The experimental study of foaming system suitable for high temperature foam gas driving

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Abstract: This paper is aiming at the most foaming agent who losing activity and fall flat under the condition of high temperature, with foam volume, drainage half-life and interfacial tension as evaluation index, using Waring Blender evaluation method, through the indoor experiment under the experimental temperature is 200^{o} C selected the system: 0.3%AOS+0.02%xanthan gum still has good foaming property and salt resistance, especially for the sodium bicarbonate has strong adaptability, which has a good application prospect for high temperature composite foam gas driving for heavy oil reservoir, meanwhile plays an important role in improving the recovery factor of heavy oil reservoir.

Introduction

Foaming agent has a wide range of application in the oil field, such as foam flooding, foam drilling, foam acid acidification, foam cement cementation, foam drainage gas recovery for water-bearing gas well, the profile control and water plugging with foam agent, steam flooding foam profile control ,etc. The foam agent using in the thermal recovery of heavy oil is due to it has the following features: the foam priority enter into the large pore path which has small seepage resistance, with the increasing of injection rate, it gradually formed blocking, thus preventing the foam enter into the high permeability channel, forcing the subsequent foam enter into the small pore path for middle-low permeability, until the foam occupying the whole core porosity, then the driving fluid can evenly advancing, so as to improving the steam absorption profile, improving the using degree of the reservoir, increasing the steam sweep area effectively, finally achieving the purpose of improving oil recovery. The foaming agent who as a kind of surfactant can reduce oil-water interfacial tension, and improve the wettability of the rock through the oil/water emulsion and liquid membrane replacement makes the bound of oil become flowing. The foam has the characteristics that when it contact oil will defoaming, but if it contact water will keep stability performance, the viscosity will keep constant when exist bubble, and the viscosity will reduce when the bubble disappeared, thus plays a role of “plugging water not blocking oil”, to improve oil displacement efficiency. Because of the foam can increase the pressure gradient of the air flow channel, and without blocking the channel, so the steam mobility could be controlled. The thermal conductivity of foam is low, it can reduce the heat to fluctuation of surrounding rock, and due to the mobility and flow direction could be controlled, reducing the leakage of the heat into the high permeable zone and water layer, makes the foam steam as heat transfer medium slow evenly sweeping the reservoir[1-2].

Experimental evaluation method

There are many performance evaluation methods for foaming agent, such as panel blow, pouring method, Ross-Miles, Waring Blender method, etc, among them the Waring Blender method is a kind of common evaluation method for foaming agent. This method has the characteristics of simple, convenient, using little drug and short experiment period, so this article using this method to screening and evaluation. The experiment process with reference to the industry standard SY/T 5672-93[3] “The evaluation method with high temperature foaming agent through injecting steam, mainly including the foamability and stability of foaming agent”. During the experiment, we can add a certain concentration of foaming agent solution into the beaker, after high speed stirring, closing the switch, and pouring the solution from the beaker into the 1000 ml measuring cylinder and reading the foam volume V_0(ml) immediately which shows the foaming ability of foam agent; then recording the required time that the bubble precipitation 50% liquid as foam drainage half-time which reflecting its stability ability.

Experimental materials

Experimental instrument

Analytical balance, oven, KJ-1 type experiment agitator, BX type super-thermostat, beaker, 1000ml measuring cylinder, stainless steel tank, stopwatch, interfacial tension meter, etc.

Experimental reagents

Foaming agent: alpha olefin sulfonate (AOS), ethoxylated lauryl alcohol sulfates (AES), sodium dodecyl benzene sulfonate (ABS); foam stabilizer: polyacrylamide (HPAM)，xanthan gum, betaine, carboxymethyl cellulose (CMC); foaming aids: sodium carbonate, sodium bicarbonate, sodium silicate.

The experimental results and analysis

Selecting of foaming agent

With foaming agent AOS, ABS, AES as the research objects, inspecting its foam volume and interfacial tension under the experimental temperature is 200^{o} C, the results are shown in Fig.1 and Fig.2..

