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Analysis of Viscosity Reduction Mechanism of Heavy Oil and Experimental Evaluation of Efficient Viscosity Reduction Systems

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Abstract

This paper elaborates on the viscosity reduction mechanism of heavy oil. The main reason for the high viscosity of heavy oil is the supramolecular gel structure formed by asphaltenes and resins. Emulsification viscosity reduction works by adding a certain amount of surfactant aqueous solution to heavy oil to disperse it and achieve viscosity reduction. After screening 8 surfactants, it was determined that the overall viscosity reduction effect of self-developed surfactant No.5 was the best. By optimizing the dosage and reaction conditions, it was found that a concentration of 0.2%, water content of 80% and suitable temperature helped achieve better viscosity reduction, while not affecting subsequent dehydration, laying the foundation for field application.

Keywords

Heavy Oil; Surfactant; Viscosity Reduction; Mechanization.

1. Viscosity Reduction Mechanism of Heavy Oil

1.1 Heavy Oil Classification Standards in China

Heavy oil is commonly referred to as heavy crude oil or high viscosity crude oil. UNITAR defines heavy oil and oil sands as naturally occurring petroleum or similar liquid or semi-solid hydrocarbons that can be characterized by viscosity and density (shown in Table 1).

Table 1. Classification Standards for Heavy Oil in China

Classification of Heavy Oil		50 °CViscosity/ (mPa·s)	20°CRelative Density/ (g·cm^{-3})
Classification	Level		
Ordinary heavy oil	I-1	50~100	>0.90
	I-2	100~10000	>0.92
Extra heavy oil	II	10000~50000	>0.95
Super heavy oil	III	>50000	>0.98

1.2 Analysis of Viscosity Causes of Heavy Oil

Heavy oil is a colloidal system, with the main components of the liquid phase (continuous phase) being: saturated hydrocarbons, aromatic hydrocarbons, resin molecules, etc.; the main component of the solid phase (dispersed phase) is asphaltene, and the wax content in heavy oil systems is very

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low[1]. Experiments prove that even if all the wax crystals in the heavy oil system precipitate, they will not form an oil structure mainly composed of wax crystals. Therefore, the viscosity of heavy oil is still high at relatively high temperatures. It can be inferred that the high viscosity of heavy oil is not due to a network structure like waxy crude oil, but is caused by the supramolecular structure formed by the interaction of various forces between the large molecules such as resins and asphaltenes and heavy oil particles inherently present in heavy oil. These super macromolecular structures are not densely packed in the heavy oil system. Lower-level molecules attract and aggregate with each other under intermolecular forces, forming a looser, higher-level sub-supramolecular structure, and so on, the sub-supramolecules further form the supramolecular structure[2]. At the same time, a large amount of liquid oil droplets are wrapped in the voids of these supramolecules, forming very high molecular weight micelles, resulting in the high viscosity of crude oil.

1.3 Emulsification Viscosity Reduction Mechanism

Emulsification viscosity reduction of heavy oil refers to adding appropriate water and suitable oil-in-water (O/W) emulsifiers to heavy oil (or oil-water dispersion system), and dispersing the crude oil into small oil droplets in water through mechanical agitation at a certain temperature, thus changing the internal friction between heavy oil and the pipe wall as well as between heavy oils into the friction between water and the pipe wall and between water and water, greatly reducing the flow resistance of the entire system and saving power consumption for heavy oil exploitation and transportation[3]. Emulsification viscosity reduction requires the following conditions: ①There must be oil and water in the system; ②Suitable emulsification viscosity reducers exist; ③Appropriate agitation conditions.

The key to emulsification viscosity reduction is to select high-quality, cost-effective and efficient emulsification viscosity reducers. Good viscosity reducers should have the following two characteristics: ① Good emulsification for heavy oil, able to form relatively stable O/W emulsions and achieve high viscosity reduction efficiency; ②The formed O/W emulsions cannot be too stable, otherwise it affects subsequent crude oil dehydration. In general, heavy oils from different blocks have different chemical compositions and reservoir structures, exhibiting different patterns in emulsification viscosity reduction and other viscosity reduction exploitations. Therefore, it is necessary to study the viscosity reducer systems specifically for heavy oils from different sources and properties.

