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Experimental study on the rheological behaviour of H46 lubricant oil

K e y w o r d s

Rheology, lubricant, thermal, experiment.

S u m m a r y

This paper aims to characterise the rheological behaviour of hydraulic lubricants in relation to the testing temperature. The oil has been tested on a Brookfield rheometer with a cone and plate geometry. In order to determine the rheological model, the variation between shear stress versus shear rate was measured. The thermal properties of the oil were measured by studying the dependence between viscosity and temperature. Finally, a few laws for the variation of the viscosity with temperature have been proposed.

1. Introduction

Rheology refers to a set of standard techniques that are used to experimentally determine rheological properties of materials (fluid or solid). The idea underpinning rheology is to realise flows, where the stress and/or

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strain fields are known in advance, which make it possible to deduce rheological properties from measurements of flow properties, [1], [2]. A rheometer is usually an experimental stand, which can exert a torque/force on a material and accurately measures its response with time (or conversely, it can impose a strain and measures the resulting torque). All the measurements can be done normally in a field of temperature between 15°C and 75°C, [3], [4].

The main purpose of the study is the experimental determination of rheological properties of H46 lubricant, mainly used in hydraulic power. The properties considered are as follows:

- The rheological model of lubricant in a new and used state (with a wear degree); and,
- The variation of viscosity versus temperature, which is made for imposed various velocity gradients.

The method of regression analysis was used to determine the laws of parameter variation for mentioned properties, and the confidence intervals are also established.

The physical and chemical properties of H46 oil are presented in Table 1, [6].

Table 1. The physical and chemical properties of H46 oil, [6]

Characteristic parameter	H46
Density at 15°C	900 kg/m^3
Viscosity at 40°C	41.4 – 50.6 cSt
Viscosity at 100°C	24.2 – 31.4 cSt
Viscosity Index	92
Viscosity CCS at 30°C	5500 cP
Pour point	- 25° C
Flash point COC	200° C
TBN	9.4 mg KOH/g
Volatile factions	10 %
Viscosity HTHS (150°C)	3.3 cP
Colour (ASTM)	L 3.5

2. Experimental stand and methodology

The experimental test stand was a Brookfield cone-plate viscometer, (Figure 1) [7]. The liquid is placed between a cone and a disc; one is moving and the other is stationary. For large opening angles of the cone (Figure 2), the rate of strain is constant across the gap, which is the advantage of this device. The viscometer is suitable for digital data acquisition, and it offers the possibility for one to determine the variation of viscosity by the temperature.

Fig.1. Brookfield cone-plate viscometer

Fig. 2. Cone geometries

To determine the lubricant rheological model in a new and used state (with a wear degree), an “imposed velocity gradient” test, with the variation limits 100 ... 2000 s^{-1} and 22°C reference temperature was used. The tests were carried out with a load up to 2000 s^{-1} and unloading up to 0 s^{-1}, in order to highlight the effects of lubricant thixotropy.

There were tested the two fluids and there were calculated the lubricant rheological parameters, by using the rheometer software, beyond the non-Newtonian fluids model, for the power law:

$$\tau = m\left(\frac{du}{dy}\right)^n \tag{1}$$

Where m - consistency index (which is equivalent to the Newtonian fluid viscosity)
n - flow index (equal to 1 if the fluid is Newtonian).

To determine the viscosity variation law versus temperature for the analysed lubricant, there were made only tests for new lubricant, for four imposed velocity gradients: 500, 1000, 1500 and 2000 s^{-1} and for a temperature range of 15 ... 75°C. The laws of variation assumed are as follows:

- The Jarchov and Theissen model:

$$\eta = \eta_{50} e^{B\cdot\frac{50-t}{95+t}} \tag{2}$$

Where η – viscosity; η_{50} – viscosity at 50°C; B – non-dimensional parameter; t – temperature.

- The Cameron model:

$$\eta = Ke^{\frac{b}{95+t}} \tag{3}$$

Where η – viscosity; K – viscosity parameter; b – temperature parameter; t – temperature.

- The Reynolds model:

$$\eta = \eta_{50} e^{m(t-50)} \tag{4}$$

Where η – viscosity; η_{50} – viscosity at 50°C; m – temperature parameter; t – temperature.

The parameter values of the variation laws were determined using the regression analysis method, by using MathCAD software, [5].

3. Results

Lubricant rheograms for new and used states are presented in Figures 3 and 4.

The results for lubricant rheological parameters in new and used states are directly obtained by using the rheometer software (Capcalc V3.0), (see the Figures 5 and 6). Results are centralised in Table 2.

