Effect of sand content on the rheological properties of heavy crude oil

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ABSTRACT: The rheological properties of heavy crude oil and its mixture with sand were investigated experimentally. The effects of sand size distribution and mass concentration on the rheological property have been investigated. From the rheological date, it was observed that the heavy crude oil containing sand shows a strong shear thinning behavior. The apparent viscosity first decreases and then increases gradually with the increase of sand mass concentration. Furthermore, the addition of sand to the heavy crude oil causes a generally enhanced in the elastic modulus, and the complex viscosity is slightly less than the apparent viscosity.

KEY WORDS: Heavy crude oil; Sand, Viscosity; Viscoelasticity

INTRODUCTION

Heavy crude oil has a density approaching or even exceeding that of water. The need for heavy crude oil has been intensifying steadily in recent decades. However, the transportation of heavy crude oil is extremely difficult owing to high viscosity and complex rheological behaviors, such as yield stress, thixotropy and viscoelasticity [1,2].

In practice, the produced fluid from oil well is oil-sand mixture. So, the rheological property of heavy crude oil can be affected by the following several reasons: mass concentration, sand size and size distribution. Oil sands are an important source of heavy crude oil and the process of heavy crude oil liberation from host rocks is an essential requirement. The studies of Dai and Chung[3] revealed that the particle size was one of the critical factors affecting liberation of bitumen from sand, namely that the finer the particles were, the stronger the attachment. The initial conditions of the bitumen-sand contact and the inherent physicochemical properties of water-wet oil sands are important to the success of oil sand process [4]. Recently, Srinivasa[5] et al. designed a novel flow visualization cell system to study bitumen liberation dynamics from oil sands. Although numerous studies have been carried out to understand the bitumen liberation process, but the rheological characteristics of heavy crude oil containing sand remain rather limited. So the present study concerns the rheological properties of heavy crude oil containing sand from *Bo-hai* oilfield in China.

EXPERIMENTAL

Two types of sand size distributions were used to study the effects of size distribution on the rheological. Sand size distribution was measured by Malvern INSITEX SX Laser Particle Size Analyzer. Here, the type 1 was used to study the effects of sand mass concentration on the rheology. The heavy crude oil was blended with sand in two different mass concentrations of 0.15 mg/L and 0.25 mg/L.

To study the effects of mass concentration and size distribution on the rheological properties of heavy crude oil, heavy crude oil and sand were mixture in batches of 300 ml and pre-heated to a fixed test temperature, and then the homogenization of heavy crude oil and sand was achieved by using the three-blade stirrer at a fixed speed of 500 r/min. After homogenization, rheological measurement was carried out on the Haake RS6000 Rheometer with a coaxial cylinder sensor system (Z38 DIN, gap width=2.5 mm and sample volume of 30.8 cm^3). In the measurement, the liquid temperature-controlled system can make the sensor system reach to a fixed temperature and maintain this temperature in the experiment.

In the viscosity measurement, the viscosity curve was got by increasing the shear rate from 0 to 200s^{-1} continuously. In the oscillatory measurement, the stress sweep was first conducted to make the selected stress sweep keep in a linear viscoelastic region. The stress sweep were conducted at a fixed frequency of 5 *Hz* in the range of 0.001-200 Pa, and the frequency sweep was carried out at a fixed shear stress of 1 Pa.

RESULTS AND DISCUSSION

Apparent viscosity

The heavy crude oil blended with two different types of sand size distributions were named sample 1 and sample 2. Table 1 shows the particle properties of the samples. Rheograms of the samples with different size distributions at a constant mass concentration of 0.15 mg/L are given in Fig.1. It's obvious that all of the samples show a strong shear-thinning behavior. For a given mass concentration of 0.15 mg/L, the heavy crude oil containing sand shows a lower apparent viscosity than the pure crude oil, namely that at this concentration the sample becomes more shear thinning behavior.