2. Experiments

Due to the diversity of normal alkane carbon number distribution and the complexity of resin and asphaltene structures in crude oil, viscosity reducers are highly selective to crude oils, and it is almost impossible to screen viscosity reducers suitable for all crude oils. Most literature studies have shown that the use of multiple surfactants and various additives can both expand the scope of application and improve the viscosity reduction effect.

2.1 Materials and Instruments

Instruments: BROOKFIELD rotational viscometer, constant temperature water bath, electronic balance, beaker, colorimetric tube.

Reagents: T-20 , T-80 , 9022 , Composite emulsifier, Butenyl surfactant, N-enyl surfactant, Sodium dodecylbenzenesulfonate, Anionic/Nonionic surfactants.

2.2 Experimental Methods and Procedures

2.2.1 Preparation of Emulsion

The heavy oil emulsion was prepared by mechanical agitation, i.e. taking appropriate amount of crude oil and viscosity reducer aqueous solution, mixing in a beaker, and stirring with a glass rod for 60 circles to form a uniform emulsion.

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2.2.2 Preliminary Evaluation and Identification of Emulsion Type

①Dilution method: Drop the emulsion in water. If it spreads quickly, it is O/W type.②Filter paper method: Drop the emulsion on filter paper. If a water ring forms nearby, it is O/W type.③Microscopy: Observe the emulsion under a microscope. If the droplets are black in the center and bright around, it is O/W type.

2.2.3 Experimental Procedures

①Sample preparation: Heat dehydrated heavy oil samples in a 50°C water bath for 2h, then let stand for 48h. All samples are pretreated the same way to ensure consistent composition and state as the experimental basis sample. Experiments should be completed quickly after pre-treatment, otherwise the sample state will change. ②Heat the oil sample in a 30°C water bath for fluidity. Weigh 42g of preheated heavy oil, 18g of water, and add viscosity reducer. ③Add the oil-water sample with viscosity reducer to a water bath at ambient temperature for thorough agitation and sufficient emulsification. ④Measure the apparent viscosity of the emulsified sample with a viscometer, and do parallel experiments.

3. Results and Discussion

3.1 Rheological Characteristics of Heavy Oil

Crude oil viscosity refers to the magnitude of its internal friction during flow, which is an important indicator for evaluating crude oil fluidity. It has a great influence on the flow process of petroleum in porous media and wellbores. The experimental oil samples were collected from the Dudongtai Oilfield in Liaohe Oilfield (shown in Fig.1).

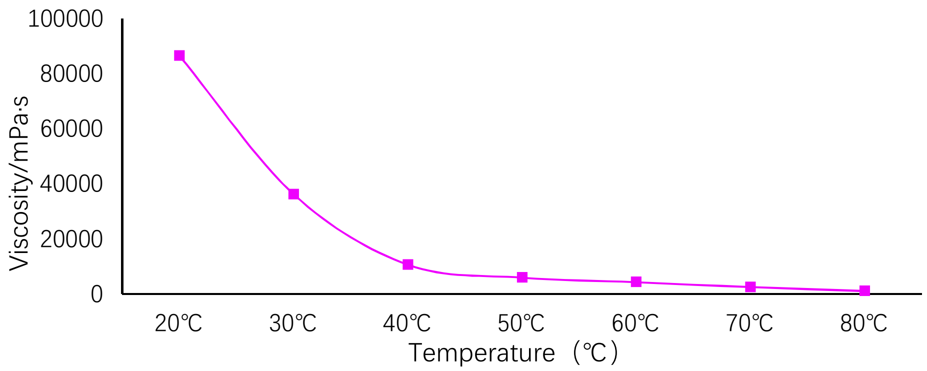

Fig. 1 Viscosity-temperature Curve of Dujiatai Reservoir in Liaohe Oilfield

3.2 Performance Evaluation and Comparison of Viscosity Reducers

Eight viscosity reducers were evaluated by identifying the emulsification and preliminary assessing the viscosity reduction. The dosage was 0.2% for all (shown in Table 2).

