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Research Article

Optimization Design Methods of Strata Combination and Injection Parameters for Strong Base ASP Flooding

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Abstract: In order to determine strata combination and optimize injection parameters. This study, making full use of laboratory core flooding experiments, field test data analysis and numerical simulation, focused on the research of strong base ASP flooding about optimum design of well pattern, well spacing, strata combination and injection pattern and parameter aiming at strong base ASP pilot test blocks and industrial promotion test block in Daqing Oilfield. The results show that: strong base ASP flooding technology is well adapted to five-spot pattern. Under the same condition, oil recovery is enhanced orderly from highness to lowness for five-spot pattern, linear pattern, four-spot pattern and inverted nine-spot pattern. The recovery rate of five-spot pattern and inversed nine-spot pattern during strong base ASP is 20.5 and 17.98%. The optimum well spacing for strong base ASP is about 125 m and the decrease of well spacing can increase the controlling area and final recovery of strong base ASP, relieve the scaling of production wells and maintain the injection and production capability. The optimum well spacing makes the best economic benefits.

Keywords: Determine strata combination, strong base ASP flooding, the mechanism of ASP flooding, the optimization of injection parameters, the optimization of injection pattern

INTRODUCTION

Alkaline Surfactant Polymer (ASP) flooding technology in Daqing began in the 80's last century, experiencing laboratory research, pilot test and industrial promotion test and now this technology is in the early stage in the industrial applications. After 30 years' research and practice of strong base Alkaline Surfactant Polymer (ASP) flooding in Daqing, the theory constraint that low acid value of crude oil is not suitable for ASP flooding has a breakthrough (Du *et al*., 2005; Cheng *et al*., 2001; Zhang *et al*., 2001) and complex system formula which is suitable for Daqing has been studied. Five Pilot tests and 5 industrial promotion tests have been carried out, all of which achieved 20% of recovery higher than water flooding (Cao *et al*., 2001; Liu, 2006; Cheng *et al*., 2009). From 2014, Daqing oilfield has used the technology in a wide range. Meanwhile, as the point of the reservoir engineering plan is whether Alkaline Surfactant Polymer (ASP) flooding can realize good application effect, so the series of layer combination and optimization design method of flooding has important theoretical meaning and engineering value. This study carries out the further study of well pattern & well spacing, series of layers combination, injection pattern and injection parameter optimization design methods for the pilot test blocks and the industrial test blocks of Alkaline Surfactant Polymer (ASP) flooding technology in Daqing oilfield, which comprehensively used laboratory core displacement experiment, oilfield test data analysis and numerical simulation method and so on.

MATERIALS AND METHODS

The mechanism of ASP flooding: The ultimate recovery of strong base ASP flooding depends on sweep efficiency and displacement efficiency (recovery = oil displacement efficiency * sweep efficiency). The mechanism of strong base ASP flooding to enhance oil recovery is increasing sweep efficiency and improving displacement efficiency.

Increase the sweep efficiency: There are two kinds of sweep efficiency coefficients, flat sweep efficiency and vertical sweep efficiency. There are several measures to increase flat sweep efficiency coefficients, such as a reasonable well pattern, reasonable polymer concentration and fracturing (Li *et al*., 2011; Wu and Jia, 2012; Ren *et al*., 2001). Optimum strata combination, fracturing, profile control and water control can increase the vertical sweep efficiency coefficient (Baviere *et al*., 1995; Wang *et al*., 1999; Krumine and Falcone Jr., 1983).

Increase the displacement efficiency: The displacement efficiency depends on dimensionless

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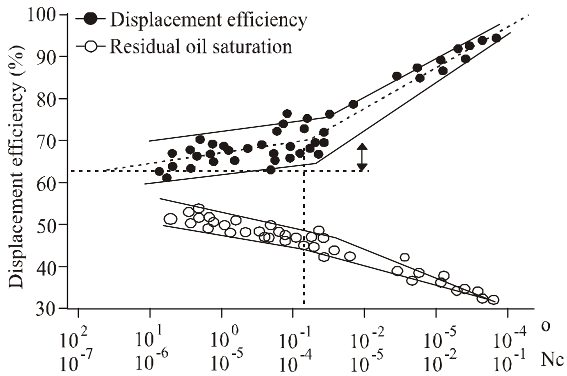

Fig. 1: The relation between interface tension or capillary number and displacement efficiency or residual oil saturation

capillary number, which is controlled by the ratio between the product of water displacement flow rate and viscosity and interfacial tension (Li *et al*., 2004; Song *et al*., 2001; Fu *et al*., 2001). Optimum chemical agent (polymer, surfactant and alkali) concentration (Lan *et al*., 2006; Liu *et al*., 2007; Che and Me, 2002), reasonable chemical agent slug and composition can increase the displacement efficiency (Fig. 1).

