Experimental Investigation on Viscosity Change of Waxy Crude Oil Emulsion with Magnetic Field

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Abstract. The rheological properties of emulsions are complex, leading to serious flow assurance issues that affect the economical and safe operation of pipelines. It has been reported that applying magnetic treatment technology can effectively improve the flowability of waxy crude oil. The study aims to investigate the influence of magnetic treatment on the viscosity of waxy crude oil emulsions. A dynamic electromagnetic treatment device was designed. The dynamic magnetic treatment experiments of waxy crude oil emulsion were carried out to explore the effects of magnetic field intensity and magnetic field frequency on the viscosity change of waxy crude oil emulsion. Research results show that with four different magnetic field frequencies, the viscosity of the emulsion decreases initially and then increases with the increase in magnetic field intensity. The variation law of emulsion viscosity with magnetic field intensity is related to the magnetic field frequency. When the magnetic field frequency is 100 Hz, the highest and lowest viscosity variation rates are 7.91% and -7.36%, respectively, which occur at the magnetic field strength of 110 mT and 30 mT, respectively. It is believed that applying a higher field strength electromagnetic field to the emulsion is beneficial for viscosity reduction. The research findings can provide guidance for the further study of the viscosity reduction of waxy crude oil emulsion magnetic treatment technology.

Keywords: crude oil emulsion; viscosity; magnetic field; intensity; frequency.

1. Introduction

The oil-water mixing process is commonly existed in the oil field extraction and gathering process, due to the development cost and extraction technology. Most of the crude oil produced in China belongs to paraffin-based crude oil with high wax content. In the process of crude oil extraction, it is easy to form a waxy crude oil emulsion [1, 2]. Waxy crude oil emulsion is one of the worst fluid conditions for crude oil extraction and gathering pipelines [3, 4]. The application of magnetic treatment technology to improve the flowability of waxy crude oil emulsion has attracted more and more researchers' interest.

Shi et al. [5] explored the viscosity changes of two waxy crude oil emulsions with a water content of 10%v/v and 20%v/v with magnetic treatment conditions of 60 mT in magnetic field intensity, 50°C in magnetic treatment temperature and 30 min in magnetic treatment time, respectively. The results indicated that the decrease of viscosity of waxy crude oil emulsions was observed, which was attributed to the disintegration of paraffin by magnetic field. Chai et al. [6] explored the effects of magnetic field intensity, magnetic treatment temperature and magnetic treatment time on the viscosity of waxy crude oil emulsion. It was proposed that the magnetic field reduced the viscosity of the emulsion by reducing the oil-water interfacial tension and crude oil viscosity. At present, there are few studies on waxy crude oil emulsion viscosity reduction by magnetic treatment. In the process of exploring the emulsion viscosity reduction mechanism by magnetic treatment, most of the previous research was based on the crude oil viscosity reduction mechanism by magnetic treatment, and the research on the influence of emulsion characteristics on

the viscosity reduction process was not deep enough. In the research on the effect of magnetic field conditions on viscosity reduction, it was less concerned with the influence of magnetic field frequency, a key parameter of electromagnetic field, on the emulsion viscosity reduction effect by magnetic treatment. It is necessary to carry out relative research on improving the flowability of waxy crude oil emulsion with the action of the magnetic field.

A dynamic electromagnetic treatment device was designed and developed to apply a magnetic field perpendicular to the direction of motion to the waxy crude oil emulsion. The viscosity variation of waxy crude oil emulsion before and after magnetic treatment was compared, aiming to investigate the effects of magnetic field intensity and magnetic field frequency on the viscosity variation of waxy crude oil emulsion. The research results can provide guidance for further study of the viscosity reduction of waxy crude oil emulsion magnetic treatment technology.

2. Experimental section

2.1 Materials.

The main physical parameters and corresponding test methods of the waxy crude oil sample used in the experiments are shown in Table 1.

