SHEAR STRENGTHENING VISCOSITY AND SHEAR-RATE-DEPENDENT MODULUS MODEL FOR A WAXY CRUDE OIL

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Summary The steady shear viscosity of a shengli waxy crude oil at the temperature 3~4 °C higher than its gel point was measured by using rotational parallel plates, which shows a slight shear thickening behavior. The shear strengthening viscosity can not be described by the spectrum model proposed in our previous work. In the present paper, the spectrum model modified by considering the change of modulus induced by shear motion can be used to well describe the shear strengthening viscosity of the waxy crude oil.

INTRODUCTION

The flowability of waxy crude oil is important in its transportation, which is not only concerned with the security of pipeline, but the economic benefit of transport. The flow behavior of waxy crude oil at low temperature has been paid more attention. In China, we have two terms used as indicator of the flowable behavior of crude oil at low temperature, i.e. gel point and pour point, respectively. The gel point is the highest temperature at which crude oil can not flow, while the so-called pour point means the lowest temperature at which crude oil can flow. An empirical rule used in the pipeline transportation of crude oil in China is that the temperature of crude oil before the inlet of oil depot should be at least 3 °C higher than its gel point. In the present paper, the steady shear flow behavior of a Shengli crude oil at the temperature of about 3.6 °C higher than its gel point was studied.
The authors once proposed a spectrum model [1] to completely describe the complicated steady shear viscosity of some complex fluids. Actually, the spectrum model has the formula of being analogous to the real part of complex viscosity, which is more flexible than some traditional viscosity models [2], such as Power-Law model, Carreau model. The power of the spectrum model stems from the success of viscoelastic theory in extensive applications. The apparent difference between the spectrum model and the real part of complex viscosity is at the approach of obtaining the parameters of model. However, the spectrum model can not be used to describe the steady shear flow behavior of the above Shengli crude oil at the temperature of about 3.6 °C higher than its gel point. The spectrum model was modified here, and then the new spectrum model can be used to calculate the steady shear viscosity of the Shengli crude oil.

EXPERIMENT

The Shengli waxy crude oil used in the experiment was supplied by Department of Petroleum Processing in East China University of Science and Technology. Some characteristics of the crude oil were shown in Table 1. the components of wax, resin and asphaltene in the crude oil were analyzed by using adsorption method of aluminum oxide. The water was measured according to the standard in China GB/T 260-77. The gel point was determined according to GB/T510-83(91).

Table 1 Properties of the Shengli waxy crude oil

Sample	Gel point °C	Wax % wt	Resin % wt	Asphaltene % wt	Water % wt
Shengli crude oil	13	25.2	2.1	3.6	0

The steady shear test of the crude oil was conducted at 16.6 °C by using the rotational stainless-steel parallel plates with diameter of 40 mm on the Bohlin-Gemini-200 system. The experimental temperature was controlled by an indoor air-conditioner, and the deviation of temperature is in the range of ±0.3 °C for the steady shear tests, which was shown in Gemini-200 rheometer. The experimental temperature is about 3.6 °C higher than its gel point, and about 2.2 °C higher than its pour point. The experimental waxy crude oil is a flowable fluid. Most of the gap size between the plates is set as 1.2 mm, except one 1.5 mm.
Figure 1 shows nine groups of the steady shear viscosity curves of the waxy crude oil, in which the shear rate range of eight groups is from 0.01 to 10 s^{-1}, and one group from 0.01 to 100 s^{-1}. The repeatability of the experiments is good, and the influence of both the deviation of temperature and the change of gap size in the experiment can be ignored. The

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characteristic of the steady shear viscosity of the wax crude oil is a shear strengthening phenomenon, i.e. so-called shear thickening, while the published researches on waxy crude oil usually show the shear thinning behavior for this kind of fluid, or yield stress, or so called shear banding phenomenon [1]. The complex components and structure of the waxy crude oil could be the factor that causes this shear thickening phenomenon. In order to describe the steady shear thickening viscosity, we calculated the average value of viscosity in the shear rate range of 0.01 to 10 s^{-1}, which was also shown in Fig 1.