The mechanism of strong base ASP flooding clearly shows: reasonable well pattern, well spacing, strata combination and injection parameter design can guarantee the highest sweep efficiency and displacement efficiency.

Optimization of well pattern, well spacing and strata combination of strong base asp flooding: Well pattern, well spacing and strata combination influence the controlling area of the strong base ASP flooding directly. A sound design of well pattern, well spacing and strata combination is the basis of a reservoir engineering plan.

Reasonable ASP flooding well pattern: The development characteristics of strong base ASP flooding is different from polymer flooding. In the strong base flooding, both the injection and production capacity and connection problem between imagining well pattern and existing well pattern should be considered, apart from the influence of the well pattern on displacement efficiency of strong base ASP flooding. This study focused on strong base ASP flooding testing blocks of Daqing oilfield. Numerical simulation is used to study strong base ASP flooding development effect of four kinds of well patterns, such as linear pattern, five-spot pattern, four-spot pattern and inversed nine-spot pattern. The injection manner of strong base ASP flooding is: water flooding to a water content of 95%; injection of strong base ASP main slug (0.3% surfactant+1.2% NaOH +1200 mg/L polymer) 0.15 PV; injection of polymer protection slug (1200 mg/L polymer) 0.2 PV; water flooding to a water content of 98%.

Table 1: Water flooding and ASP flooding recovery on the condition of different well patterns

Well pattern	Water flooding recovery (%00IP)	ASP flooding final recovery (%00IP)	ASP flooding enhanced recovery (%00IP)
Linear pattern	41.89	61.51	19.62
Five-spot pattern	42.42	62.92	20.50
Four-spot pattern	41.56	60.52	18.94
Inversed nine-spot pattern	41.13	59.11	17.98

The results show (Table 1): Five-spot pattern is suitable for strong base ASP flooding. Under the same condition, the EOR (Enhanced Oil Recovery) from highness to lowliness in turn is five-spot pattern, linear pattern, four-spot pattern and inversed nine-spot pattern. When the water content reaches 95% in water flooding, the final recovery values of five-spot pattern and inversed nine-spot pattern are 42.42 and 41.13% accordingly (about 1.29% points' difference between the 2 patterns). At the end of strong base ASP flooding, the final recovery values of 5-spot pattern and inversed nine-spot pattern are 62.92 and 59.11% accordingly (about 3.81% points' difference between the 2 patterns). During the strong base ASP flooding, the EOR values of five-spot pattern and inversed nine-spot pattern are 20.5 and 17.98% accordingly (about 2.52% points' difference between the 2 patterns). The data above shows that, compared with the inversed nine-spot pattern, the EOR values of the five-spot pattern during the strong base flooding is bigger. The main reason is that the impact of well pattern is relying on the ratio between the number of injection well and production well and injection well position. With the decrease of the ratio between the number of injection well and production well or the uneven distribution of injection wells, the sweep efficiency and EOR decrease. The strong base ASP flooding amplifies this effect.

Reasonable ASP flooding well spacing: Another important factor during strong base ASP flooding, which must be considered, is well spacing. Under the same condition the bigger the well spacing, the less the cost. But the controlling area by a single well is small and flooding effect is bad. Because of the high viscosity of the ASP fluid, the injection pressure is much higher than water flooding. If well spacing is big enough, the injection pressure will rise too fast or surpass the fracture pressure of the reservoir. This study analyzes the test data of strong base ASP flooding in Daqing oilfield and gives four suggestions about well spacing design of ASP flooding.

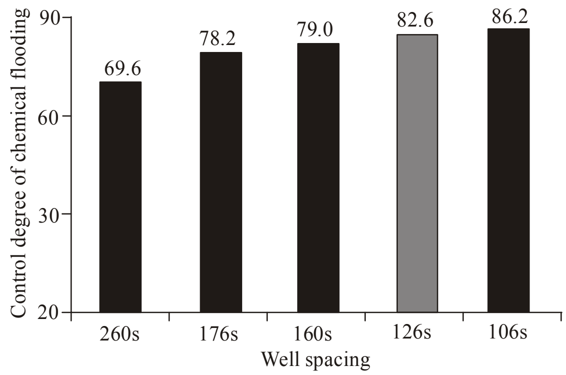

Fig. 2: Control degree histogram of chemical flooding in different strong base ASP flooding test blocks

