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Research Article

Optimization and Evaluation of Foam Flooding Formula after Polymer Flooding

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Abstract: Aiming at the problems of vertical and lateral uneven production of the oil reservoir and further tapping the remaining oil after polymer flooding, in the paper, the foam flooding feasibility after polymer flooding is studied by laboratory experiment. On the basis of the real situation of polymer flooding in Daqing oilfield, by assessing foam height, foam half-life and foam comprehensive value, optimizes the sort, concentration of the foaming agent and foam stabilize, examines the sealing capacity of foam of various permeability cores, gas liquid ratio and injection rate, determines the gas liquid ratio and injection rate, do foam flooding experiment after polymer flooding. The results show that after water cut reach to 98% after polymer flooding, foam flooding could further increase the oil recovery by about 8%.
Keywords: foam flooding; polymer flooding; foaming agent; gas-liquid ratio; injection rate; enhanced oil recovery

INTRODUCTION

The mechanism of foam flooding, a new tertiary recovery technology, is in two ways. One is the character of dissipating when encountering oil and keeping stable when encountering water [1-2]. The foam in low oil saturation region, with a high stability, has a high percolation resistance and can drive the injection fluid to the unswept areas by water or polymer flooding, which can expend swept volume. The second is that foam agent is a kind of surfactant [3]. It can decrease oil-water interfacial tension, thereby improving oil-driving efficiency. It can be seen from the domestic and foreign literature that Referring to foreign articles, the research doesn't have practical significance due to the differences of oil field real situation in despite of much research on enhanced oil recovery(EOR) mechanism and application of foam flooding.

Polymer flooding EOR technology has been well promoted and it received an excellent performance in Daqing [4]. But most blocks in Daqing have entered the later period of polymer flooding and water cut rises dramatically. So how to further enhance oil recovery is the key to Daqing oilfield sustainable development [5-6]. On the basis of geologic features, research foam flooding feasibility after polymer flooding by sealing experiments and oil displacement experiments, which is significance to analyze seepage characteristics of foam system and know foam flooding EOR.

SELECTING FOAM SYSTEM

Experimental section

The water in experiment is injection water of Daqing Sixth Oil Production Plant. Water quality analysis is shown in Table 1.

Table 1 Water quality analysis

Water type	Ion constitution and content (mg/L)							Total mineralization(mg/L)
	K^++Na^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-	
Sewage	1559	18	3.6	1010	0	120	2227	4937

Experimental method: In the experiment, we use 100 mL foaming agent solution and its concentration is 0.5%. The gas-liquid ratio is 2:1. Use Roche foaming method to get the average value by conducing the experiment three times. And then measure the foam height and half-life after bubbling and calculate foam composite value which is the composite target of foaming capacity and stability of foaming agent, equal to foaming volume multiply by half-life.

Primary selection of the foaming agent sorts

By research we find that Common foaming agent are mainly anion, non-ionic foaming agent, and composite foaming agent, of which performance varies from each other. We selected six kinds of foaming agent with nice foaming performance under the conditions of formation fluid in Daqing oil-field, namely SDS, ABS, BS13, ST-2, YH-4 and DY-1. The result is shown as Table 2.

Table 2 Foaming performance indicators of different kinds of foaming agent

Foaming agent	Variety	Foaming height (cm)	Half-life (s)	Composite value (mL.min)
Lauryl sodium sulfate (SDS)	Ionic surfactant	13.6	548	5594
Sodium dodecylbenzene sulfonate (ABS)	Alkylbenzene sulfonate	9.4	798	5653
Betaine hydrochloride (BS13)	Ampholytic surfactant	11.5	901	7749
ST-2	Non-ionic surfactant	7.2	440	2382
YH-4	Non-ionic surfactant	8.2	334	2061
DY-1	Carboxylate	10.0	541	4077

It can be seen that for SDS, ABS, BS13 and DY-1 foam height is high, foaming capacity is good, half-time is long, the foam is stable, and composite value is big. ST-2 and BS13, two kinds of nonionic foaming agent, have a poor performance with a lower half-life and composite value. In the view of foaming capacity, SDS and BS13 are optimal. In foaming stability view, BS13 and ABS are optimal. So SDS, ABS, BS13 and DY-1 are the preliminary choices for further experiment.

Selection of foaming agent concentration

Foaming agent concentration is an important factor influencing foam volume and half-life. And not only the performance, but also economical factor should be considered when determining foaming agent concentration. Determine the foam volume and half-life of the four kinds of foaming agent under various concentration and calculate the composite value, as shown in Fig.1, Fig.2 and Fig.3.