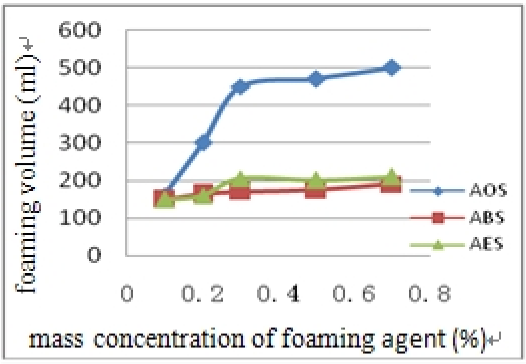

Fig.1 The foaming volume of three kinds of foaming agent under 200^{o} C

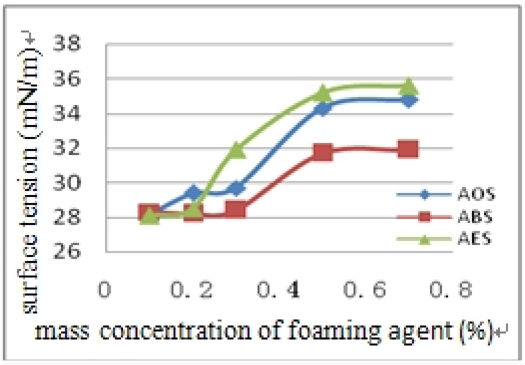

Fig.2 The foaming volume of three kinds of foaming agent under 200^{o} C

From the experimental results of Fig.1 we can see that along with the enlargement of the concentration of foaming agent, the foaming volume will increasing gradually until the concentration of foaming agent reached a certain value when the experimental temperature is 200°C; this is due to the foam surface viscosity magnifying with the increasing foam agent concentration, so that makes the foam more stable, when continue increasing the concentration of foaming agent the foam volume will magnify which making the concentration and density too large, and increasing the drainage tendency of liquid film, finally resulting the foam stability declining. Among the three kinds of foaming agent the foaming effect of AOS is superior to the AES and ABS, and the curve slope is the largest when the mass concentration of AOS is 0.3%, so the optimum concentration of AOS is 0.3%; from the Fig.2 we can see that along with the enlargement of AOS concentration, the interfacial tension will increase until the concentration of AOS reached a certain value, and the interfacial tension of AOS is lower and between the AES and ABS, so combined Fig.1 and Fig.2 the AOS has a good foam performance and the mass concentration is 0.3%.

Selecting of foam stabilizer

Foam stabilizer is the core issue of foam research. If we using single foam agent, the foam ability is well but the half-time is gradually short, and falling the desired effect. In order to improve the stability of the foam and prolong the half-life of foam we have to add stabilizing agent. The stability of foam will elevate obviously once adding the foam stabilizer. Foam stabilizer can be divided into two categories according to the strength: the first kind of foam stabilizer which caused the increasing amplitude of solution viscosity is smaller, and the foam stabilizer as a kind of active substances added to the foam agent, through the synergy to enhance surface adsorption of molecular interactions that makes the surface adsorption film strength, and increasing the elastic membrane of foam, decreasing the air permeability of foam to improve the stability of foam; the secondary category of foam agent is increasing viscosity stability foam agent which mainly through increasing the liquid viscosity to retard the drainage rate of foam, meanwhile reducing the gas solubility in the liquid film, thus improving the stability of foam which can prolong the half-time of foam obviously[4]. This article is aiming at four kinds of increased viscosity stability foam agent to research by indoor experiment.

With polyacrylamide, xanthan gum, betaine, sodium carboxymethyl cellulose-1 as foam stabilizer, the experimental temperature is 200°C, the Fig.3 inspected the foam stability of different foam stabilizer for the AOS; the Fig.4 studied the impact of foam stabilizer type and different add-mount for the interfacial tension of AOS.