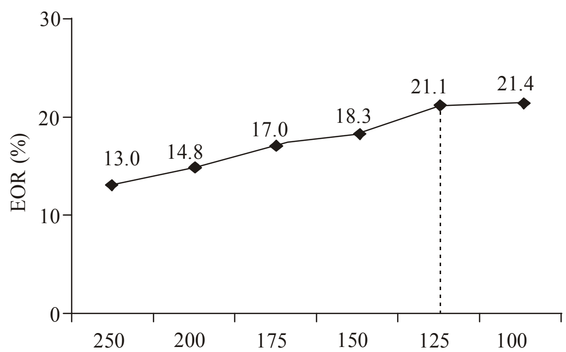

Fig. 3: Relation curve between well spacing and EOR

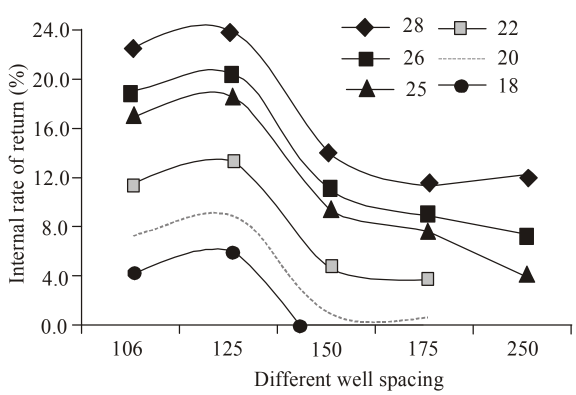

Fig. 4: The relation curve of different well spacing and internal rate of return

The decrease of well spacing can increase the controlling area and EOR: Figure 2 shows control degree histogram of chemical flooding in different strong base ASP flooding test blocks, having been put into production in Daqing oilfield. As can be seen from the figure, the smaller the well spacing, the higher the control degree is. Under the condition of 125 m well spacing, the connectivity of the test block reaches 89.8% and control degree of water flooding reaches 100%. As can be seen from the relation between well pattern and control degree of chemical flooding, with the decrease of well spacing the control degree of chemical flooding rises gradually, but the increasing magnitude decreases gradually. Under the condition of 125 m well spacing, the control degree of chemical flooding reaches 82.5%.

The numerical simulation result of ASP flooding for different well spacing, such as 250, 175, 150, 125 and 106 m, respectively shows that the EOR magnitude for well spacing of 125 m is 21.1%, which is 0.3% lower than the magnitude for well spacing of 106 m and 2.8% higher than the magnitude for well spacing of 150 m. So the EOR increment from well spacing of 125 to 106 m is low (Fig. 3).

The decrease of well spacing can reduce the scaling of production well during strong base ASP flooding: Field test shows that, if the well spacing is less, the time for injection becomes less. Then the residence time of chemicals in reservoir is less and the scaling degree is less (Table 2). Such as the short well spacing (75 m) of strong base ASP pilot test blocks, it takes only 9 months to finish the main and auxiliary plug. The center well did not continue scaling, nor the work of pump inspection occurred because of scaling.

The decrease of well spacing can maintain injection-production capacity during the strong base ASP flooding: The field test of strong base ASP flooding pilot test blocks which have been put into production shows that (Table 3), with the narrowing of the well spacing the descend range of water injectivity index, fluid production and liquid production index became smaller. When the well spacing is about 100 m, the fluid production will stay above 80%.

The optimal well spacing which can make the best economic benefits in strong base ASP flooding: Economic evaluation results of different well spacing shows that (Fig. 4), on the condition of different oil prices the highest internal rate of return after tax internal rate of return occurs, when the well spacing is 125 m, which means economically feasible. Integrated the influence of well spacing of chemical flooding control degree, enhanced oil recovery value, injection-production capability, scaling degree and economic benefits, the reasonable well spacing of test blocks is 125 m.

The reasonable strata combination of ASP flooding: The optimum strata combination means take the reservoir which has similar properties together, using the same well pattern to exploit, in this way we can reduce the interference among strata and achieve the goal of EOR. Development practice shows that, the reservoir permeability, permeability ratio and reservoir thickness are the key factors affecting development result in a set of development strata. At the same time different displacement media has different requirements on strata combination.

Table 2: The statistics of scaling of the strong base ASP production well

Test block (well spacing) (m)	Time of main and auxiliary plug (month)	Well spacing (m)	Total well number	Duration of center well scaling (month)	The time of pump inspection of center well (time)
75	9	75	4	/	/
200	23	200	9	18	4
250	41	250	12	27	12

Table 3: The variation of injection-production capability for different well spacing of ASP flooding blocks which have been put into production

	Item									
		Fluid production (m^3/day)			Liquid production index (m^3/day·m·MPa)			Injectivity index (m^3/day·m·MPa)		
Block	Well spacing (m)	Water flooding	Chemical flooding	Decrease amplitude (%)	Water flooding	Chemical flooding	Decrease amplitude (%)	Water flooding	Chemical flooding	Descend range (%)
The Middle west	106	35	30	14.2	0.94	0.397	58.8	1.95	1.47	24.6
South fifth district	175	2013	970	51.0	1.20	0.450	64.6	2.23	1.35	39.4
Xing Er Qu	200	120	45	62.5	10.32	2.400	81.0	2.76	1.83	33.7
Xing ErZhong	250	861	307	64.3	4.17	0.630	84.8	1.82	0.87	52.2

