ISSN:2790-1688 DOI: 10.56028/aetr.4.1.19.2023

Development and Application of New Fracturing Fluid System for Shale Oil Reservoir Displacement

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Abstract. Shale reservoir has tight reservoir, ultra-low permeability and poor development of natural fractures, which need to be completed by fracturing reconstruction. There are some problems in conventional fracturing fluid construction, such as serious reservoir damage, poor salt resistance, inability to reuse flowback fluid, poor dispersion and wetting change performance. According to the characteristics of reservoir and the problems existing in the construction, a hydraulic fracturing fluid system for shale oil reservoir with surfactant as its main component has been developed. There is no residue after the thickener is broken, and the damage to the reservoir is small. It's salt resistant is 100000mg/L, can realize the reuse of flowback liquid and reduce the oil water interfacial tension to 10-3mN/m level because of good dispersion. At present, the application effect is good at the 725 strata of 13 Wells in H100 platform.

Keywords: Shale oil; Surfactant; Oil displacement efficiency.

1. Introduction

The energy demand of our country is increasing year by year. It is predicted that the imports of oil and gas will be more than 80% in the 2030. Therefore, the focus of oil and gas exploitation is changing from conventional gas reservoirs to unconventional gas pools, such as shale oil and gas pools. Compared with alkali flooding and polymer flooding, surfactant flooding has advantages such as simple mechanism, temperature resistance and salt resistance in shale oil exploitation, so it has become one of the effective ways to improve oil recovery [1-3]. Based on the characteristics of shale oil reservoir and the performance requirements of volume fracturing fluid, LGF-80 oil displacement fracturing fluid system composed of surfactant gaffer XYZC-6 and regulator XYTJ-3 has been developed through laboratory tests and successfully applied in the field.

2. Materials and method

2.1 Materials and instruments

2.1.1 Experimental drugs

Sodium alpha-alkenyl sulfonate (AR), propylene chloride (AR), diethanolamine (AR), acrylamide (AR), 2.2-diazo (2-methylpropyl mi) dihydrochloride (Aladdin), anhydrous ethanol (AR), potassium chloride (AR), calcium chloride (AR), magnesium chloride (AR), sodium chloride (AR).

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2.1.2 Experimental equipment

Electronic balance, magnetic stirring heater, circulating water type multi-purpose vacuum pump, vacuum drying oven, automatic surface tension, interface tensiometer, contact Angle measuring instrument, PVS rheometer, six-speed rotating viscosity measuring instrument.

2.2 Experimental methods

2.2.1 Preparation of thickener XYZC-6

Through repeated laboratory tests, it was found that viscoelastic surfactants with the structure of peptide chain have good salt and acid resistance, and at the same time, the winding between the surfactant molecules can quickly form micellar solutions with peptide chain structure, so as to achieve rapid viscosification. A compound surfactant with a special structure was prepared by molecular modification in the laboratory as the system thickener [4]. Specific preparation process: Firstly, an electronic balance was used to weigh an appropriate amount of solid powder of sodium α-allyl sulfonate, and then an appropriate amount of allyl diethanolamine was weighed, and an appropriate amount of water was measured with a measuring cylinder. The three of them were poured into a three-port flask and mixed evenly to prepare a solution with a mass percentage of 30%. A magnetic stirring heater was used to heat it to a certain temperature, and then a small amount of initiator 2, 2-azobiazo (2-methylpropyl) was added After a period of reaction, the experiment was finished and the instrument was shut down. Add anhydrous ethanol and filter to purify, after a period of vacuum drying to get orange solid-modified surfactant (Fig.1).

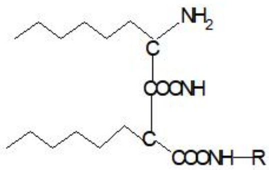

Fig. 1 Molecular structure of regulator

2.2.2 Optimization of regulator XYTJ-3

Regulator XYTJ-3 is a kind of organic complex acid. After the molecules of the thickening agent are rapidly dispersed in water, the regulator with weak acidic pH is added, which can rapidly aggregate from small micelles to form globules within a few seconds. With the increase of chain length, the aggregates rapidly increase to form globule micelles. In the case of globule micelles, it is not easy for the molecular monomers to fill tightly into the micelle, so the asymmetric growth occurs, forming ellipses. And even round plate micelles eventually form viscoelastic solution [5]. The thickening process is shown in Figure 1. Based on this reaction mechanism, the dosage of thickener and regulator determines the number of spherical micelles formed, and the liquid viscosity varies with different dosage. Therefore, the viscosity of fracturing fluid can be changed by changing the dosage, which is convenient for the transformation of low viscosity and high viscosity in field construction.

