.54	5.75	72
Block N- II WE	Before polymer injection		160	9	94.49	1.81	4.28			
	Effective time	113	155	11	93.00	2.18	5.17	0.50	0.98	4
	17months	184	136	19	86.52	3.64	8.60	2.08	3.26	33
Block N- II EW	Before polymer injection		118	7	93.81	1.17	3.07			
	Effective time	48	143	10	92.79	2.17	4.26	1.11	2.18	6
	17months	161	147	20	86.45	4.20	8.22	4.10	7.04	48

4. Conclusions

1. The injection rate has a great influence on the rheological properties of polymer solution, the higher injection rate, the larger shearing degradation and the greater viscosity loss. The injection rate is related to not only the quantity variation but also the concentration.

2. After the polymer injection, with the injection of polymer solution, the viscosity of the formation fluid increases to enhance the resistance and reduce flow rate with essential drop of both injection and production capacity. But injection and production adjustment through slow adjustment rate and high displacement rate can control the decline extent of injectivity and liquid productivity during the early stage of polymer injection.

3. In the whole process of polymer flooding, the profile adjustment has direct effect on the development performance. In different stages variable functions of profile adjustment by polymer solution result in different dynamic characteristics.

4. During the whole polymer flooding process, it is necessary to adjust the injection rate considering the injection intensity and concentration. In the initial stage of polymer injection, injection intensity should be reduced and injection concentration should be enhanced to some extent to control the rising injection pressure, so as to ensure the layering profile control and the second profile control in later stage of polymer flooding to improve the integral development effect.

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