

Stabilization of SiO₂ nanoparticle foam system and evaluation of its performance

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Abstract. As tertiary recovery is applied in the oil field, foam flooding technology plays an important role in the oil field. Steam flooding is easy to generate a series of problems such as excessive pressure, gas channelling, heat loss ect. The foam flooding can be better used in the formation of plugging and profile control. However, the foam is not stabilizing in thermodynamics and breaks easily while it encounters oil. So the emphasis of the research is how to make the foam stable. The Warning Blender method is used to evaluate the foam In the course of experiment, which verifies that the modified Nano SiO₂ solid not only works very well in coordination with SDS solution but also contributes to the generation of stable foam in solution. The optimum concentration of SDS is determined by 0.5%, and the best concentration is 1.4% of H₂O type SiO₂ particles that the concentration is 79.26°. Finally, the 0.5%SDS+1.4%H₂O type SiO₂ is chosen as the complete foam flooding system, and the performance of salt tolerance and oil displacement of composite foam system is evaluated. It is concluded that the stability of foam is the key to improve the oil recovery.

1. Experiment Condition

1.1. Experiment reagent

SDS(Sodium dodecyl sulfate, anionic surface active agent); H15,H18,H20,N15,FM150 five types SiO₂ grain (particle size is 20nm, white powder with negative charge on surface); air; distilled water; NaCl(AR); CaCl₂(AR); MgCl₂(AR).

1.2. Laboratory apparatus

PL203 electronic balance ; ultrasonic dispersing instrument ; C-J type high speed agitator ; powder compressing machine ; GT10 type high speed centrifuge.

2. Experiment method

2.1. Contact angle measurement

The experiment method of measuring the contact angle between SiO₂ nanoparticles and the interface of water is sessile drop method [1-3]. The experiment sets the pressure parameter of tablet press is 20MP and takes the right amount of the five-type SiO₂ nanoparticles to press them into a pie shape by using powder compressing machine. The experiment uses the contact angle measurement function of



the full automatic interfacial rheometer to measure the contact angle between the five-type SiO_2 nanoparticles and the interface of water. The temperature of the experiment is indoor temperature. The experiment takes 3 different measuring points of the same sample during the experimentation. The average value of the result is taken as the final result. The results are shown in the following table.

Table 1. The measurement of SiO_2 particle contact angle

Sample type of SiO_2	measuring point			average value of contact angle
	First	Second	Third	
H15	67.56	67.63	67.58	67.59
H18	121.44	121.47	121.77	121.56
H20	79.12	79.45	79.21	79.26
N20	39.32	39.63	39.31	39.42
FM150	51.16	51.32	51.63	51.37

2.2. Foam evaluation experiment

The concentration of five group SDS solution is 0.25g/L should be prepared in the 22°C temperature condition. The experiment uses the electronic balance to weigh the fraction of the five-type SiO_2 nanoparticle which is 0.15g. And five-type SiO_2 nanoparticles are added to the SDS solution. The experiment disperses the mixed solution 3minutes by ultrasonic dispersing [11] instrument. The 100g dispersion is weighed in a high stirring cup and then the sealing is covered. The air is put into the high stirring cup about 3minutes. The speed of the high speed mixer is adjusted with 8000r/min and the mixture is stirred 3minutes. Then we pour the generated foam into the cylinder rapidly and record the initial foam volume and the time that the foam precipitates 50ml liquid. The time is seen as the half-life $T_{1/2}$. During the experiment, each sample is measured 3 times and the average value is taken as the final result. The results are shown in the following table.

Table 2. The volume and half-life of SiO_2 solid particles with different contact angles

Sample type of SiO_2	Foaming volume (v/ml)	Half-life (min)
H15	330	16.5
H18	325	15.6
H20	435	27.6
N20	314	6.7
FM150	318	9.6

3. The quality optimization of SDS and SiO_2

3.1. The quality optimization of SDS

The foam evaluation experiment is carried out by Warning Blender method. The experiment uses distilled water to prepare the anionic surfactant SDS solution that the mass fraction are 0.1%, 0.3%, 0.5%, 0.7%, 0.9%. The solution is stirred for 3 minutes by high speed mixer that its speed is 8000r/min. The foam is poured into the cylinder in time. The volume and half-life $T_{1/2}$ are recorded at the same time. The result of each group should be measured three times and the average value is taken as the final result. The results are shown in the following table.

Table 3. Foaming volume and half-life of SDS solution

Content of SDS (g)	Foaming volume (v/ml)	Half-life (min)
0.1	545	6.8
0.3	586	7.0
0.5	635	8.1
0.7	628	8.8
0.9	640	7.6

The experiment result shows when the content of SDS solution is 0.5% the foaming volume and half-life are the best.

3.2. Content optimization of H₂O type SiO₂

The experiment of foam evaluation is carried by Warning Blender method. Firstly, 10 groups SDS solution that the mass fraction is 0.5% are prepared and 0.3g, 0.5g, 0.8g, 1.0g, 1.2g, 1.4g, 1.6g, 1.8g, 2.0g H₂O type SiO₂ particles are obtained by electronic balance. These SiO₂ particles are added into the 0.5% SDS solution one by one. The mixing solution is mixed into the high stirring cup 3minutes and the speed of high-speed mixer is 8000r/min. The foam is produced into a measuring cylinder firstly and the foaming volume and half-life $t_{1/2}$ are recorded. The production of foaming volume V and half-life $t_{1/2}$ are regarded as the comprehensive value of foam. The result of each group should be measured three times and the average value is taken as the final result. The results are shown in the following table.