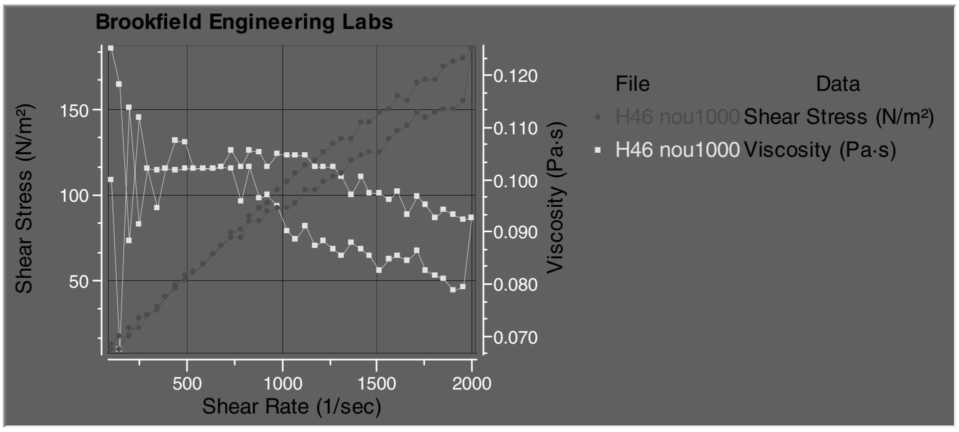

Fig. 3. Lubricant rheogram for fresh state

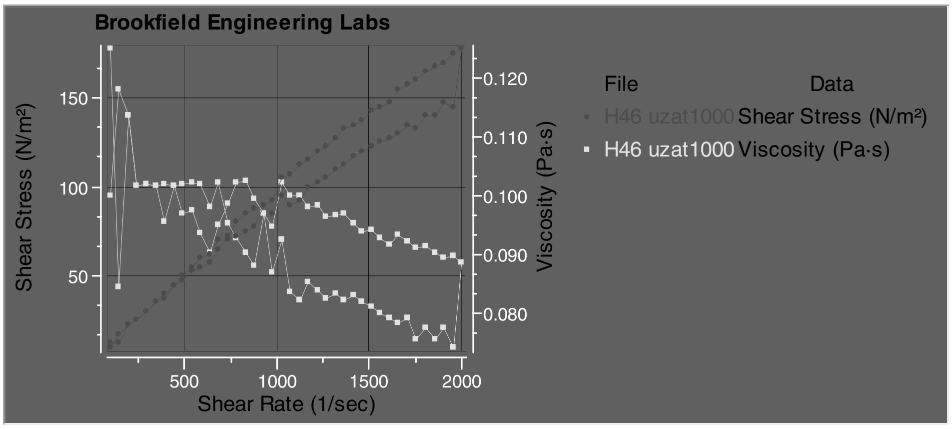

Fig. 4. Lubricant rheogram for used state

Table 2. The lubricant rheological parameters in fresh and used state

Lubricant type	Consistency index (m), Pa·s^n	Flow index (n)	Correlation coefficient
H46 fresh lubricant	0.144	0.939	93%
H46 used lubricant	0.180	0.902	93.5%

