Experimental Research on Deformation Change of Waxy Crude oil With Uniformly Increased Stress

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ABSTRACT

The experiments of constant stress loading rate were conducted in order to investigate the deformation problem for waxy crude oil. The yield strains have a small range from 0.01 to 0.20. The yield stress increases dramatically with the decreasing temperature and is less dependent on the stress loading rate. The yield time decreased as the stress loading rate is increased at a certain temperature.

INSTRUCTION

Most of the crude oils produced in China and many foreign oilfields are waxy crude. Owning to precipitation of wax and formation of network structure of wax crystals, waxy crude exhibits irreversible thixotropy, viscoelasticity, yielding behaviour and other complex rheological properties near gel point. Yielding behaviour is an important project for deformation research. In 1958, Houwink et al. proposed that there are two kinds of yield stress, corresponding to the end of elasticity and the appearance of viscosity[1]. In 1999, Li et al. studied the yield behaviour of Xinjiang crude oil and proposed the yield strain concept[2]. In 2007, Hou et al. proposed that the yield strain did exist objectively through experiments of creep, constant stress loading rate, oscillatory shear stress sweep and constant shear rate[3]. However, the range of yield strain still needs to be studied and there is a little research for the relationship between the yield time and the loading stress. In this paper, the yield behaviours of 3 kinds of waxy crude oils were investigated through the experiment of constant stress loading rate.

EXPERIMENTAL SECTION

The yield experiments were conducted by a RheolabQC rheometer (Anton Paar Corporation, Austria) and a controlled-stress rheometer RSH150 (HAAKE Corporation, Karlsruhe, Germany). 3 different kinds of waxy crude oils were adopted as test specimens. For an oil specimen at a definite temperature, the shear action was exerted at a constant stress loading rate. The physical properties of the specimens are listed in Table 1.

The oil specimens were pretreated to eliminate the memory effect for the thermal and shear history. First, the oil specimens in sealed bottles were heated quiescently to 80 °C in water bath. After having been kept in this temperature for 2 h to become homogeneous due to thermal diffusion, the oil specimens were statically held at the room temperature for 48 h.

Table 1. Physical property and heating temperature of oil specimens

physical property	Specimen No.		
	1	2	3
Wax content (wt. %)	24.37	23.27	17.47
Wax appearance temperature (°C)	42.13	44.04	40.28
Wax appearance peak temperature (°C)	19.27	21.23	17.56
Wax appearance enthalpy (J/g)	26.91	29.44	20.36
Gelation temperature (°C)	32	33	17
Density at 20°C (kg/m^3)	—	863.08	844.02
Heating temperature (°C)	45	50	50

The pretreated oil specimens were kept at the heating temperature in water bath for 15 min, being higher than the wax appearance temperature (WAT). Then they were loaded to the cup of rheometer. After having been held undisturbed for 10 min to make the inside temperature fully uniform, the oil specimens were cooled to different test temperatures at a cooling rate of 0.5 °C/min. Then the oil specimens were statically kept at the test temperature for 30 min to make the oil gel adequately. For an oil specimen at test temperature, the shear stress was loaded at a constant stress loading rate. The curves of the strain with the loading time were measured.

RESULTS AND ANALYSES

Yield Stress

The yield stress was defined as the minimum shear stress for the occurrence of flow portent. The relationship between the strain and the loading time is plotted on logarithmic coordinate. Then the yield point is considered as the starting point where the strain increases dramatically. The strain and the loading time of the yield point respectively correspond to the yield strain and yield time.

Based on the yield time and the stress loading rate, the yield stress accords with the following equation:

$$\tau_y = \frac{v_s t_y}{60} \quad (1)$$

Where τ_y is the yield stress, Pa; v_s is the stress loading rate, Pa/min; t_y is the yield time, s.

Discussion for Results

Uniformly increased stresses were applied to the oil specimens at the test temperature. The curves of strain measured at different stress loading rates and different temperatures were plotted in Fig. 1-3. The results showed are as follows:

(1) The yield strains have a small range from 0.01 to 0.20. As shown in Fig. 1-3, the yield strain changes a little with the test conditions and can be used as the criterion for the yielding of the structure of gelled crude. 7 groups of experimental data were obtained. The minimum of yield strain is 0.01 for specimen No.2 at 31 °C with a stress loading rate of 2.2 Pa/min. The maximum is 0.2 for specimen No. 2 at 32 °C with a stress loading rate of 0.6 Pa/min.

(2) For the same oil specimen, the minimum yield stress measured at the low temperature is larger than the maximum yield stress measured at the high temperature. That is to say, the yield stress increases with the decreasing temperature. For the oil specimen No. 2, the minimum yield stresses at 31 °C is 12.1 Pa, while the maximum yield stresses at 32 °C is 5.8 Pa only. For the oil specimen No. 3, the minimum yield stresses at 13 °C is 139.3 Pa, while the maximum yield stresses at 16 °C is 33.8 Pa only.

