High Pressure Vane in Cup Rheometer
Statoil Rheometer (E3722)

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ABSTRACT

Yield stress and gel strenght of waxy crude oil is anticipated to depend on the amount of dissolved gas. To measure the yield stress and gel strenght in crude oils with high wax content as a function of the amount of dissolved gas, a specially designed vane-in-cup rheometer, able to operate at high pressure and at different temperatures, has been constructed. This paper describes the use of this specially constructed rheometer.

DESCRIPTION

The rheometer configuration consists of a vane with four blades and a magnet fastened to a shaft. The magnet transfers the vane torque to the equipment outside the high pressure cell. The magnet and the vane is placed inside the cell (Fig. 1). This cell is able to withstand high pressures and temperatures. The ends of the vane shaft rests in jewel bearings to give minimum friction.

Above the pressurized chamber another magnet is connected to a Baldor motor. This motor is hanging in a thin wire, given a preloaded torque by turning the wire. The torque makes the motor stay in contact with three stress transducers. The motor can rotate the vane both ways. Therefore the preloaded torque induced from the wire must be large enough to keep the contact between the motor and the stress transducers when rotated in the opposite direction of the preloaded torque. The reason for using three stress transducers is the enhanced accuracy achieved by using the mean of the three torques being measured.

The motor and the cell is placed on a table where the cell is beneath table level. A refrigerator bath can be mounted from beneath to cover the cell unit with refrigerated liquid to regulate the temperature in the cell without moving the rheometer.

The rheometer is built by ROP France.

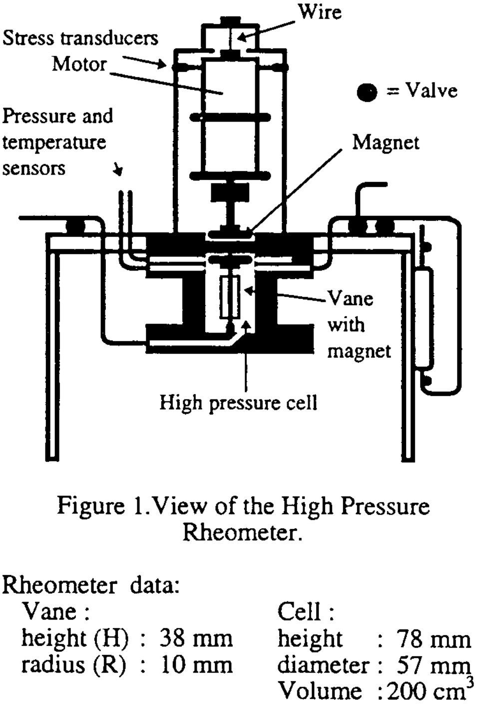


Figure 1.View of the High Pressure Rheometer.

Rheometer data:

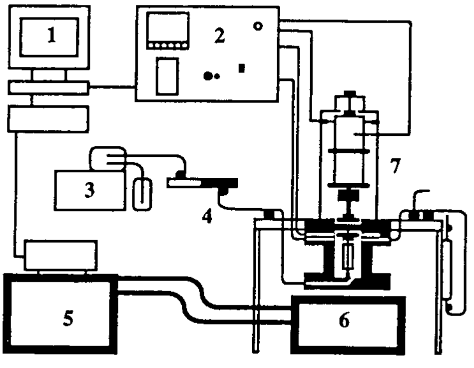
Vane :		Cell :	
height (H) :	38 mm	height :	78 mm
radius (R) :	10 mm	diameter :	57 mm
		Volume :	200 cm^3

Max. pressure : 200 bar
Temperature : -30...+120 °C
Distance from bottom cell to bottom vane : 15mm

SUPPORTING INSTRUMENTS

To control pressure, different kinds of pumps can be connected to the rheometer. A Gilson Pump 305 has been used to pump water into a piston filled with sample liquid (Fig. 2). The piston is connected to the pressurized cell.

Temperature regulation is performed using a Julabo FP 35-HC refrigerator/ circulator bath. This temp.bath can easily be changed. The "Julabo bath" is connected to an isolated trough designed to cover the high pressure cell (Fig. 2).



1.PC
2.Layout cabinet
3.Pump
4.Piston
5.Refrigerator/circulator
6.Isolated trough
7.Rheometer

Figure 2. Instrument set up.

Other instruments needed for operating the rheometer is a PC with the program "Cyber for Windows" (ROP) installed.

A layout cabinet is necessary for transfering the signals between the PC and the stress transducers/motor. The layout cabinet also measures the pressure and temperature in the cell and transfers these values to the PC. The layout cabinet consists of a Eurotherm 900 EPC regulator for torque and pressure measurement, and a Eurotherm Three Therm Controller type 808 for temperature measurement. The cabinet also consists of an amplifier and a reducer.

OPERATION

The rheometer is mainly operated from the PC, where the rheometer configuration is shown on the screen. The menu on the screen gives the possibility to input values as rotation speed or torque, and transfer these values to the motor. Programs controlling the temperature in the refrigerator unit are also available. Programs needed to run the rheometer are mainly started by clicking on push buttons with the mouse directly on the wanted program.