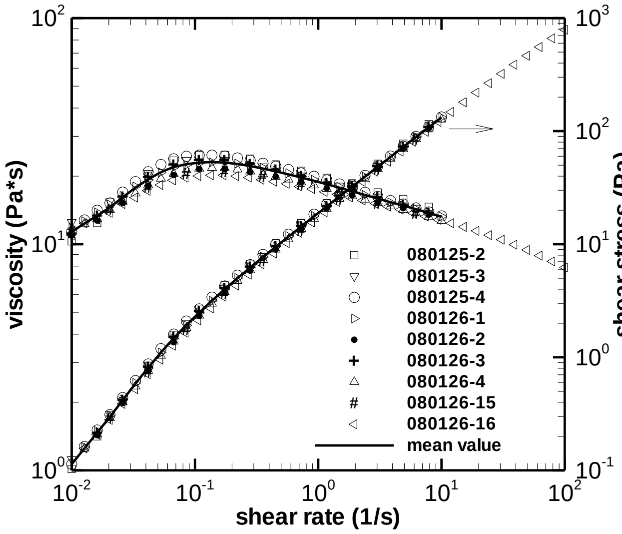

Fig 1 Steady shear experiment of a Shengli crude oil

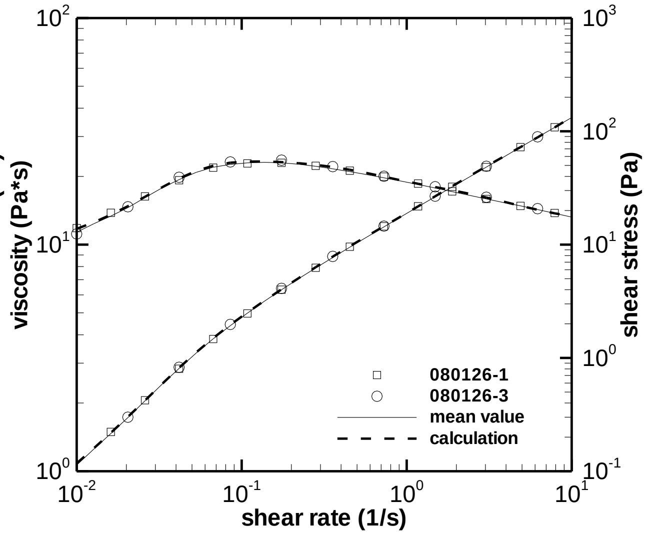

Fig 2 Description on the shear viscosity of the crude oil

CHANGING SPECTRUM MODEL AND ITS APPLICATION

The spectrum model [2] is given here by,

$$\eta = \sum_i \frac{\lambda_i g_i}{1+\lambda_i^2 \dot{\gamma}^2}, \tag{1}$$

where the parameter λ_i and g_i are of the unit of time and modulus, respectively. We modified the spectrum model here by considering the modulus changing in spectra caused by the assumed shear-induced varying internal structural status. The change of modulus obeys the following equation,

$$g_i(\dot{\gamma}) = g_i \frac{m}{1+ne^{-k\dot{\gamma}}}, \tag{2}$$

where m, n, k are the parameters. Figure 2 shows the description of the changing spectrum model on the steady shear viscosity of the waxy crude oil, and the calculation agrees well with the experiment. The values of the parameters in the model are listed in Table 2. The modulus-change form is effective in describing the shear thickening behavior.

Table 2 Values of the parameters in the model for the Shengli crude oil at 16.6℃

i	λ_i (s)	g_i (pa)	m	n	k (s)
1	3.550×10^{4}	3.550×10^{-3}			
2	3.600×10^{3}	1.953×10^{-2}			
3	3.015×10^{2}	2.485×10^{-1}	0.06532	1.678	50.41
4	5.389×10^{1}	1.644×10^{0}			
5	4.768×10^{-1}	4.752×10^{0}			

CONCLUSIONS

The steady shear thickening viscosity of the Shengli waxy crude oil was introduced in the present paper, which was measured by using the rotational stainless-steel parallel plates at the temperature of 3.6 °C higher than the gel point of the crude oil. A changing spectrum model was proposed to describe the steady shear thickening viscosity of the waxy crude oil. The calculation agrees well with the experiment.

References

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