Table 1. Physical properties of the waxy crude oil

Parameter	Value	Test method
Density at 20°C (kg/m^3)	803.6	ISO 3675-1998
WAT (°C)	22.29	DSC
WDT (°C)	12.77	DSC
Pour point (◦C)	8	ASTM D5853-17
Wax (wt.%)	8.95	DSC
Resins (wt.%)	2.38	ASTM D4124-09
Asphaltenes (wt.%)	0.81	ASTM D4124-09

In order to explore the viscosity variation of crude oil emulsion by magnetic treatment, it is necessary to prepare an emulsion with a certain water content. The water content of crude oil emulsion is 30%v/v in the experiments, and the type is W/O emulsion. The waxy crude oil sample needs to be dehydrated thermally and electrically dehydrated for 2 h each. In order to eliminate the thermal and shear history of the crude oil sample, the sample was heated to 80°C in an oven and kept for 2 h, and then cooled at room temperature for 48 h. The emulsion was prepared by the oil-water emulsion preparation device shown in Fig. 1. The mixture of 100 ml water and pretreated crude oil was put into a 250 ml beaker, and the MINISTAR 20 control agitator (IKA, Germany) was used to stir the mixture for 20 min at 1200 rpm.

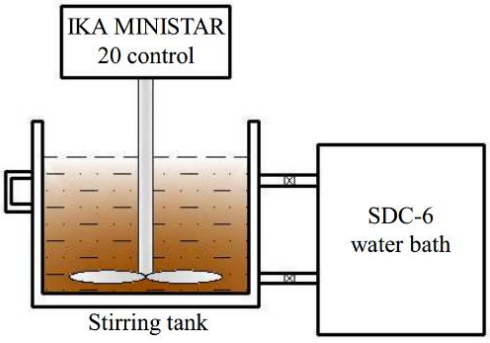

Fig. 1 Oil-water emulsion preparation device

2.2 Dynamic magnetic processing device.

A set of dynamic magnetic processing experimental device has been developed. As shown in Fig. 2, the device is mainly composed of the following parts: (1) a 20 kW alternating power supply; (2) a SDC-6 circulating water bath (Ningbo Scientz Biotechnology Co.,Ltd, China) with a temperature

ranging from 5°C to 90°C; (3) a MINISTAR 20 control agitator used as the stirring power equipment; (4) a cylindrical stirred vessel with a water jacket outside it, 90 mm in diameter and 205 mm in height, connected with the AC200 circulating water bath for temperature control; (5) an electromagnetic field generator with fixed magnetic processing slot connection port with a magnetic field intensity adjustment range of 0~150 mT and a magnetic field frequency adjustment range of 40~250 Hz.

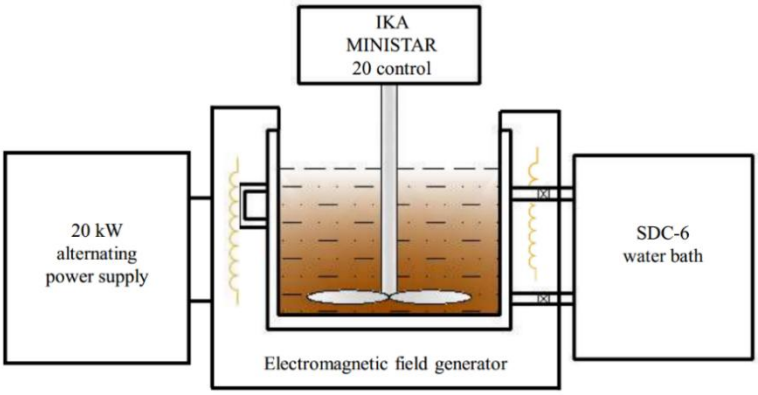

Fig. 2 Dynamic magnetic processing experimental device

2.3 Determination of mean shear rate in the device.

In order to characterize the variation of the apparent viscosity of non-Newtonian fluids such as crude oil emulsion with shear rate, it is necessary to determine the mean shear rate corresponding to different stirring speeds. Zhang et al. [7, 8] proposed a method to calculate the mean shear rate of non-Newtonian fluids in a stirred vessel based on the relationship between the energy dissipation rate and the shear rate. The mean shear rate can be calculated according to the fluid density, average velocity, pipe diameter, flow friction factor or friction pressure drop and rheological parameters. The method was used and the equation is as follows:

$$\overline{\dot{\gamma}} = \left[(2\pi Mn)/(\mu V)\right]^{1/2} \tag{1}$$

where M is the torque acting on the mixing shaft, N·m; N is the stirring speed of the mixing shaft, rps, μ is the liquid viscosity, Pa·s, and V is the fluid volume, m^3.