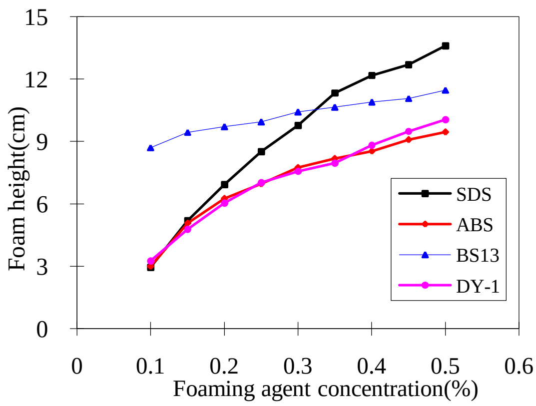

Fig.1 Foam height of different foaming agent under different concentration

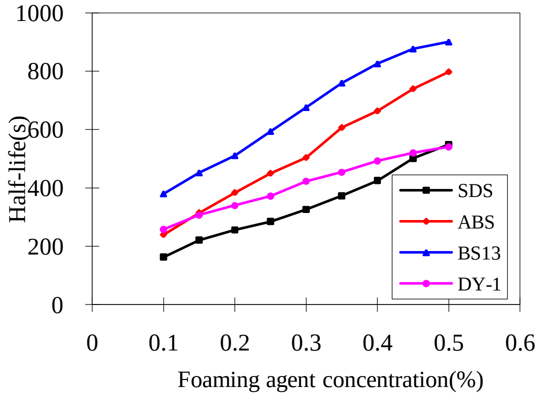

Fig.2 Half-life of different foaming agent under different concentration

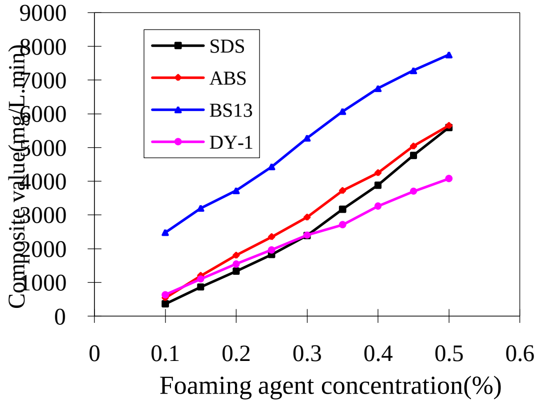

Fig.3 Composite value of different foaming agent under different concentration

From the perspective of foaming capacity, SDS and BS13 have the best performance under concentration of 0.1%~0.5%. SDS bubbles poorly under lower concentration, but it improves immensely as the concentration rise, while under different concentration the foaming capacity of BS13 is stable, a little difference. From the perspective of stability, for all four kinds of foaming agent foam half-life change longer and stability increase as the concentration rising. Furthermore, BS13 and ABS have a better foaming stability than that of SDS and DY-1. View from composite value, foaming composite value of BS13 is obviously better than that of SDS, ABS, and DY-1. So BS13 is selected. As concentration rising, foam height of BS13 increase inconspicuously only with a better stability. So the concentration of BS13 is 0.3%.

Selection of foam stabilizer concentration

In order to raising the foam stability, an amount of foam stabilizer is often added into the solution. And polymer always plays the role. In the experiment, we research several parameters of polymer concentration from 0 to 1500mg/L. According to experimental results, the height of foam decrease and half-life increase with polymer concentration rising, which is because as polymer concentration rising the viscosity and viscous resistance when foaming to overcome increase, foaming volume and foaming height diminishes. On the other side, it brings benefit that liquid film drainage velocity reduces and the half-life increase under the same conditions. So the capacity of foaming diminishes while the stability promotes after adding polymer. Viewed from the composite value, it's bigger when the concentration of polymer is 500mg/L~800mg/L. Taking economical factors into account the concentration of 500mg/L is selected.

FOAM SEAL-OFF EXPERIMENT

Foam sealing property of cores under different permeability

In order to study on the foam sealing property to cores with different permeability, eight cores, with the permeability from $100\times10^{-3}\mu m^2$ to $2000\times10^{-3}\mu m^2$, are selected in the experiment. Injection gas-liquid ratio is 2:1, and injection rate is 0.15mL/min. We measure the differential of water flooding and foam flooding and calculate the resistance factor as shown in Fig.4.

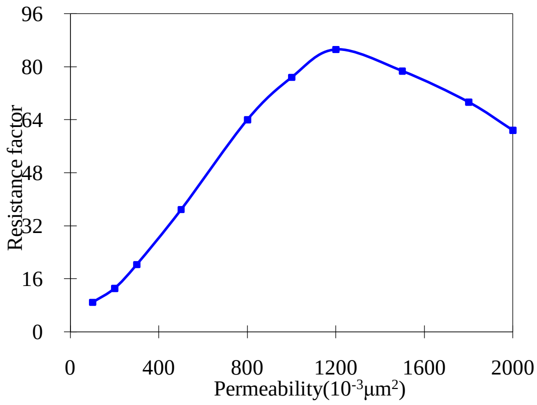

Fig.4 Resistance factor of cores with different permeability

From the experimental results can be seen that when the permeability is lower than $1200\times10^{-3}\mu m^2$, the resistance factor increases with permeability rising; On the contrary, when the permeability is higher than $1200\times10^{-3}\mu m^2$, it decreases with permeability rising. When the permeability is about $1200\times10^{-3}\mu m^2$, the resistance factor reaches a maximum. Mainly because the foam is a kind of non-newtonian fluid with shear thinning property, its sealing effect in the core relies mainly on the gas Jamin effect. When the permeability is lower, due to the stronger shear stress, foam fluid viscosity reduces, so that with the increase of permeability, foam selling effect becomes strong. But if permeability is more than $1200\times10^{-3}\mu m^2$, core pore throat becomes big, gas Jamin effect weakens, leading to foam sealing beginning to reduce. It can be seen that the foam can increase the flow resistance of high permeability layer, give play to the role of low permeability layer, and have the effect of adjusting section.