2.2.3 Formulation determination and performance evaluation of the system

The formulation of fracturing fluid system should be closely adapted to the geological characteristics of the reconstructed reservoir. The physical properties of sandstone samples in Chang 7 reservoir were analyzed and statistically found (Table 1) that the porosity distribution range was 1.18%-14.05%, mainly 2%-12%, with a distribution frequency of 94.5% and an average porosity of 7.16%. From the permeability distribution histogram, the permeability distribution peak is also obvious, mainly concentrated in the range greater than $0.01\text{-}1\times10^{-3}\mu m^2$, the distribution frequency is 92.5%, and the average permeability is $0.596\times10^{-3}\mu m^2$.

The basic formula of fracturing liquid system was preliminarily determined to conduct experimental research and data analysis, optimize and adjust the dosage of thickener and regulator

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screening, and optimize and adjust the dosage of thickener and regulator screening to meet the requirements of reservoir conditions and fracturing process. The formula is: XYC-6, a thickener of 0.8-1.2%, and XYTJ-3, a regulator of 1.0%-1.5%, have functions such as fast thickening, online mixing, reuse, low damage and oil displacement to meet the requirements of reservoir conditions and fracturing process [6]. The performance evaluation of the system was based on the requirements of the oil industry standards "Evaluation Method for Water-based fracturing Fluid Performance", "General Technical Conditions for Fracturing Fluid", "Evaluation Method for Water-based Carrying Fluid Performance of gravel pack sand Control" and other standards, and the rheological properties, sand suspension properties, salt resistance, oil displacement properties, dialysis properties and other properties of the system were measured respectively.

3. Results and discussion

3.1 Indoor comprehensive performance evaluation

3.1.1 Rheological property test

According to the formula: 1.2% thickener and 1.0% regulator, water was used to prepare fracturing fluid, and PVS rheometer was used to test the temperature and shear resistance at 80°C and 170s-1 shear rate. The test results are shown in Fig. 2.

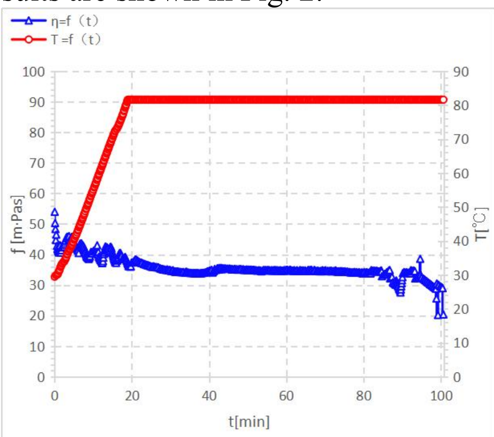

Fig. 2 Test curve of temperature and shear resistance

As can be seen from Figure. 2, the viscosity of the system is 20.38mPa·s after shearing for 100min at 80°C and $170s^{-1}$, showing good temperature and shear resistance.

3.1.2 Rubber breaking performance test

According to the formula: 1.2% thickener and 1.0% regulator, clean water was used to prepare fracturing fluid. Combined with reservoir temperature and crude oil content, 3% kerosene was added at 60°C for gum-breaking, and the gum-breaking liquid was taken for interfacial tension, anti-swelling, core damage and other performance tests. The test results are shown in Table 1.

Table.1 Performance test of fracture breaking fluid

Index	T (°C)	Type	Content (%)	T (min)	Viscosity (mPa·s)	Interfacial tension (mN/m)	Anti-swelling rate (%)	Core damage rate (%)
Numeric value	60	Kerosene	3	90	2.1642	0.397	89.9	15.6

3.1.3 Performance test of flowback liquid remix

In order to further reduce the cost of fracturing fluid allocation, alleviate the main contradiction between flowback fluid treatment and production system, and solve the problems of various production links, one of the design objectives of the system is: good salt resistance, can use

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flowback fluid reallocation, to complete the reuse of flowback fluid. Potassium chloride was used to prepare brine with salinity of 2.0%, 4.0%, 6.0%, 8.0% and 10.0% respectively. Fracturing fluid was prepared according to the formula of 1.5% thickener and 0.6% regulator, and PVS rheometer was used. The temperature resistance performance was tested at the shear rate of $170s^{-1}$, and the test results are shown in Figure 3.