Table 4: The producing degree of reserves of strong alkali ASP flooding test blocks in different levels of the reservoir permeability

	Item			
	Water flooding stage		APS main plug flooding stage	
Reservoir permeability (um^2)	Strata ratio (%)	Effective thickness ratio (%)	Strata ratio (%)	Effective thickness ratio (%)
K<0.1	8.3	10.81	41.7	45.9
0.1≤K<0.3	13.3	21.15	53.3	71.2
0.3≤K<0.5	55.6	56.86	44.4	52.0
0.5≤K<0.7	60.0	68.32	80.0	79.2
0.7≤K<0.9	87.5	84.86	100.0	100.0
K≥0.9	75.0	88.69	91.7	96.4
Total	45.5	74.73	66.7	87.5

Table 5: The lower limit of permeability when polymer go through the core during the strong base ASP flooding

PAM molecular weight	HPAM cyclotron radius (μm)	HPAM molecules cyclotron radius in ASP system (μm)	The lower bound of effective permeability when polymers can go through the core (μm^2)	The lower bound of effective permeability when polymers can go through the core in ASP system (μm^2)
15,000,000	0.195	0.179	125	110
19,000,000	0.226	0.198	145	125
25,000,000	0.258	0.238	195	180

Table 6: Producing degrees of reserves of different thickness level in the test block in which strong base ASP flooding has been put into operation

	Item			
	Water flooding stage		APS main plug flooding stage	
Effective thickness (m)	Strata ratio (%)	Effective thickness ratio (%)	Strata ratio (%)	Effective thickness ratio (%)
H≥2	82.6	89.0	91.3	90.0
1≤H<2	50.0	65.1	66.7	70.5
H<1	16.1	25.0	48.4	44.2
Total	45.8	75.0	66.7	80.3

Determine the lower bound of permeability is 0.1 μm^2: There was a positive correlation between reservoir permeability and the size of injection polymer molecular weight, one molecular weight of injection system is difficult to suit the development of all reservoirs. The producing degree of reserves of different permeability level in the test blocks in which strong base ASP flooding has been put into operation has indicated (Table 4), the producing ratio of effective pay thickness whose reservoir permeability is less than 0.1 m^2 is 10.8% in water flooding stage. In the same condition, the producing ratio of strong base alkaline ASP flooding is 45.9%. Although the strong base alkaline ASP flooding improve the producing degree of reserves of the reservoir whose permeability is less than 0.1 m^2, but the producing degree of reserves is still lower than the reservoir whose permeability is greater than 0.1 m^2.

Through a lot of natural core injectivity experiment at the same time, the statistics are given under the condition of strong alkali ASP flooding about the matching relationship between polymer molecular weight and the permeability of natural core (Table 5). Due to the presence of alkali to make polymer molecules curl, the ultra-low interfacial tension of ternary flooding system reduce the capillary resistance at the same time. Therefore under the condition of not emulsification and scaling, the ternary flooding system has better injection capacity to enter in the reservoir whose permeability is much lower compared with polymer flooding. Based on the analysis of the above, determine the lower limit of reservoir permeability is 0.1 for test blocks ultimately.

Determine the lower bound of single reservoir thickness is 1.0 m: The producing degree of reserves of

Table 7: The corresponding relationship between different permeability and reservoir thickness in the objective strata of test block

Reservoir effective thickness (m)	Reservoir permeability (μm^2) ≥0.3	≥0.2	≥0.1
0.5	19.11	32.48	63.69
0.6	25.00	40.48	70.83
0.8	44.34	65.09	83.96
1.0	53.68	66.32	87.37
1.5	72.73	83.33	95.45
2.0	76.92	87.18	100.00

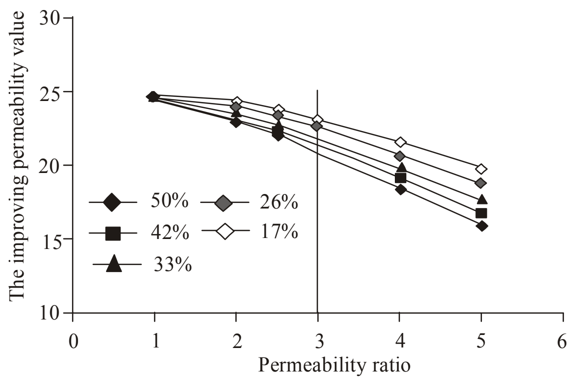

Fig. 5: Relation curve between permeability ratio and recovery

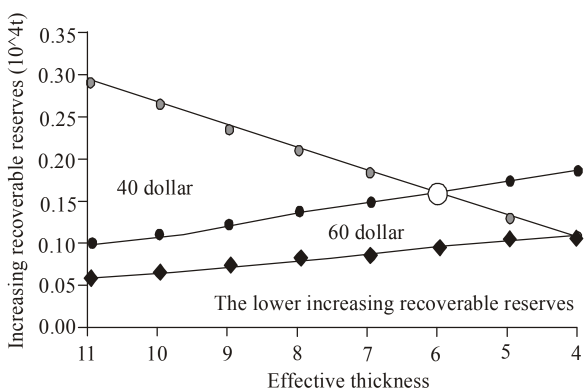

Fig. 6: Relation curve between single well effective thickness and increasing recoverable reserves