Table 2. Comparison and Evaluation of Viscosity Reducing Agents

SN	Sample Name	Concentration/%	Temperature/℃	Oil-water ratio	Emulsification situation
1#	T-20	0.2	50	7:3	Deny
2#	T-80				Deny
3#	9022				Coarse Dispersion
4#	Composite Emulsifier				Coarse Dispersion
5#	Butenyl S				Deny
6#	N-enyl S				Deny
7#	SDS				Coarse Dispersion
8#	Anionic/Nonionic				Completely Dispersed

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The anionic-nonionic viscosity reducer emulsion spread quickly in water as identified by the dilution method, indicating complete emulsification. The anionic-nonionic viscosity reducer was preliminarily determined as the experimental reagent.

3.3 Effect of Concentration on Heavy Oil Viscosity Reduction

The viscosity values at dosage from 0.05% to 0.2% were tested according to the experimental steps (shown in Fig. 2).

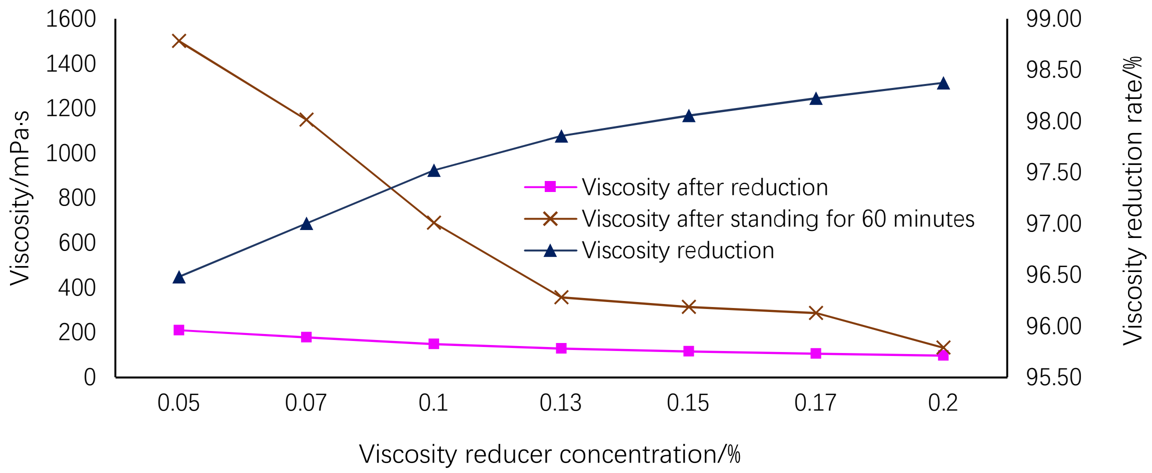

Fig. 2 Effect of viscosity reducer concentration on viscosity reduction of heavy oil

When the viscosity reducer concentration was 0.2%, the apparent viscosity was less than 100 mPa·s, and the viscosity reduction reached 98.3%. The static viscosity was 132.5 mPa·s, meeting the requirements for wellbore lifting. At a dosage of 0.05%, although the viscosity was 210 mPa·s, the static viscosity exceeded 1500 mPa·s, failing to meet the Q/SY 118-2013 standard. Therefore, 0.2% was selected as the optimal viscosity reducer concentration.

3.4 Effect of Temperature on Viscosity Reduction

The viscosity variation at 0.2% viscosity reducer concentration under different temperatures was measured (shown in Fig. 3).