2.4 Determination of mean shear rate in the device.

The macroscopic viscosity is usually used as an important evaluation index to evaluate the rheology of emulsion in engineering practice. The viscosity of crude oil and emulsion was measured by the MCR302 rheometer (Anton Paar, Austria). In the process of viscosity measurement, the shear rate was set to 20 s^{-1}~200 s^{-1}, 30 ml of fluid before and after magnetic treatment was loaded into the rheometer, the temperature was kept constant for 15 min at the magnetic treatment temperature, and then the viscosity measurement started. The measurement was repeated three times and considered valid once the viscosity deviation did not exceed 10%.

3. Results and discussion

3.1 Determination of preparation temperature, magnetic treatment temperature and time.

In the magnetic treatment experiments, the crude oil needs to be prepared into an emulsion with a water content of 30%v/v. It is necessary to determine the appropriate preparation temperature. Previous research [9] have explored the viscosity of emulsion at preparation temperature of 55°C and 55°C respectively, and the results showed that the preparation temperature displayed little effect on the emulsion viscosity. Therefore, the preparation temperature was set to 60°C. Studies have shown that for waxy crude oil, the viscosity reduction effect is the best when the magnetic

treatment temperature is close to WAT [10, 11]. The WAT of the crude oil sample is 22.29°C, hence the magnetic treatment temperature was set to 23°C.

In order to determine the suitable magnetic treatment time, the magnetic field intensity was set to 70 mT and the magnetic field frequency was set to 100 Hz, to explore the viscosity variation of waxy crude oil emulsion by magnetic treatment when the magnetic treatment time was 0 min, 5 min, 10 min and 15 min respectively. The experimental results are shown in Fig. 3. It can be seen from the figure that when the magnetic treatment time is 5 min, 10 min and 15 min, the viscosity of crude oil emulsion decreases. The viscosity reduction effect is similar when the magnetic treatment time is 10 min and 15 min, which is better than that of 5 min. Consequently, the magnetic treatment time was set to 10 min.

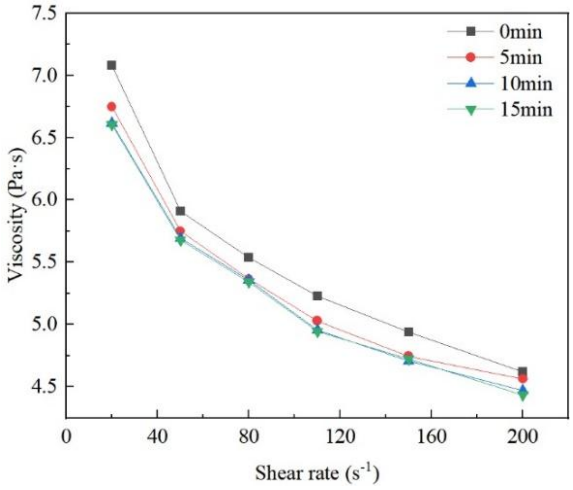

Fig. 3 Viscosity reduction effect of waxy crude oil emulsion with different magnetic treatment times

3.2 Viscosity variation of emulsion by magnetic field.

In the waxy crude oil emulsion magnetic treatment experiments, the magnetic treatment temperature was set to 23°C, the magnetic treatment time was set to 10 min, the magnetic field intensity was set to 30 mT, 70 mT, 110 mT and 150 mT, and the magnetic field frequency was set to 40 Hz, 100 Hz, 150 Hz and 200 Hz. The shear rate during the viscosity measurement process was set to 20 s^{-1}, 50 s^{-1}, 80 s^{-1}, 110 s^{-1}, 150 s^{-1} and 200 s^{-1}. The viscosity variation rate was defined so as to quantitatively evaluate the viscosity reduction effect of magnetic field on waxy crude oil emulsion. The equation is as follows:

$$r = \left(\mu_b - \mu_a\right) / \mu_b \tag{2}$$

where r is the viscosity variation rate, %; μ_b and μ_a are the viscosity of waxy crude oil emulsion before and after magnetic treatment, Pa·s.