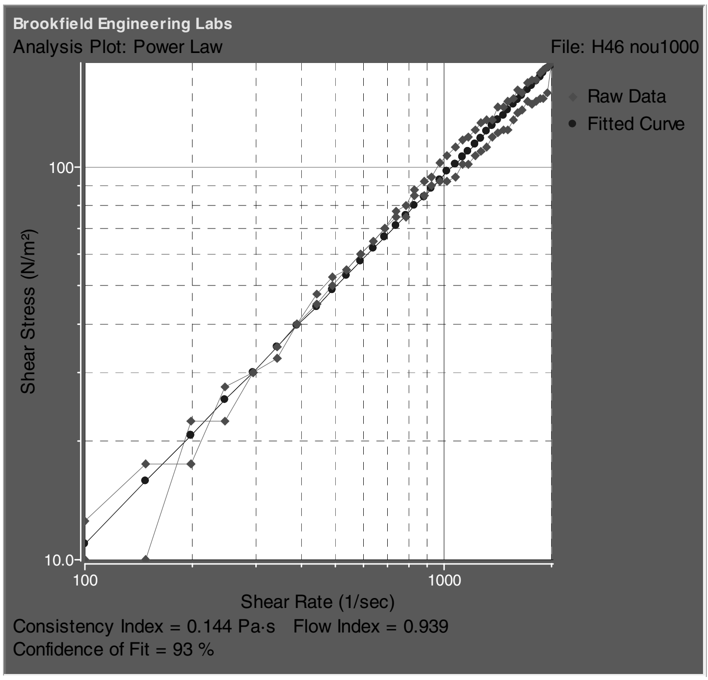

Fig. 5. Numerical regression for the results of new lubricant

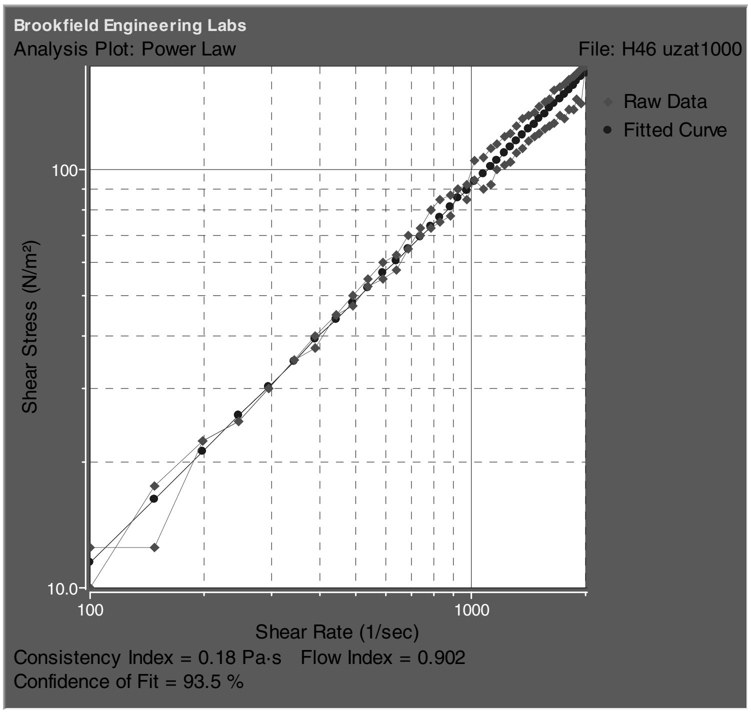

Fig. 6. Numerical regression for the results of used lubricant

For the new state lubricant, the results concerning the viscosity variation versus the temperature are obtained for the imposed velocity gradients: 500, 1000, 1500 and 2000 s^{-1} and for a 15…75°C temperature range (Figures 7, 8, 9 and 10).

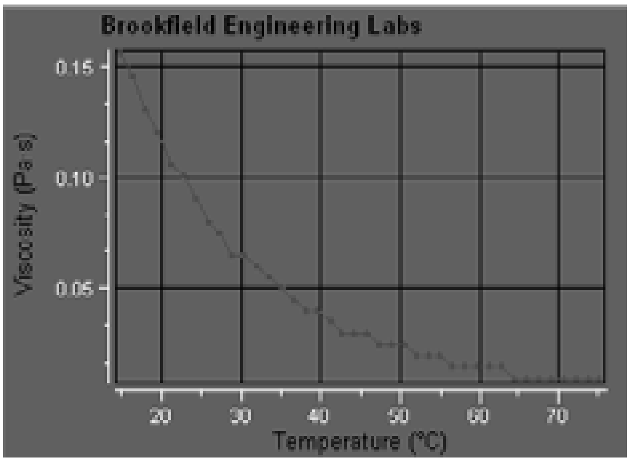

Fig. 7. Viscosity versus temperature variation for new lubricant, at the 500 s^{-1} velocity gradient

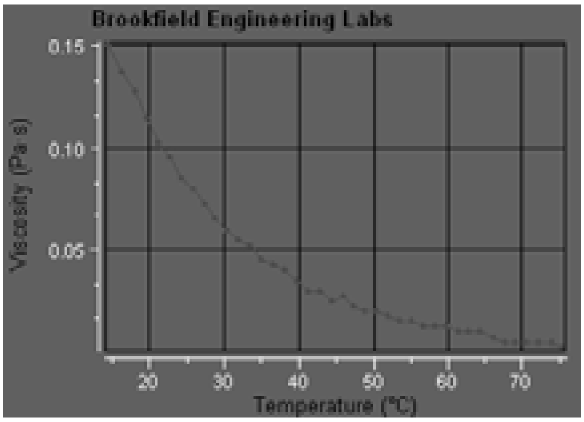

Fig. 8. Viscosity versus temperature variation for new lubricant, at the 1000 s^{-1} velocity gradient