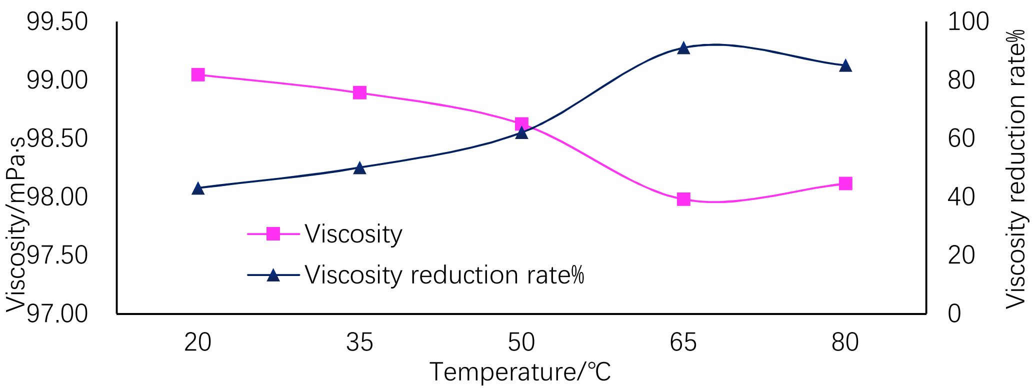

Fig. 3 Effect of temperature on viscosity reduction of crude oil

The viscosity-temperature curve did not show a positive correlation, because at 80°C, the temperature determined the viscosity, so the effect of the viscosity reducer was relatively weak. When the temperature dropped to 65°C, due to the temperature effect, some crude oil stuck together and the

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viscosity increased. As the temperature continued to decrease, the viscosity reducer played a major role, and the crude oil became granular, reducing the viscosity.

3.5 Effect of Water Content on Viscosity Reduction

The viscosity variation at 0.2% viscosity reducer concentration under different water content was measured (shown in Fig. 4).

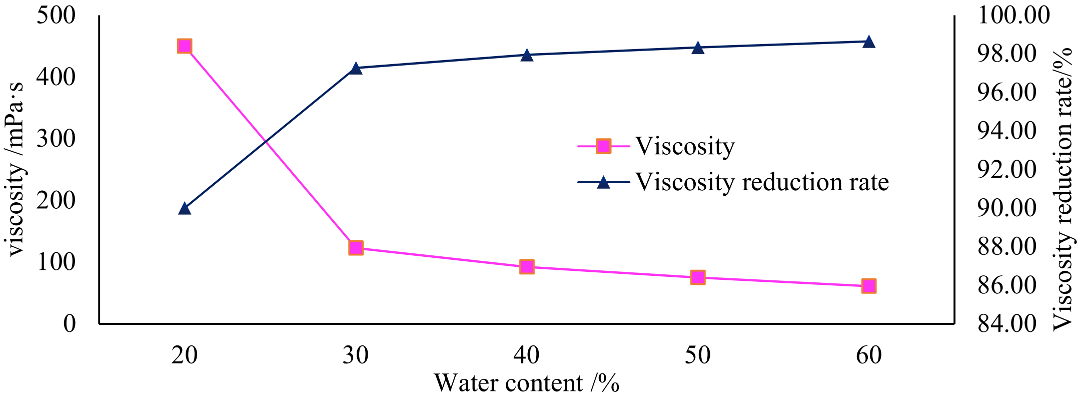

Fig. 4 Effect of Water Content on Viscosity Reduction of Crude Oil

When the crude oil water content was between 20% and 80%, the viscosity reduction effect was good. Below 20%, emulsification could not occur due to insufficient water. Above 80%, viscosity increased and slight layering occurred. This was because as the water content increased, the proportion of reagents decreased. When the water content exceeded 80%, the emulsification effect weakened due to severe layering.

3.6 Compatibility Evaluation

One colorimetric tube was added with 0.2% viscosity reducer, and another without as reference. Following the oilfield water treatment process, demulsifier, pre-dehydrator, flocculant and coagulant were added sequentially. The demulsification temperature was 90-95°C. The impact on water treatment was tested. The water removal amount of the tubes with and without viscosity reducer addition was the same, 75mL and 82mL respectively, and the water content in the upper oil was less than 5% for both, indicating no impact of viscosity reducer addition on demulsification. The floc content and water quality color were the same for the two tubes, suggesting no effect on flocculation. Therefore, adding viscosity reducer does not affect dehydration at the central processing facility.

4. Conclusion

The high viscosity of heavy oil originates from the supramolecular structure formed by asphaltenes and resins, explaining the microscopic mechanism of heavy oil viscosity.

Surfactants can be used for heavy oil emulsification viscosity reduction treatment to reduce viscosity by destroying the supramolecular structure. The self-developed surfactant No. 5 showed excellent viscosity reduction effect.

Optimizing the dosage, reaction temperature and water content of the surfactant can significantly improve the viscosity reduction efficiency. The treated heavy oil is compatible with conventional dehydration methods.

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