When the instrument is running different kinds of diagrams are produced.One example is shown in Fig. 3, where a Newtonian liquid was tested to see if the rheometer produced constant viscosity for increasing speed. The torque is seeing to increase and the slope is almost constant.

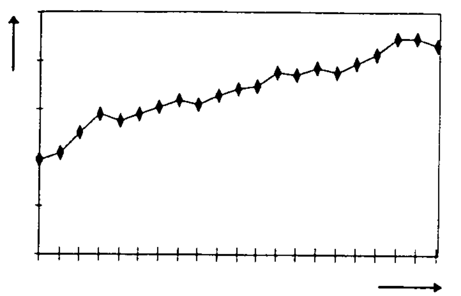


Figure 3. Example of a curve produced by the rheometer. Newtonian liquid.

THEORY

To calculate the shear stress (ι_s) from the torque, a method similar to one described by Dzuy and Boger[1] will be used, however with modifications. Different from the vane used by Dzuy and Boger, the pressurized vane is fastened to a magnet which also contributes with shear effects. According to Dzuy and Boger, the constant speed and total torque (T) experienced by the shaft is the sum of T_s and $2T_e$ due to shearing on the side and the two ends of the cylindrical shear surface :

$$T = T_s + 2T_e \qquad (1)$$

This equation has to be modified. The preloaded torque (T_p) and the torque caused by the magnet (T_m) submersed in the fluid has to be taken into consideration. Thus,

$$T = T_s + 2T_e + T_m + T_p \qquad (2)$$

T_p is found by rotating the vane both ways with a constant speed (Fig. 4). The preloaded torque must then be :

$$T_p = (T_2 + T_3)/2 \qquad (3)$$

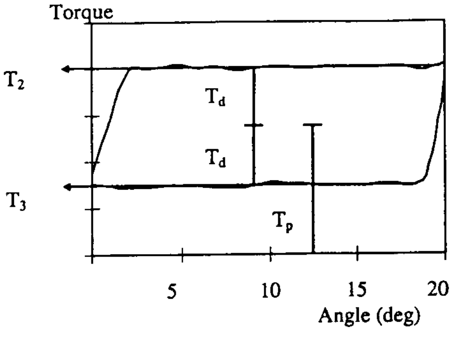


Figure 4. Diagram shown when the vane is rotated 20 deg both ways at a constant speed.

The difference :

$$T_d = (T_2 - T_3)/2 = T_s + 2T_e + T_m \qquad (4)$$

$$T_s = H(2\pi R^2)\,\iota_s \qquad (5)$$

$$T_d = (2\pi R^2 H)\,\iota_s + (2T_e + T_m) \qquad (6)$$

T_d is linearly dependent on the vane height (H). By plotting T_d versus different H-values and different speeds it is possible to calculate ι_s from the slope of the line [1]. At the intercept $T_d = 0$ an imagined height (H_i) is found. Using Eq. 6, H_i defines the size of ($2T_e + T_m$).

$$0 = (2\pi R^2 H_i)\,\iota_s + (2T_e + T_m) \qquad (7)$$

Using Eq. 6 and Eq. 7,

$$T_d = (2\pi R^2 H)\,\iota_s - (2\pi R^2 H_i)\,\iota_s \qquad (8)$$

$$\Rightarrow \iota_s = T_d / 2\pi (H-H_i) R^2 \qquad (9)$$

Using Eq. 4 and Eq. 9,

$$\iota_s = (T_2 - T_3)/ 4\pi (H-H_i) R^2 \qquad (10)$$

This equation must be modified if gelling due to wax formation occurs (Fig. 5), since the gel structure (i.e yield) will be broken by the movement of the vane. The yield stress of the gel is then not measurable on the vane's return.

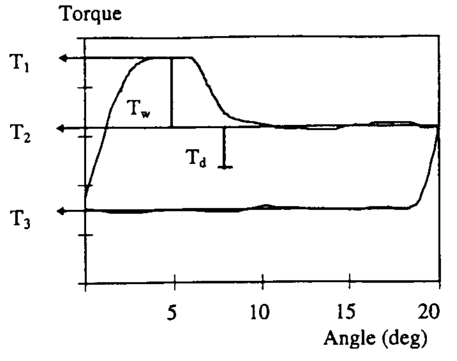


Figure 5. Crude oil with wax content.

If $T_dH/(H-H_i)$ is the fraction of the side effect (T_s) of the vane to the torque T_d, it is assumable that $T_wH/(H-H_i)$ will be the contribution of T_s to the torque T_w. Thus, by using this assumption and Eq. 10, the yield stress is given as :

$$\iota_s = [(T_1 - T_2)/2 + (T_2 - T_3)/4]/\pi R^2 (H-H_i) \qquad (11)$$

By using this equation the shear stress contribution from the side of the vane can be calculated.

CONCLUSION

By the present work it is shown that yield stress and gel strenght in crude oils with high wax content can be measured with the high pressure rheometer described.

REFERENCES

1. Nguyen Q. Dzuy and D.V. Boger, "Direct Yield Stress Measurement with the Vane Method", Departement of Chemical Engineering, University of Melbourne, Parkville, Victoria, 3052, Australia.