different thickness level in the test block during strong base ASP flooding showed (Table 6), the producing ratio of effective thickness of reservoir whose thickness is less than 1.0 m is 25% in the water flooding stage. The producing ratio of effective thickness of reservoir whose thickness is less than 1.0 m is 44.2% in the APS main plug flooding stage. Although the strong base ASP flooding increases the producing degree of reservoir whose thickness is less than 1.0 m, the producing degree of this part of reservoir is still smaller than the producing degree of reserves of those reservoir whose thickness is greater than 1.0 m.

Table 7 gives the corresponding relationship between different permeability and reservoir thickness in the objective strata of test block. We can see that the ratio of thickness whose effective permeability is over 0.1 m^2 accounts for more than 80% in thickness of those whose effective thickness is greater than 1.0 m in the test block. At the same time, reservoir whose single strata effective thickness is larger than 1.0 m can ensure that more than 80% of reserves are used, the reserves occupied by single strata whose effective thickness is larger than 2.0 m accounts for 52.2% of total reserves, the reserves occupied by single strata whose effective thickness is between 1.0-2.0 m accounts for 32.5% of total reserves, the reserves occupied by single strata whose effective thickness is less than 1.0 m accounts for 15.3% of total reserves.

Integrated the analysis results above, determining the main exploration object of the objective strata of test block is channel sand body and non channel sand body whose reservoir effective thickness is more than 1.0 m and permeability is greater than 0.1 m^2, at the same time the variable department of channel edge can also be considered as part of tapping potential, which can perfect the relationship between injection and production of object during strong base ASP flooding.

Determine the upper bound of permeability ratio is around 3.0: To clarify how much the interlayer permeability ratio have influence on strong base ASP flooding, we can apply the FACS three-dimensional chemical flooding numerical simulation software which is developed by American company GRAND to conduct numerical simulation study. Figure 5 shows the relation curve between the permeability ratio and recovery. We can see that the reservoir permeability ratio and the thickness ratio of low permeability strata have a great influence on strong base ASP flooding to improve oil recovery, with permeability ratio and the thickness ratio of low permeability strata increasing, the value of strong base ASP flooding EOR will reduce. In order to ensure the value of strong base ASP flooding EOR is greater than 20%, the permeability ratio should be controlled at around 3.

The lowest strata thickness is 6 m: The exploitation effect and economic benefit are the main indicators to measure the boundary of strata thickness. From this point of view, in a strata combination, the fewer strata, the smaller thickness, the lower interlayer interference influence degree is, the better the mining effect we get; but with the strata thickness decreasing, the output of single well will reduce, the investment recovery period is prolonged, the internal rate of return will fall and it's not conducive to the use of original ground equipment. Therefore, as for determining the thickness of strata combination, we should not only consider raising the amplitude of recovery, but also ensure a certain scale of production and economic benefits at the same time. It indicated through the research that when the oil price is at $40/barrel, effective thickness of strata must be greater than 6 m (Fig. 6).

The lower bound of barrier thickness is determined as 1.5 m: In order to make type II reservoirs in the test blocks get a larger degree of use, it cannot do without stimulation and so on, therefore we should consider the thickness of interlayer in the development strata and interlayer stability. Appropriate thickness of interlayer can not only meet the current downhole operation technology, but also make the storage of the interlayer loss to a minimum extent. And good interlayer between the sandstone groups is good for the division of strata and reduce the loss of reserves and provide conditions for the future of interlayer injection, such as separated injection, fracturing, so when we make series of strata combination, as far as possible to put sandstone group as a unit. Based on the previous research results and the current research of downhole operation technology, interlayer thickness between two adjacent formations is about 1.5 m.

THE OPTIMUM DESIGN OF INJECTION PATTERN AND INJECTION PARAMETERS IN THE PROCESS OF STRONG BASE ASP FLOODING

The injection pattern of ASP flooding: ASP flooding uses the effect of alkali and surfactant to reduce the interfacial tension effectively, which contributes to improve oil displacement efficiency, at the same time increases the displacing fluid viscosity and improves sweep efficiency by adding the polymer. So that it has a dual role in the combination of physical and chemical methods and can greatly improve the oil recovery. Through years of field researches and indoor tests, Daqing Oilfield gradually worked to determine the four-part injection method which is suitable to ASP flooding: front polymer slug + strong base ASP main slug + ASP auxiliary slug + polymer protection slug. In this way, we can greatly improve the recovery and increase economic efficiency by saving chemical dosage (Wang and Huang, 1996; Liao *et al*., 2001). Its mechanism is as follows:

- Adjusting the injection profile by the injection of front polymer slug to decrease the adsorption loss of ASP main slug.
- By the injection of ASP main slug, we can control mobility reduce the interfacial tension and form emulsion to improve oil displacement efficiency.
- Further improve oil displacement efficiency and reduce the amount of chemical agent by injecting the ASP auxiliary slug polymer.
- Protect the ternary flooding system by injecting the polymer protection slug to prevent the breakthrough of the inject water in the following water flooding.