3.2.1 Effect of magnetic field intensity on emulsion viscosity

Fig. 4 shows the viscosity variation rate with magnetic field intensity under different shear rates and magnetic field frequencies. It can be seen from the figure that with four different magnetic field frequencies, the viscosity of the emulsion decreases initially and then increases with the increase in magnetic field intensity. According to the magnetic field frequency, the viscosity reduction effect of the magnetic treatment changing with magnetic treatment intensity can be divided into two cases. When the magnetic field frequency is 40 Hz and 200 Hz, the viscosity reduction of the emulsion occurs with all the tested magnetic field intensities. When the magnetic field frequency is 100 Hz and 150 Hz, the emulsion viscosity at two magnetic field frequencies increases by magnetic treatment when the magnetic field intensity is 30 mT. Nevertheless, the emulsion viscosity decreases by magnetic treatment when the magnetic field intensity is over 30 mT. In the experiment, the highest viscosity variation rate is 7.91%, which occurs with the magnetic treatment condition of 100 Hz in magnetic field frequency, 110 mT in magnetic field intensity, and 20 s^{-1} in shear rate.

Meanwhile, the lowest viscosity variation rate is -7.36%, which occurs with the magnetic treatment condition of 100 Hz in magnetic field frequency, 30 mT in magnetic field intensity, and 110 s^{-1} in shear rate.

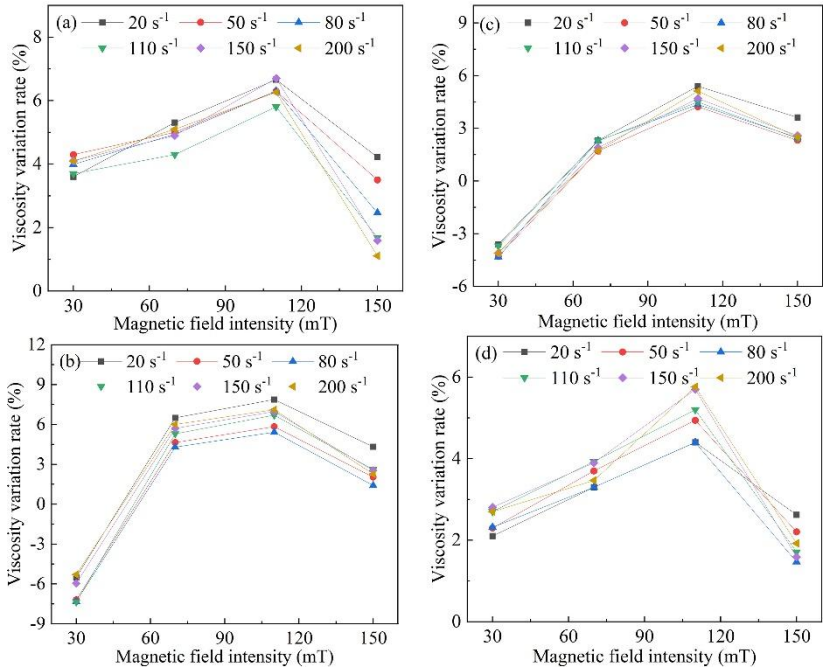

Fig. 4 Viscosity variation rate with magnetic field intensity under different shear rates when magnetic field frequency is (a) 40 Hz, (b) 100 Hz, (c) 150 Hz, (d) 200 Hz

3.2.2 Effect of magnetic field frequency on emulsion viscosity

Fig. 5 shows the viscosity variation rate with magnetic field frequency under different shear rates and magnetic field intensities. As can be seen from the figure, when the magnetic field intensity is different, the emulsion viscosity shows different trends with the change in magnetic field frequency. When the magnetic field intensity is relatively low, the viscosity of the emulsion first increases and then decreases with the increase of the magnetic field frequency. When the magnetic field intensity is relatively high (70~150 mT), the viscosity of the emulsion exhibits multi-extreme changes with the increase of the magnetic field frequency, and there is no increase in viscosity. These phenomena show that applying a higher field strength electromagnetic field to the emulsion is beneficial for viscosity reduction.