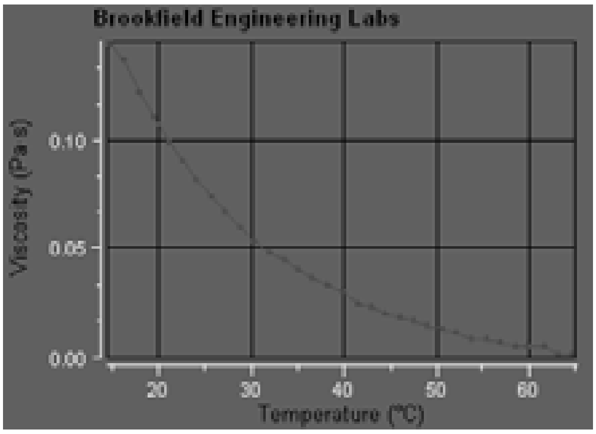

Fig. 9. Viscosity versus temperature variation for new lubricant, at the 1500 s^{-1} velocity gradient

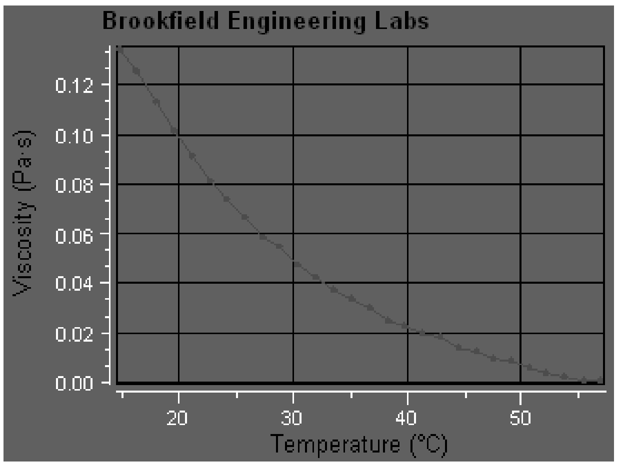

Fig. 10. Viscosity versus temperature variation for new lubricant, at the 2000 s^{-1} velocity gradient

4. Discussion

To determine the characteristic parameters for the viscosity variation related to temperature, we used MathCAD software. The results are presented in Table 3.

Table 3. The characteristic parameters of the viscosity variation law versus temperature for H46 oil

Parameter / Velocity gradient, s^{-1}	Jarchov and Theissen model		
	η_{50}, Pa·s	B	Correlation coefficient
500	0.02454	5.90199	0.99812
1000	0.02167	6.20840	0.99616
1500	0.01737	6.86477	0.99425
2000	0.01404	7.31500	0.99106
Parameter / Velocity gradient, s^{-1}	Cameron model		
	K, Pa·s	b, ^0C	Correlation coefficient
500	$6.7093 \cdot 10^{-5}$	855.76735	0.99616
1000	$4.3654 \cdot 10^{-5}$	900.08298	0.99616
1500	$5.99809 \cdot 10^{-5}$	846.50065	0.99616
2000	$0.98789 \cdot 10^{-5}$	1052.7700	0.99616
Parameter / Velocity gradient, s^{-1}	Reynolds model		
	η_{50}, Pa·s	m, $^0C^{-1}$	Correlation coefficient
500	0.02250	-0.05466	0.99849
1000	0.01954	-0.05805	0.99947
1500	0.01466	-0.06609	0.99893
2000	0.01117	-0.07208	0.99715

The comparison between the results of the numerical regression and experimental results is presented in Figures 11, 12, 13 and 14.

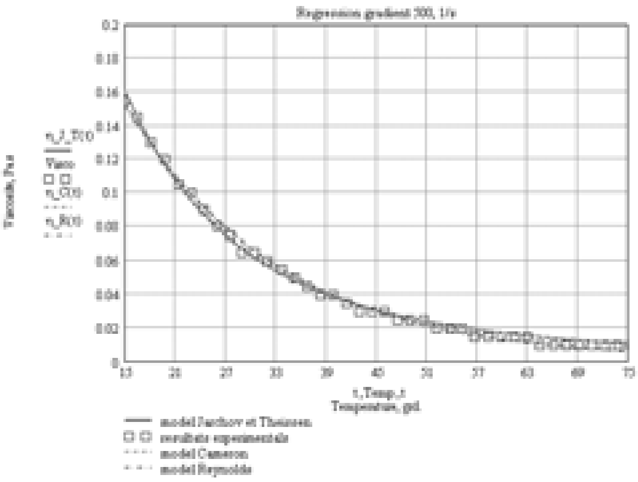

Fig. 11. The comparison between the results of the numerical regression over the experimental results, for 500 s^{-1}