Injection parameters of ASP flooding:

The injection volume of the front polymer slug is 0.04 PV: The chemical solution which was injected in

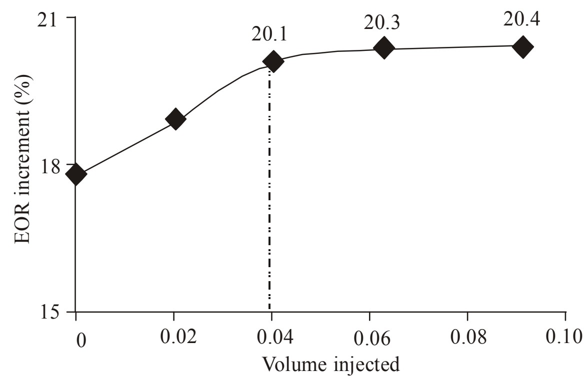

Fig. 7: The effect of front polymer slug size on oil displacement

front polymer slug has a certain viscosity, which can decrease the mobility ratio of displacing fluid and oil, adjusting the injection profile and improve sweep efficiency. Simulation studies show that when the front polymer slug injected is 0.04 PV, we can gain the best development effect. When we continue to increase the use of polymer solution, the increase rate of recovery became smaller and at the same time, the economy benefits became worse. So we believe that the injection volume of the front polymer slug is 0.04 PV.

Determine the chemical solution concentration of ASP main slug and injected volume: The synergy of polymers, alkali and Surfactant can effectively expand the swept volume and improve oil displacement efficiency. Alkali and surfactant produces a synergistic effect which can significantly reduce interfacial tension and alkali can make the rock surface negative charge increases, reduce the adsorption of surfactant on the rock, which can reduce the amount of surfactant. Besides, it can reduce the cost of displacing fluid. Surfactant as the main agent displacing fluid can effectively reduce the interfacial tension, change rock wettability, which contributes to the start, coalescence and movement of droplet and improve oil displacement efficiency. Polymer interaction, alkali and surfactant can improve the use of state of the reservoir, emulsifying crude oil in a certain degree and expanding the swept volume. To achieve the best medicine ternary displacement effect, we need design the concentrate and volume of different medicals (Fig. 7).

Core test results show that: with the increase of alkali concentration, the core washing efficiency increases. When the alkali concentration is between 1.2 to 1.4%, the flooding effect of compound system is better and with the continuing increase of the alkali concentration, the core oil washing efficiency became magnitude smaller (Fig. 8). As the surfactant concentration increases, the core EOR became larger. When the surfactant concentration is between 0.3 to 0.4%, the flooding effect of compound system is better