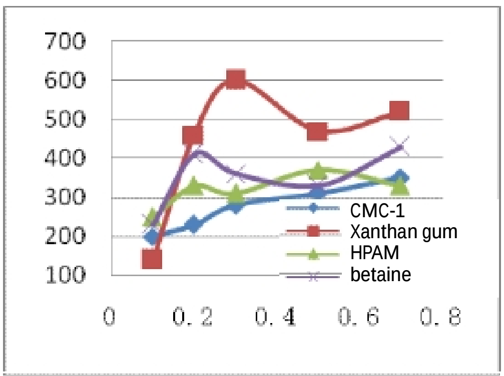

Fig.3 The influence of foam stabilizer for foaming volume under 200° C

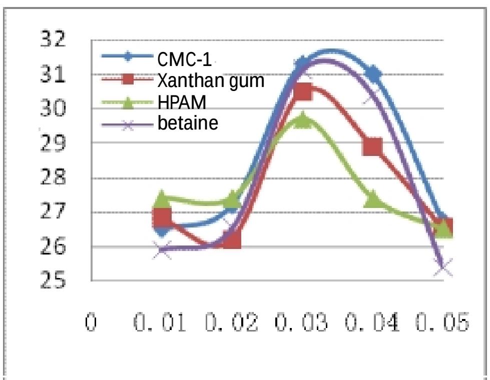

Fig.4 The influence of foam stabilizer for interfacial tension under 200° C

The Fig.3 shows the foam system: AOS+0.02%different foam stabilizer, and the other condition is same under 200° C, the foam volume of the system which increases firstly then decreases with the variation trend of AOS concentration, compared the stable foam effect of four foam stabilizer that the xanthan gum is the best one, that is because the xanthan gum sol molecule can form super combination of banded spiral copolymer, constitute a fragile similar plastic mesh structure, so that support the foam of solid particles, liquid droplets and foam pattern which shows a strong ability of emulsion stability and high suspended. From the Fig.4 we can see when adding CMC-1 and betaine the interfacial tension of foam system is increasing relatively, but joining the xanthan gum the effect is opposite, and when the concentration of xanthan is 0.02% the interfacial tension is relatively low which the same situation in other condition under 200^{o}C,. Combined the Fig.3 and Fig.4 we can see that the xanthan gum has a good stability and the suitable concentration is 0.02%.

The evaluation of salt resistance

With sodium carbonate, sodium bicarbonate, sodium silicate as additive to study the salt resistance of the foaming system 0.3%AOS+0.02% xanthan gum respectively, from the Table 1 we can see that this foaming system has a good salt resistance ability, in contrast to the adaptability the sodium silicate is relatively weak that is because the sodium silicate also known as water glass which is a kind of mineral binder and has a characteristics of poor water resistance which makes the foaming system has a weak adaptability relatively, but it has a good adaptability for sodium bicarbonate this is because the sodium bicarbonate is a substance which thermal decomposition by heating easily, and producing sodium carbonate, water, and carbon dioxide, of which the carbon dioxide can promote the foaming agent blow, so as to improve the foaming properties, and we can see along with the enlargement of the additive concentration, the foaming volume will increase until the concentration of the additive is reached 0.09%, so the optimum concentration of sodium bicarbonate is 0.09%.

Table1 The influence of foaming aids for foaming system

Experimental temperature (°C)	Foaming agent AOS (%)	foam stabilizer Xanthan gum (%)	foaming aid Na_2CO_3 (%)	Forming volume (ml)	foaming aid $NaHCO_3$ (%)	Forming volume (ml)	foaming aids Na_2SiO_3 (%)	Forming volume (ml)
200	0.3	0.02	0.05	150	0.05	175	0.05	150
200	0.3	0.02	0.07	300	0.07	350	0.07	310
200	0.3	0.02	0.09	380	0.09	415	0.09	350
200	0.3	0.02	0.11	365	0.11	385	0.11	315
200	0.3	0.02	0.13	350	0.13	360	0.13	300

The influence of temperature

Table2 The influence of the experimental temperature for foaming system

AOS (%)	Xanthan gum (%)	$NaHCO_3$ (%)	temperature (°C)	Forming volume (ml)	temperature (°C)	Forming volume (ml)	temperature (°C)	Forming volume (ml)
0.1	0.02	0.09	50	250	100	235	200	220
0.2	0.02	0.09	50	450	100	360	200	290
0.3	0.02	0.09	50	535	100	470	200	400
0.5	0.02	0.09	50	510	100	450	200	350
0.7	0.02	0.09	50	480	100	400	200	300

From the Table 2 we can see that the foaming system：AOS+0.02% xanthan gum+0.09% sodium bicarbonate, the foaming volume presents downtrend along with the rising of temperature, this is because the bubble demonstrates metastable state when the temperature is low, the main decay mechanism is gas diffusion; with the increasing temperature, the top of the bubble upper always convex upwards, this bending film has a great influence for evaporation, and the evaporation rate increases with the rising of the temperature, meanwhile the function of gas diffusion is enhancing, and speed of the membrane film will discharge fluid outside, and it makes the liquid membrane burst soon when it not reached the stable of final thickness, and the system became unstable due to an overall increase in energy, finally caused the decline of foam stability; and along with the enlargement of the concentration of AOS the foaming volume of the system is increasing until concentration of AOS increased to an extent value at the same temperature, and the increasing extent of foaming volume is the maximum, so it consistent with the conclusion in Fig.1.

Conclusions

（1）When the experimental temperature is 200°C for three kinds of foaming agent AOS, AES, ABS, the overall trend of the foaming volume are increased with the rising of the mass concentration of foaming agent, but the AOS has a good foaming performance in contrast, and the optimized mass concentration is 0.3%。

（2）When the experimental temperature is 200°C， through the screening evaluation of four kinds of increased viscosity stabilizing foaming agent for AOS, it is concluded that xanthan gum has relatively good foam stability and the optimum concentration is 0.02%.

（3）When the experimental temperature is 200°C, through the screening evaluation the salt resistance of the foaming agent 0.3%AOS+0.02%xanthan gum, it is concluded that the system has good salt resistance and has a strong adaptability for sodium bicarbonate relatively and the suitable concentration is 0.09%.

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