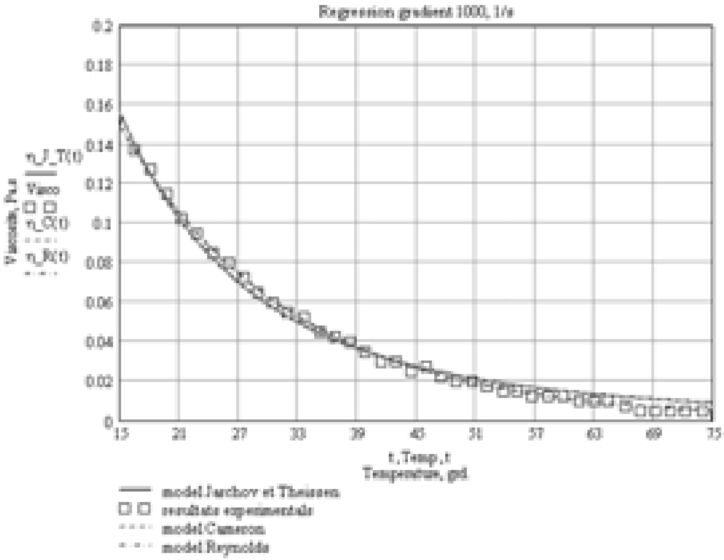

Fig. 12. The comparison between the results of the numerical regression over the experimental results, for 1000 s^{-1}

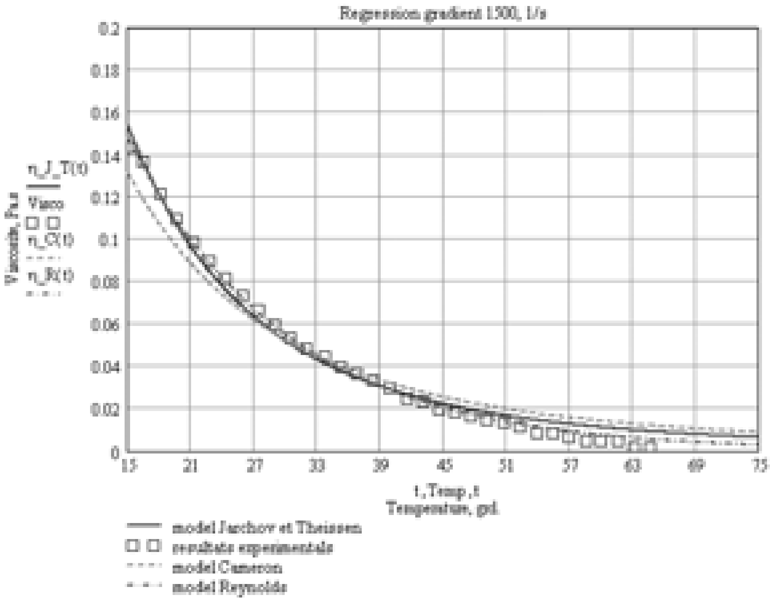

Fig. 13. The comparison between the results of the numerical regression over the experimental results, for 1500 s^{-1}

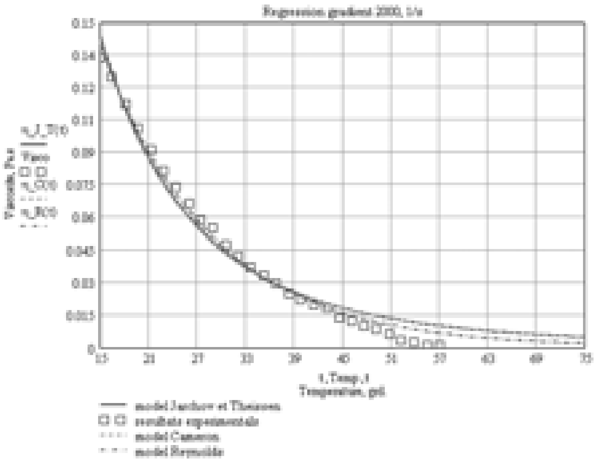

Fig. 14. The comparison between the results of the numerical regression over the experimental results, for 2000 s^{-1}

5. Conclusions

1. The lubricant rheological parameters have been determined, and the difference between new lubricant characteristics and used ones was obtained.
2. Experimental tests showed lubricant thixotropy at high velocity gradients, which is present also for the new lubricant and for the used one.
3. Both for the new or used state, the lubricant behaviour is almost Newtonian, and the viscosity is presented in Table 2.
4. All three analysed models used for viscosity variation versus temperature are available. Their characteristic parameters are presented in Table 3.
5. Increasing the velocity gradient obtained a sliding of the lubricant wall for temperatures higher than 60°C.

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