Table 1 Several basic properties of sands for two different types

No.	Density of sediment grains ρ_s	D_5	D_{50}	D_{95}
Type 1	2345 kg/m^3	25.25 μm	112.95 μm	516.79 μm
Type 2	2324 kg/m^3	25.21 μm	95.15 μm	207.62 μm

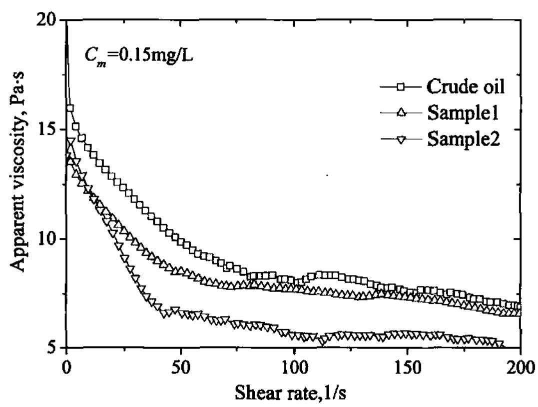

Fig. 1 Rheograms of the heavy crude oil containing sands with different size distributions at 30°C

Fig.2 gives the rheograms of the sample 1 with different mass concentrations at 30°C. As can be seen that the apparent viscosity of heavy crude oil containing sand shows a more low value than the pure crude oil when the mass concentration lower than 0.2 at lower shear rate. The reason for this phenomenon may be explained by the fact that the interfacial interaction between the particles and the feature of shear thinning become noticeable. Thus, the apparent viscosity of heavy oil will reach the minimum value for certain concentration.

Viscoelastic property

Fig.3 presents the variation of the elastic modulus and the loss modulus of as a function of the shear stress for different sand mass concentrations at a fixed sweep frequency (f=5 Hz). Measurements are undertaken to obtain these parameters for recognizing the linear region. It can be seen that stress amplitudes from 0.1 Pa to 100 Pa are all in the linear viscoelastic region. Therefore, τ=1 Pa is selected for the following frequency sweep.

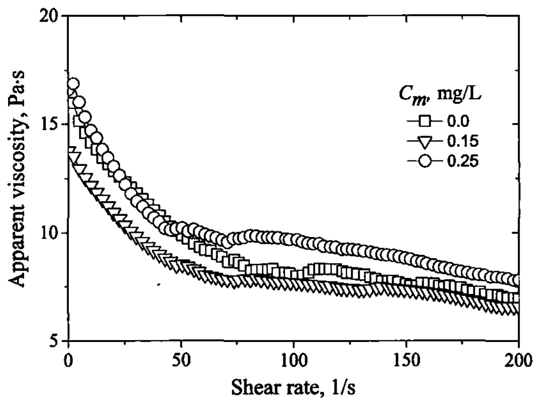

Fig. 2 Rheogram of the sample 2 with different sand mass concentrations at 30°C

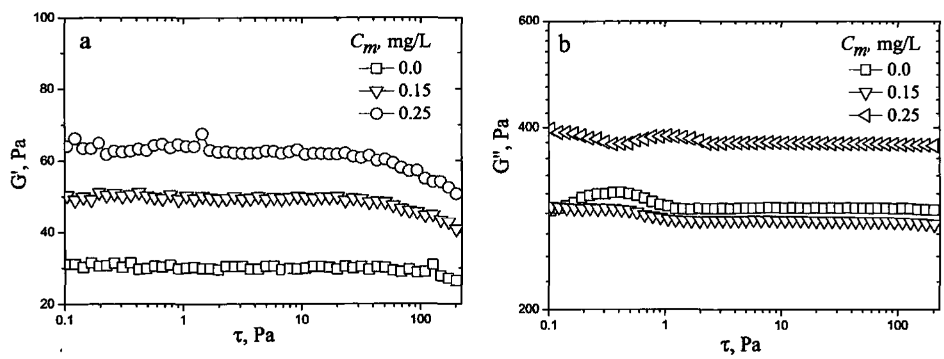

Fig. 3 Variation of the elastic modulus and the loss modulus of the sample 1 as a function of the shear stress at a fixed frequency

The results of frequency sweep at a fixed shear stress with various mass concentrations are depicted in Fig.4. The basic point is that the loss modulus is greater than the elastic modulus over the entire range of frequency, indicating that the heavy crude oil containing sand is predominantly viscous. Clearly, after adding the sand into the heavy crude oil, the elastic modulus can be enhanced. But, the increase of elastic modulus is not obvious as the mass concentration increasing. It's obvious that the loss modulus increase linearly as the frequency increasing. Moreover, the decrease of the complex viscosity becomes more significant with the frequency increasing. In addition, the effects of sand mass concentration on the complex viscosity are similar to those on the apparent viscosity.