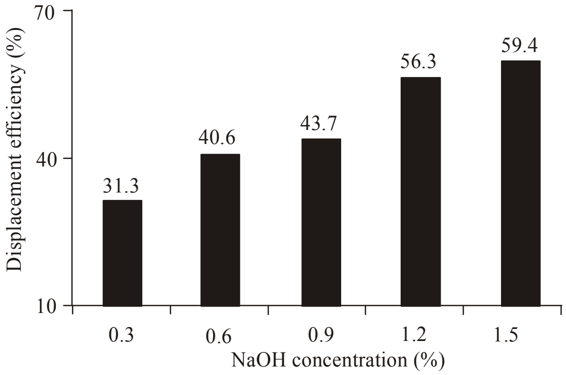

Fig. 8: Comparison of displacement effect in difference alkali concentration

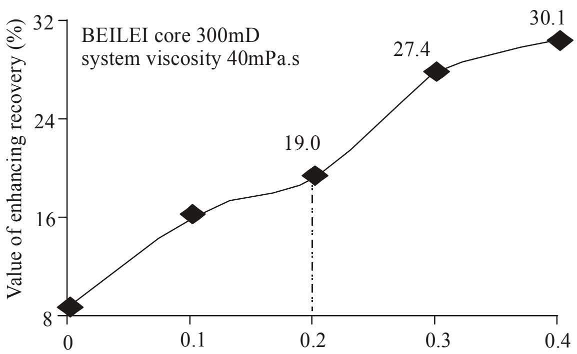

Fig. 9: Chemical concentration and recovery of ASP system

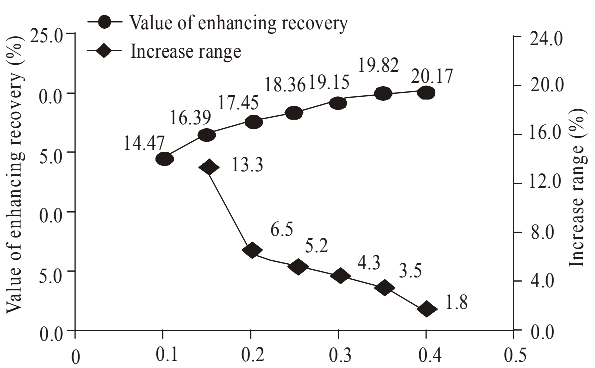

Fig. 10: Relation between injection volume and oil recovery

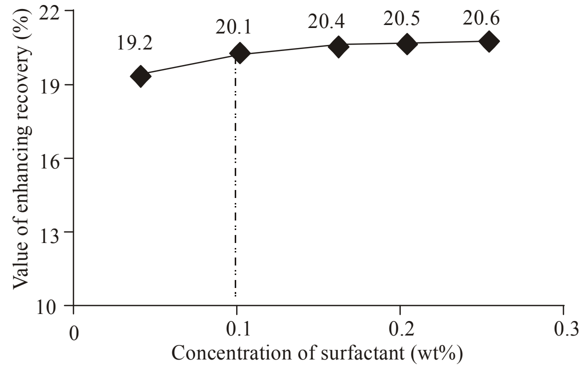

Fig. 11: Influence of alkali concentration on the effect of displacement in auxiliary slug

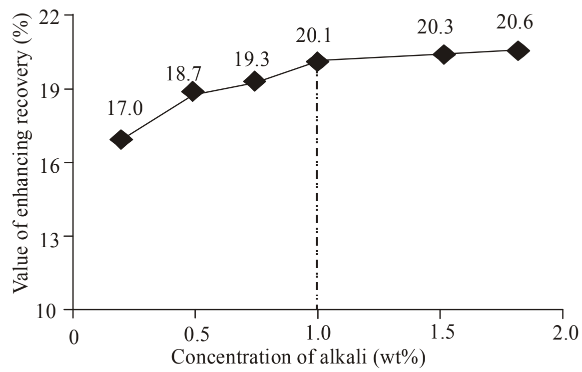

Fig. 12: Influence of surfactant concentration on the effect of displacement in auxiliary slug

and with the continuing increase of the alkali concentration, the core oil washing efficiency became magnitude smaller (Fig. 9). So we can determine the surfactant concentration of ASP main slug concentration is between 0.2 to 0.4% and the alkali concentration is between 1.2 to 1.4%, in this way, we can get the best reasonable viscosity recovery.

Modulus results show that: with ASP system main slug injection volume increases, the oil recovery increase amplitude decreases. When ASP system main slug is below 0.3 PV, the oil recovery rate is enhanced significantly (greater than 4%). When ASP system main slug is above 0.3 PV, the oil recovery rate is enhanced insignificantly (less than 4%). The reason is that when the ASP system main slug is less than 0.3 PV, with increase of injected volume, the absorption and retention of basic chemicals reached saturation and the concentration of the flooding system in the reservoir increases, when the interfacial tension value reaches ultra-low, the effect of oil flooding has improved significantly. When the ASP system main slug is greater than 0.3 PV, injection volume continues to increase and at this time, the oil displacement effect has been reached or almost reached its limit, the effect of increasing the injection rate is mainly to improve sweep efficiency, but the enhancement of oil displacement efficiency becomes unobvious and recovery is also slowly rising (Fig. 10). In summary ASP flooding system main slug injection volume is determined to 0.3 PV.

Determine the concentration of ASP auxiliary slug and injected volume: When the main slug exceeds the amount of 0.3 PV, if we continue to increase the amount, the cost of chemical required by the flooding system will be higher than the economic benefits of increased crude oil, although recovery can be further improved. If at this time we inject the low concentration of alkali and ASP auxiliary slug, the interfacial tension