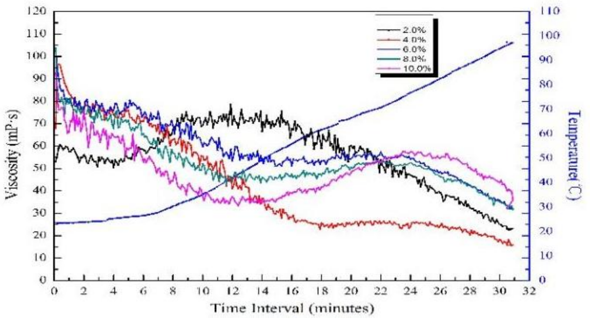

Fig. 3 Test curve of temperature resistance of fracturing fluid with different salinity

As can be seen from Figure 3, the fracturing fluid was prepared with brine with salinity of 20000mg/L. At the shear rate of $170s^{-1}$, when the temperature rose to 90℃, the viscosity was above 25.3mPa·s. The fracturing fluid was prepared with brine with a salinity of 4.0%, and the viscosity was above 20mPa·s when the temperature rose to 90℃ at the shear rate of $170s^{-1}$. The fracturing fluid was prepared with salt water with salinity of 6.0%. When the temperature rose to 90℃ at the shear rate of $170s^{-1}$, the viscosity was above 36.8mPa·s. The fracturing fluid was prepared with salt water with a salinity of 8.0%. When the temperature rose to 90℃ at the shear rate of $170s^{-1}$, the viscosity was above 35mPa·s. The fracturing fluid was prepared with brine with salinity of 10.0%. At the shear rate of $170s^{-1}$, the viscosity was above 39.1mPa·s when the temperature rose to 90℃. It can be seen that when the salinity reaches 100000mg/L, the prepared fracturing fluid has good temperature resistance.The temperature and shear resistance performance of the flowback liquid mixture on the Hua H34 (oil displacement fracturing fluid construction) platform was evaluated. The results are shown in Figure 4. For 1h shear at 80℃, the viscosity is 20mPa·s, meeting the construction requirements.

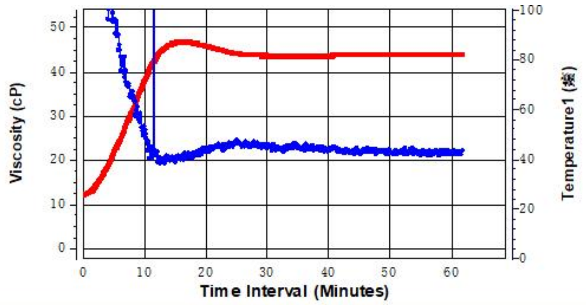

Fig. 4 Rheological property test curve of flowback remix liquid

3.1.4 Suspension sand performance test

At room temperature (25℃), thickener concentrations were 1.0%, 1.5% and 2.0% respectively, numbered 1, 2 and 3. Sand carrying performance of fracturing fluid in different time periods was measured. When the thickener is between 1.5% and 2.0%, the sand carrying performance of fracturing fluid is good. At 80℃, the concentration of thickener was 1.0%, 1.5% and 2.0% respectively, and the sand carrying performance of fracturing fluid in different time periods was measured. As can be seen from Fig. 4, the sand carrying performance of fracturing fluid within 5 minutes is good and has certain high temperature resistance, which can meet the requirements of oil well fracturing construction.

ISSN:2790-1688 DOI: 10.56028/aetr.4.1.19.2023

3.1.5 Steady-state interfacial tension test

Under the constant temperature condition of 80 ℃, TX500C rotary drop interfacial tensiometer was used to measure the steadystate interfacial tension between the clean fracturing breaking liquid system and crude oil at low temperature with the rotating speed of 6000 rpm. The experimental results are shown in Figure. 5.

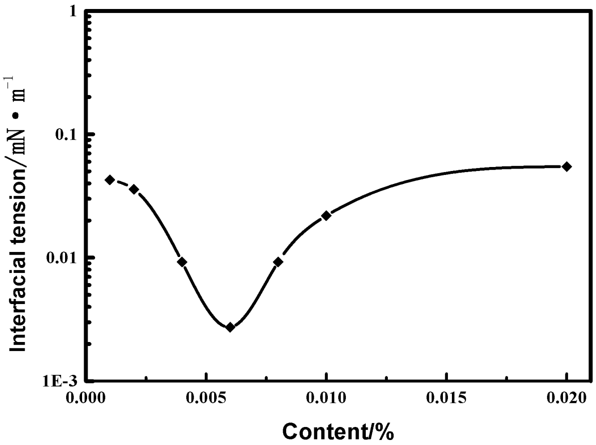

Fig. 5. Trend of steady-state interfacial tension with concentration of breaking liquid