From a practice point of view, the hydrocyclones on desanding of crude oil typically operates at a high tangential acceleration, i.e. the large angular velocity. Thus, the variations of the complex viscosity, the elastic modulus and the loss modulus with sand mass concentration at angular velocities ω=6.28 and 62.8 rad/s are given in Fig.5, respectively. An important point to note is that with sand mass concentration increasing the elastic modulus, the loss modulus and the complex viscosity show a trend of increasing. Moreover, the effects of angular velocity on the elastic modulus and the loss modulus are greater than those on the complex viscosity.

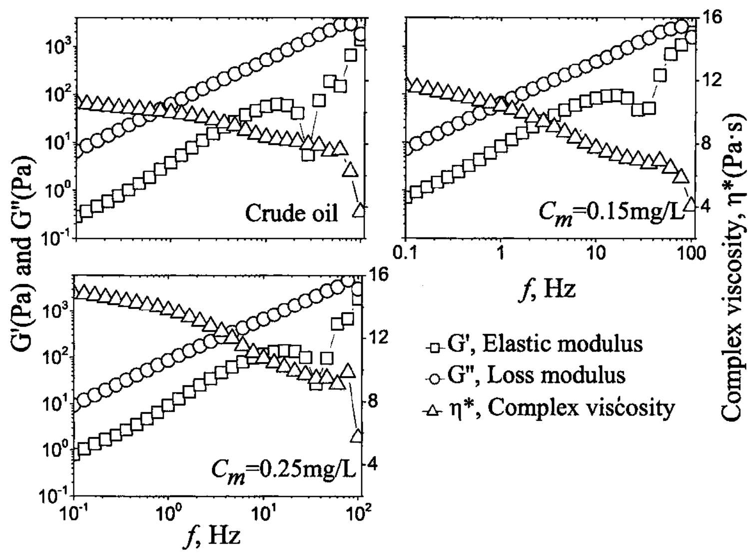

Fig. 4 Variation of the elastic modulus, the loss modulus and the complex viscosity as a function of the frequency at a fixed shear stress (τ=1 Pa) for various sand mass concentrations

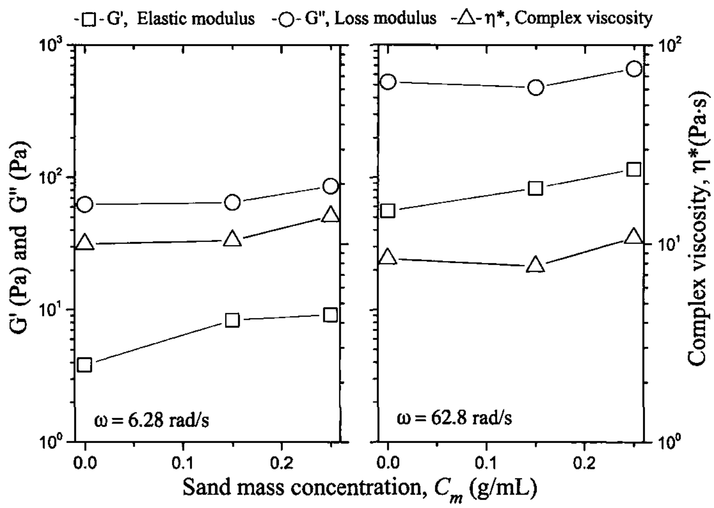

Fig. 5 Variations of the complex viscosity, the elastic modulus and the loss modulus with sand mass concentration at angular velocities ω=6.28 and 62.8 rad/s, respectively

CONCLUSION

In this work, a study on rheological properties of heavy crude oil containing sand has been carried out. The effects of sand size distribution and mass concentration on apparent viscosity and viscoelastic property are investigated. The heavy crude oil containing sand shows a strong shear-thinning behavior. After the heavy crude oil is blended with a small amount of sand, the apparent viscosity of the mixture can be reduced. However, with the further increase of sand mass concentration, the apparent viscosity will increase until more than the heavy crude oil. In general, the elastic modulus, the complex viscosity and the loss modulus show a trend of increasing with the sand mass concentration increasing. In addition, the complex viscosity is slightly less than the apparent viscosity. These results might be helpful for the processing of sand removal from heavy crude oil.

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