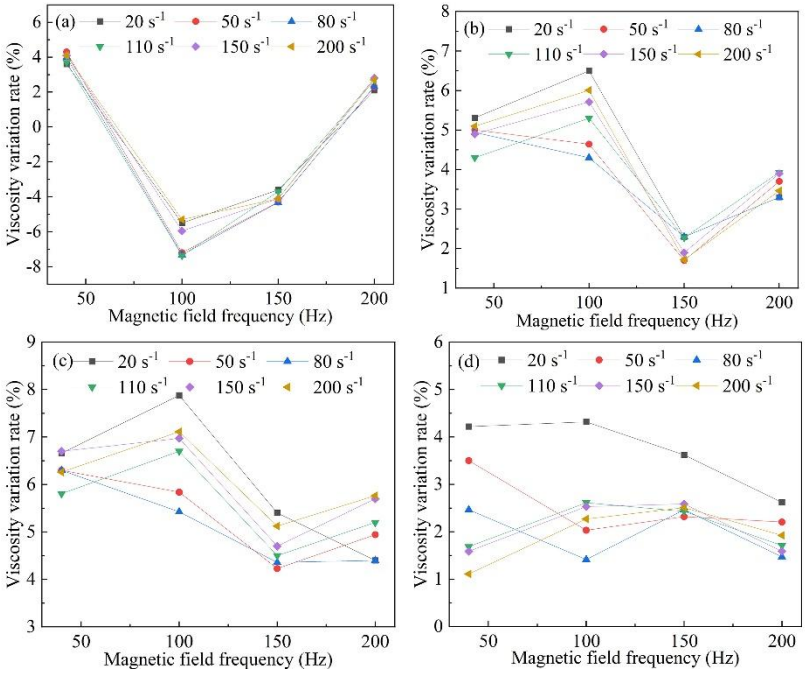

Fig. 5 Viscosity variation rate with magnetic field frequency under different shear rates when magnetic field intensity is (a) 30 mT, (b) 70 mT, (c) 110 mT, (d) 150 mT

4. Conclusions

A dynamic electromagnetic processing device was designed to carry out the viscosity reduction experiment of waxy crude oil emulsion. The influence of magnetic field intensity and frequency on the viscosity variation of waxy crude oil emulsion was discussed through experiments. According to a comprehensive analysis, with four different magnetic field frequencies, the viscosity of the emulsion decreases initially and then increases with the increase in magnetic field intensity. When the magnetic field frequency is 40 Hz and 200 Hz, the viscosity reduction of the emulsion occurs with all the tested magnetic field intensities. When the magnetic field frequency is 100 Hz and 150 Hz, the emulsion viscosity changes at multiple extremes with the increase in magnetic field intensity. When the magnetic field intensity is relatively low, the viscosity of the emulsion first increases and then decreases with the increase of the magnetic field frequency. When the magnetic field intensity is relatively high, the viscosity of the emulsion exhibits multi-extreme changes with the increase of the magnetic field frequency. In the experiments, the highest viscosity variation rate is 7.91%, which occurs with the magnetic treatment condition of 100 Hz in magnetic field frequency, 110 mT in magnetic field intensity, and 20 s^{-1} in shear rate. Meanwhile, the lowest viscosity variation rate is -7.36%, which occurs with the magnetic treatment condition of 100 Hz in magnetic field frequency, 30 mT in magnetic field intensity, and 110 s^{-1} in shear rate. Research results show that applying a higher field strength electromagnetic field to the emulsion is beneficial for viscosity reduction. When an electromagnetic field of lower field strength is applied to the emulsion, the viscosity may increase.

Acknowledgements

This work has been funded by the National Natural Science Foundation of China (Grant No. 51974335).

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