(3) Even under different shear stress loading rates, the value of the yield stresses

are close to each other at the same temperature for any oil specimen. The relative ranges of 7 groups of yield stresses are within 20%. For the specimen No. 1 at 30 °C, the yield stress is 64.6 Pa, 69.9 Pa and 74.0 Pa when the stress loading rate is 2 Pa/min, 5 Pa/min and 10 Pa/min respectively. The corresponding relative range is 13%. The yield stress at 31 °C is 35.5 Pa, 39.5 Pa and 43.5 Pa when the stress loading rate is 2 Pa/min, 5 Pa/min and 15 Pa/min respectively, and the corresponding relative range is 20%.

(4) The yield time is shortened as the stress loading rate is increased at a certain temperature. For example, at 32 °C, the yield time of the oil specimen No. 2 are 504 s under the stress loading rate of 0.6 Pa/min; while the yield time is 385s under the stress loading rate of 0.8Pa/min. For the oil specimen No. 3 at 16°C, the yield time is respectively 451 s and 198 s with the stress loading rate respectively being 4.5 Pa/min and 8.5 Pa/min.

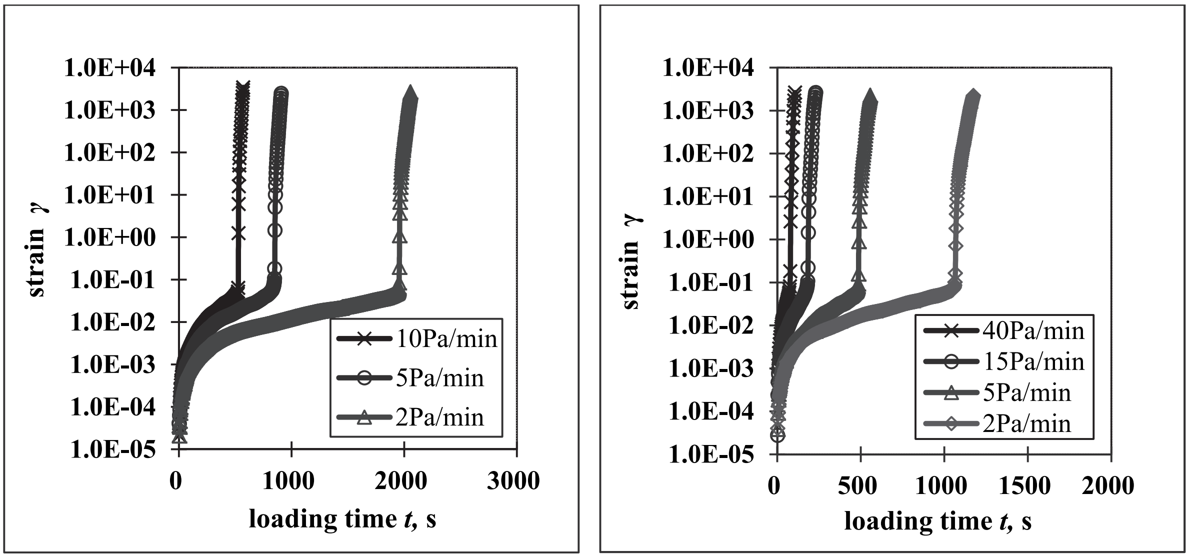
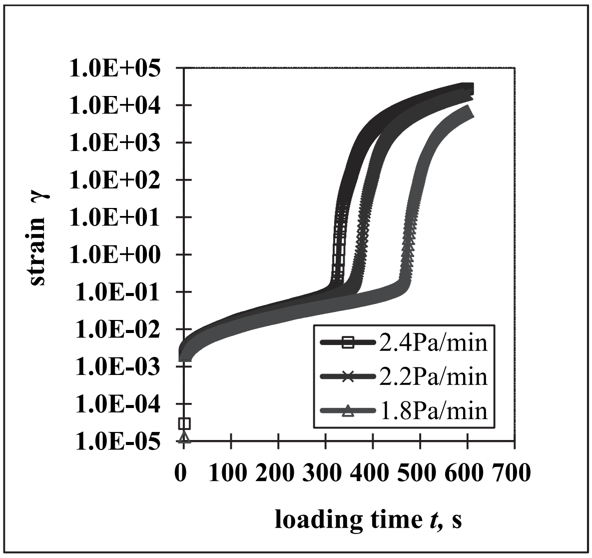
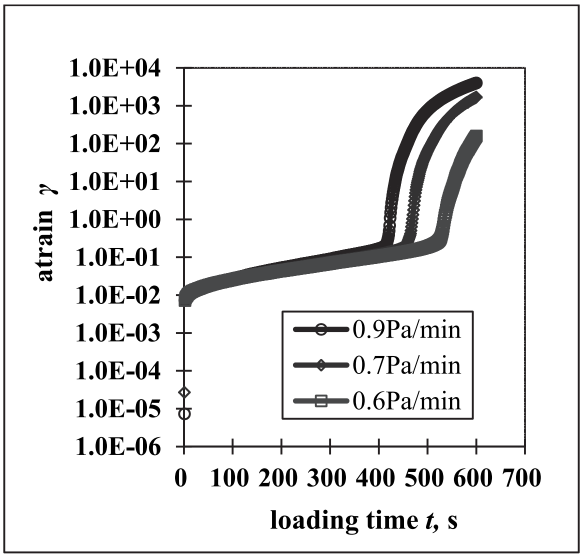


Fig. 1 Variation of strain with loading time for specimen No. 1 (a 30 °C， b 31 °C).