Foam sealing property under different gas-liquid ratio

In order to study on the foam sealing property to the core under different gas-liquid ratio, cores with permeability of $500\times10^{-3}\mu m^2$ are selected for experiment and the injection rate is 0.15 mL/min. Based on the result generated by altering gas-liquid ratio from 1:1 to 5:1, when gas-liquid ratio is lower than 3:1, with gas-liquid ratio rising resistance factor increases and foam sealing promotes. When gas-liquid ratio is higher than 3:1, the stability of foam gets worse and a great amount of gas generating by the burst of bubbles results in gas channeling and resistance factor getting lower. So the rational gas-liquid ratio is 2:1~3:1. If the permeability of oil layer is larger, the gas-liquid ratio could be enhanced on the premise of foam stability. The selected gas-liquid ratio in this research is 2.5:1.

Foam sealing property under different injection rate

In order to study on foam sealing property under different injection rate, cores with the permeability of $500\times10^{-3}\mu m^2$ are selected and the injection gas-liquid ratio is 2.5:1. Based on results generated by varying the injection rate from 0.05 mL/min to 0.35 mL/min, it can be seen that injection rate influences dramatically the foaming sealing property, foaming capacity and shearing stresses of foam in porous medium improve. But when injection rate reaches an exaggerated value, rupture rate gets quicker than formation rate, leading to a worse stability. When the injection rate is lower than 0.25 mL/min, with injection rate rise the formation rate get quicker than rupture rate and the resistance factors of foam in cores increase. When the injection rate reaches 0.15 mL/min, the growth of resistance factors slows; when injection rate is greater than 0.25 mL/min, the rupture rate get quicker than formation rate and the resistance factors of foam in cores decreases with injection rate rising. Synthesizes the injection capacity and sealing capacity, it's rational to limit the injection rate in the range of 0.15 mL/min~0.2 mL/min.

EXPERIMENT OF FOAM FLOODING AFTER POLYMER FLOODING

Experiment condition

On the basis of Daqing oilfield condition, a vertical heterogeneous rectangle model of three layers with a size of 30cm×30cm×4.5cm is designed and established, of which coefficient of permeability variation is 0.72 and permeability of each layer is about $300\times10^{-3}\mu m^2$, $500\times10^{-3}\mu m^2$ and $800\times10^{-3}\mu m^2$. There is one oil well in the central and four injection well around in the five points well pattern. In the experiment, a kind of simulative oil of which viscosity is 6.84 mPa•s and it is mixed by crude oil and aviation oil.

Experimental scheme and the results

The first scheme: water flood until the water cut reaches 98%;

The second scheme: water flood until the water cut reaches 95%, and then polymer flood with the polymer concentration of 1500mg/L until the water cut reaches 98%. At last add 0.3PV foaming agent (gas-liquid ratio is 2.5:1) and water flood until the water cut reaches 98%. This scheme was done three times. The result is shown as Table 3.

Table 3 Flooding effect of two schemes

Scheme	Water flooding recovery percent(%)	Recovery percent of polymer flooding(%)	Water cut drops of foam flooding(%)	Recovery percent of foam flooding(%)	Oil recovery(%)
1	46.0	/	/	/	46.0
2	43.7	16.6	17.3	8.1	68.4
	42.5	16.2	20.4	8.3	67.0
	42.8	15.9	16.1	7.8	66.5

It can be seen from the result that oil recovery rises 8 percent by foam flooding after polymer flooding till the water cut of 98%. After the polymer flooding, by injecting 0.4PV foam, the oil recovery of these three blocks rises 8.1%, 8.3%, and 7.8%, the water cut drops by 17.3%, 20.4% and 16.1%. The oil recovery rises 22.4%, 21% and 20.5% after water flooding till the water cut of 98% and rises by an average of 8.1% on the basis of polymer flooding.

CONCLUSION

(1)Aiming to the formation water characteristic in oilfield, evaluate the foaming property of foaming agent commonly adopted in oil field and come to the conclusion that BS13 has the optimal foaming and stability capacity. Then select 0.3% as the concentration of BS13 by optimizing.

(2)Research the foam sealing property under different permeability of cores, gas-liquid and injection rate and get a conclusion that when the permeability of cores is larger than $1200\times10^{-3}\mu m^2$, gas-liquid ratio is higher than 2.5:1 and injection rate is higher than 0.25 mL/min, the foam sealing capacity decreases.

(3)Conduct the experiment of foam flooding after polymer flooding. The result shows the oil recovery rises about 8% by injecting 0.4PV foam after polymer flooding till the water cut of 98%.

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