Table 4. The height and half-life of foam system

Content of SiO ₂ (g)	Foaming volume (v/ml)	Half-life (min)	comprehensive value of foam $vt_{1/2}$ (ml min)
0.0	635	8.1	5143.5
0.3	345	10.5	3622.5
0.5	353	14.8	5224.4
0.8	380	20.4	7752
1.0	410	25.7	10537
1.2	395	34.5	13627.5
1.4	390	45.6	17784
1.6	375	48.2	18075
1.8	365	49.8	18177
2.0	355	50.2	17821

4. Evaluation of optimization formula performance

It is necessary to evaluate the effect of inorganic salts on the SiO₂+SDS foam system because the formation water contains a certain degree of mineralization. The laboratory prepared 0.5% SDS and 1.4% SiO₂ composite foam solution. Warning Blender method is used to evaluate the foam performance of composite foam solution by adding NaCl, MgCl₂, and CaCl₂. The foam is poured into the cylinder after we fully stir the solution. The changings of foam volume and half-life are observed under the different condition of concentration and salinity. The effects of these three ions on the foam system are mainly evaluated because the content of Na⁺, Mg²⁺ and Ca²⁺ in the formation water is more. The experiment results are shown in the following figure.

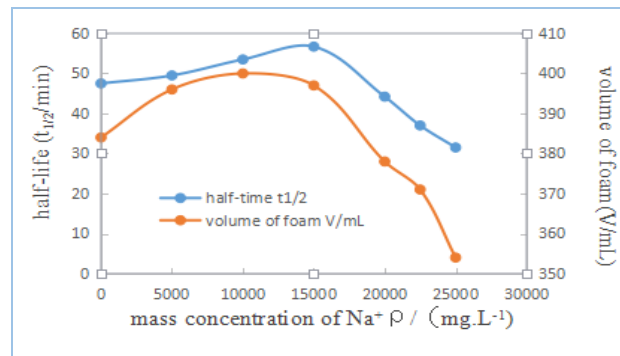


Figure 1. The influence of Na⁺ effects on SiO₂+SDS system

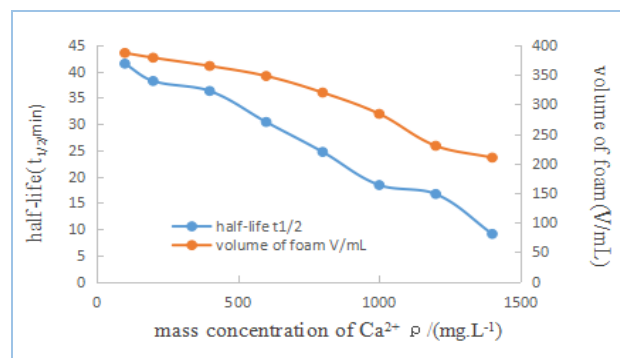


Figure 2. The influence of Ca²⁺ effects on SiO₂+SDS system

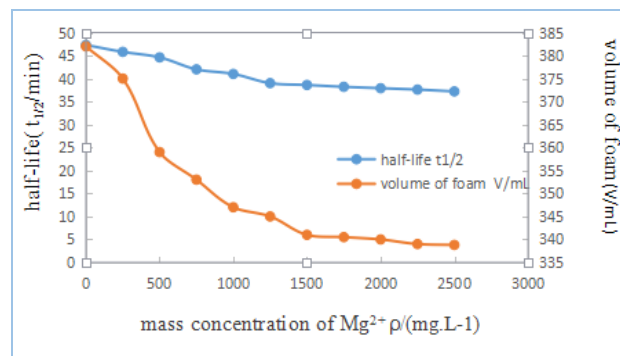


Figure 3. The influence of Mg²⁺ effects on SiO₂+SDS system

The figure 1 shows that with the increase of Na⁺ content, the height and half-life of foam increase at first but then decrease. It can be seen that the appropriate amount of Na⁺ plays an important role in the foaming volume and half-life. There are three reasons can analysis above phenomenon. The first one is the appropriate amount of Na⁺ can reduce the interfacial tension of SDS and enhance its surface activity. The second one is Na⁺ which can reduce the repulsion between particles, which dues to the negative charge of SiO₂ itself. The particles will be better adsorbed on the interface in this way. The third one is the negative electricity can exact the surface of SiO₂ nanoparticles and SDS hydrophobic group at the same time. The Na⁺ can make the combination between hydrophobic chain of SDS and SiO₂ hydrophobic group, so that the SiO₂ particles will be pulled to the foam surface in this way [14].

The figure 2 and 3 show that Mg²⁺ and Ca²⁺ are not like Na⁺ can promote the foam volume and half-life of the foam in a certain amount. With the increase of the content of Mg²⁺ and Ca²⁺, the height and half-life of foam decreases gradually. The foaming volume and half-life of Mg²⁺ foam solution

decrease slowly, it shows that the foam system of SiO_2 +SDS is better at confrontation of Mg^{2+} . The Ca^{2+} greatly destroys the hydration properties of SDS and reduces the content of SDS solution, which causes more SiO_2 particles break away from the interface of the liquid film and reduces the interaction between SDS and SiO_2 [15].

5. Conclusion

1.Finally, the 0.5%SDS+1.4%H₂O type SiO_2 foam flooding system is selected as the complete system.

2. The SDS+ SiO_2 composite foam system is better than single SDS foaming system in terms of improving oil recovery and plays an active role in resisting inorganic ions.

3.The SiO_2 solid particles can increase the mechanical strength of the foam liquid film in order to stabilize the foam and the stable foam is the key to improve the recovery rate of foam flooding.

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