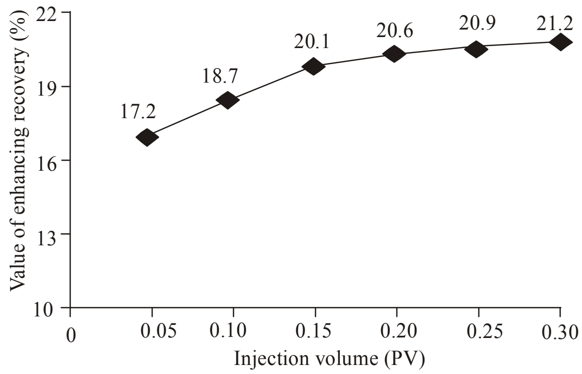

Fig. 13: Optimization results of ASP auxiliary slug size

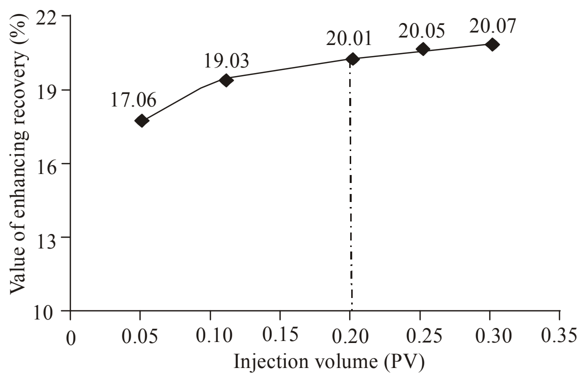

Fig. 14: Optimization modules results of rear slug size

values between the system and crude oil still remained in ultra-low. Apparently, due to lower chemical costs, we can be further enhanced oil recovery by increasing the slug. Although the concentration of the surfactant system decreased from 0.3 to 0.1% and the alkali concentration from 1.2-1.4%. Using the method of injection of low concentration of compound system of alkali, we can further enhance the ultimate recovery of ASP flooding (Fig. 11 and 12). With the increasing in volume of the auxiliary slug of strong alkali ASP system, the increase of recovery declines. While the volume of the auxiliary slug of strong alkali ASP system is less than 0.15 PV, the recovery boosts significantly with the increase of the auxiliary slug volume of strong alkali ASP system, otherwise, the recovery boosts slowly (Fig. 13). In conclusion, the volume of the auxiliary slug of strong alkali ASP system is 0.15 PV, the concentration of surfactant should be 0.1%, the concentration of alkali should be 1.0%.

Determine the injection volume of subsequent polymer protection slug: Experimental results show that: the subsequent injection of polymer slug can prevent subsequent injection water breakthrough, the degree of EOR will decrease when the injection volume of subsequent polymer protection slug increases, while it will increase greatly if the injection volume of subsequent polymer protection slug is less than 0.2 PV, but if the injection volume of subsequent polymer protection slug is above 0.2 PV, the degree of EOR will increase slowly. So taking these the best injection volume of subsequent polymer protection slug is 0.2 PV (Fig. 14).

CONCLUSION

- The results show (Table 1): Five-spot pattern is suitable for strong base alkaline ASP flooding. Under the same condition, the EOR (Enhanced Oil Recovery) from highness to lowliness in turn is five-spot pattern, linear pattern, four-spot pattern and inverted nine-spot pattern. When the water content reaches 95% in water flooding, the final recovery values of five-spot pattern and inverted nine-spot pattern are 42.42 and 41.13% accordingly (about 1.29% points' difference between the 2 patterns). At the end of strong base alkaline ASP flooding, the final recovery values of five-spot pattern and inverted nine-spot pattern are 62.92 and 59.11% accordingly (about 3.81% points' difference between the 2 patterns). During the strong base alkaline ASP flooding, the EOR values of 5-spot pattern and inverted nine-spot pattern are 20.5 and 17.98% accordingly (about 2.52% points' difference between the 2 patterns).
- The best well spacing of strong base alkaline ASP flooding is around 125 m. The decrease of well spacing can increase the controlling area and EOR, reduce the scaling of production well during strong base ASP flooding, maintain the production capacity of strong base alkaline ASP flooding, meanwhile the best well spacing of strong base alkaline ASP flooding can obtain the best economic benefits. So according to the influence of control degree of chemical flooding, EOR, Injection-production capacity, scaling degree and economic benefit, we eventually determine that the best well spacing of strong base alkaline ASP flooding is 125 m.
- Determine the strata combinatorial optimization design principles of strong base alkaline ASP flooding technology: the lower bound of permeability is 0.1, the lower bound of single reservoir thickness is 1.0 m, the upper bound of permeability ratio is around 3, the lower bound of strata thickness is 6 m and the lower bound of barrier is 1.5 m.
- Determine the 4-part injection method which is suitable for strong base alkaline ASP flooding: front polymer slug + ASP main slug + ASP auxiliary slug + polymer protection slug, to ensure the ternary system form the basis of ultra-low interfacial tension, according to the connectivity and development of the oil layer to design each

slug injection sizes and formulations, can greatly improve the recovery, while saving chemical dosage and increase economic efficiency.

- The concentration of surfactant (0.3-0.4%), the concentration of alkaline (1.2-1.4%) and the injection volume of main plug (0.3 PV) of the main slug of ASP flooding are determined. The concentration of surfactant (0.1%), the concentration of alkaline (1.0%), the injection volume of main plug (0.15 PV) and the injection volume of subsequent polymer protection plug (0.2 PV) of the auxiliary plug are determined. Each stage polymer concentration should be designed according to the connectivity and development of specific block.

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