As shown in Figure 5, when the surfactant concentration is less than 0.006%, the steady-state interfacial tension decreases with the increase of the concentration, and when the surfactant concentration is more than 0.006%, the interfacial tension increases with the increase of the concentration. The reason is that when the concentration is lower than 0.006%, the number of surfactant molecules in the system increases with the increase of the concentration, and more and more surfactant molecules tend to be adsorbed on the oil-water interface, and the interfacial tension decreases gradually. When the concentration exceeds 0.006%, with the increase of the concentration, the micelles formed in the solution will dissolve the highly active components at the oil-water interface, and the surfactant molecules at the oil-water interface will decrease, resulting in the increase of interfacial tension. The low temperature fracturing fluid of peptide-like surfactant can reach the order of 10-2 mN·m-1 in the concentration range of 0.001%-0.02%, and the interfacial tension between the system and crude oil can reach the order of 10^{-3} mN $\cdot m^{-1}$ when the concentration of the fluid system is 0.004%-0.008%.

3.1.6 Oil displacement performance evaluation

The oil displacement performance evaluation of the rubber breaking fluid of the system was carried out.Reservoir cores of Chang 6, Chang 7, and Chang 8 Wells were selected for the experiment. LGF-80 fracturing fluid with completely broken gel was used for the experiment, and distilled water was used for the control group. Before the experiment, the basic core data was determined, the natural core was saturated with standard brine, and then the dehydrated kerosene was used to flood the core 10PV to achieve stability and establish oil saturation. During displacement, the confining pressure was set at 3.5MPa and heated to 75℃. After injecting the fracturing fluid of the LGF-80 system into the rubber breaking fluid, the constant pressure was maintained at 3.0MPa for displacement to the output fluid. The parameters were adjusted and the constant flow was changed to 0.1ml/min to continue displacement until the produced fluid contained more than 98% water. Table 2 shows the core displacement results.

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Table. 2 Core displacement results

No.	Gas permeability（10-3μm2）	Pore volume（cm3）	Porosity（%）	Displacement system	Recovery（%）
C6-22	1.45	3.57	10.02	LGF-80 breaking fluid	44.23
C6-36	1.59	3.58	11.73	LGF-80 breaking fluid	47.19
C7-20	1.37	3.66	8.70	LGF-80 breaking fluid	50.74
C7-39	0.97	3.49	7.44	LGF-80 breaking fluid	51.91
C8-25	0.81	3.77	8.36	LGF-80 breaking fluid	47.37
C8-13	1.22	3.94	10.67	LGF-80 breaking fluid	48.99
C6-51	1.49	3.85	10.72	Distilled water	21.02
C7-34	0.87	3.52	6.37	Distilled water	20.14
C8-18	1.79	3.34	9.18	Distilled water	19.67

Table 2 shows that fracturing fluid of LGF-80 system can effectively improve oil recovery. Compared with water flooding, the breaking liquid can improve the efficiency of water flooding by more than half. In summary, the fracturing fluid of LGF-80 system has the dual effects of fracturing and oil displacement.

3.2 Field application

On H100 platform in China, 13 Wells were constructed at the 725 layer level of Chang 71 and Chang 72. The site adopted on-line construction with side mixing and side injection. The liquid thickening time was within 100s, and the liquid viscosity was 27-33mPa·s, meeting the requirements of on-site sand addition. The overall construction pressure on site is stable. At present, 11 Wells discharge liquid and 10 Wells see oil, accounting for 90.9%. The wellhead pressure is 0.3-2.3MPa, the average daily fluid volume is 59.1m^3, the cumulative oil production is 985.8m3, and the average flowback rate is 12.5%.

4. Conclusion

(1) The viscoelastic surfactant with the main structure of near peptide chain was synthesized as the thickening agent, and the weak acidic solvent composed of multi-component organic solvent was selected as the regulator, so as to construct the fracturing liquid system of LGF-80 displacement surfactant.
(2) The system can withstand salt 100000mg/L and temperature above 80℃, which can significantly reduce the oil-water interfacial tension to 10^{-3} mN $\cdot m^{-1}$ and greatly improve the oil recovery.
(3) In H100 platform in China, 13 Wells were constructed in the 725 interval, and the application effect was good.

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