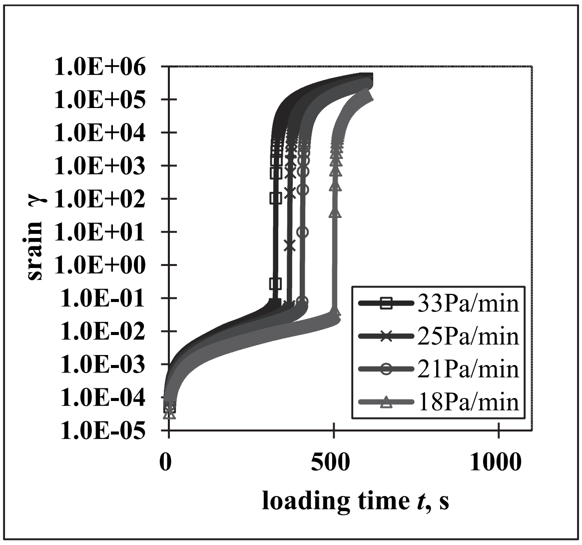


(a)



(b)

Fig. 2 Variation of strain with loading time for specimen No. 2 (a 31 °C， b 32 °C).



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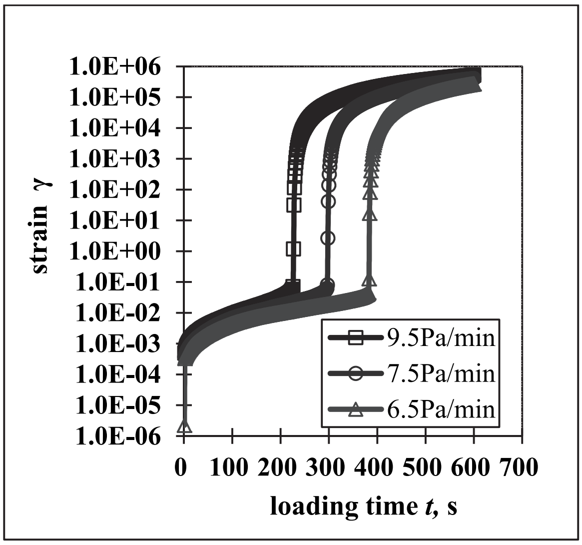

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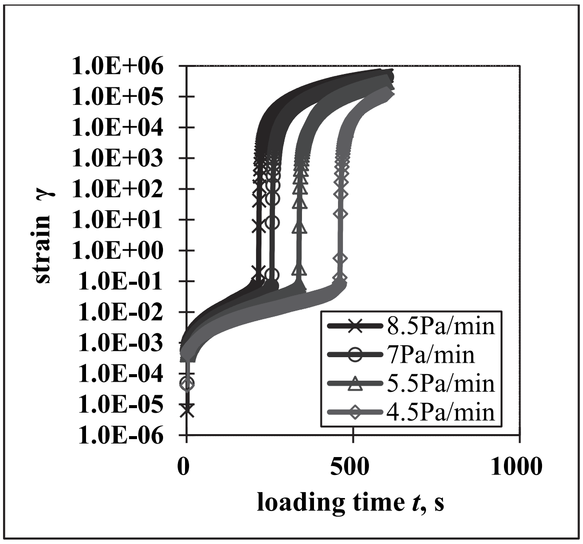

(c)

Fig. 3 Variation of strain with loading time for specimen No. 3 (a 13 °C，b 15 °C，c 16 °C).

CONCLUSION

(1) The yielding property of the waxy crude oil was studied by the experiment of constant stress loading rate. It can be concluded that the yield strain ranging from 0.01~0.2 with the measuring conditions, which demonstrate that the yield strain can be used as a criterion for the crude oil yielding.

(2) The yield stress was studied in great detail through the experiment. The yield stress is largely dependent on the test temperature. For the same oil specimen, the minimum yield stress measured at the low temperature is greater than the maximum yield stress measured at the high temperature, which accords with the decrease of the yield stress with increasing temperature.

(3) The experiments of constant stress loading rate show that the yield stress is less affected by the stress loading rate. At a certain temperature, the shear stresses with different stress loading rates were applied to

oil specimens in order to get the yield properties. The values of the yield stresses are close to each other at the same temperature.

(4) The yield time is focused through the experiments and is varied with the test conditions. It is also can be seen that the yield time is shortened as the stress loading rate is increased at a certain temperature.

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