TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 67, Issue Special II, April, 2024

EXPERIMENTAL ANALYSIS OF THE RHEOLOGICAL PROPERTIES OF HYDRAULIC OILS

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Abstract: *In this paper, the rheological behavior of mineral hydraulic oil H46 and of the two biodegradable hydraulic oils HETG46 and HF-E46 is presented. The oils were tested from a rheological perspective using both the Newtonian model and the power law. From a thermal perspective, the oils were tested using the Reynolds model. Oil testing was carried out on the BROOKFIELD CAP 2000+ viscometer, which is controlled by CAPCALC 32 software through which the numerical data processing was carried out, as well as the general setting of the working parameters of the viscometer. The aim of the paper is to observe which of the hydraulic oils show good rheological behavior and subsequently can be used in hydraulic power plants.*

Key words: *hydraulic, biodegradable, rheology, Newtonian model, Power Law*

1. INTRODUCTION

In order to extend the lifespan and enhance the reliability of hydraulically powered equipment, it is crucial to consider the type of hydraulic oil being used. Hydraulic oil primarily serves the purpose of lubricating the equipment within the system and is also utilized for power transmission and controlling hydraulically operated components [1].

Lately, there has been a growing demand for environmental protection in the agricultural machinery sector. All agricultural machines require a working environment for the operation of their equipment, and in most cases, this environment is represented by hydraulic oil. Trends in hydraulic fluid usage indicate a gradual replacement of traditional hydraulic fluids, which are often less biodegradable and more environmentally harmful, with vegetable oil-based fluids [2].

Special attention has been given to biodegradable lubricants due to heightened environmental concerns. These lubricants are derived from vegetable oils and exhibit good rapid biodegradability characteristics, thus contributing to environmental preservation [3].

2. APPLICATION FIELD

The development and utilization of biodegradable lubricants for industrial purposes have gained popularity due to environmental considerations. Lubricants and derivatives based on vegetable oils surpass traditional mineral oils by a significant margin in terms of biodegradability. Furthermore, lubricants based on vegetable oils offer superior lubrication and higher viscosity indices, resulting in reduced frictional losses and improved fuel efficiency [4].

There is a wide range of fields in which hydraulic oils are used. Lubricants derived from vegetable and animal oils are relevant, along with numerous options for formulating lubricants using sustainable raw materials or creating stable esters from vegetable oils. Biodegradable lubricants also find applications in other areas, such as transmission and engine oils used in agricultural technologies or construction machinery [5].

3. RESEARCH STAGES

From the point of view of rheological properties, biodegradable hydraulic oils are much better, compared to mineral ones. This can be highlighted by a reduced dependence of the viscosity on the temperature of the biodegradable hydraulic oils. The viscosity index is an indicator that evaluates the correlation between viscosity and temperature. The higher it is, the more temperature-dependent viscosity decreases [6].

The aim of this study is to determine the rheological properties of mineral hydraulic oil H46 and also biodegradable hydraulic oils HETG 46 and HF-E 46, which are made from vegetable oils.

Finally, a comparison will be made among all these oils to observe which one exhibits optimal rheological performance.

Fig. 1. shows the visual appearance of the three hydraulic oils used in the rheological tests.

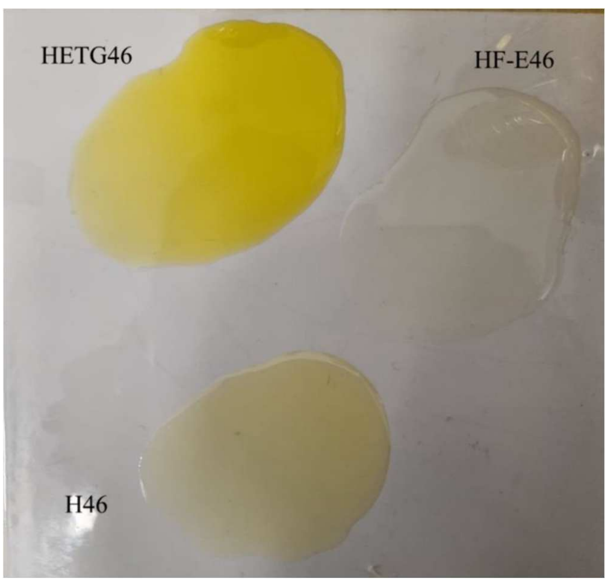


Fig.1. Hydraulic oils used in experimental testing

3.1 METHOD USED

The experimental testing setup was a Brookfield cone plate viscometer, controlled by CAPCALC 32 software. The oil is placed between the rotating cone and the stationary disc. The advantage of this device is that for large cone opening angles, the shear rate remains constant throughout the gap. With the help of the viscometer, you can acquire digital data and determine the variation of viscosity with temperature. Measurements can be taken within a temperature range between 5 and 75°C (fig. 2) [7].

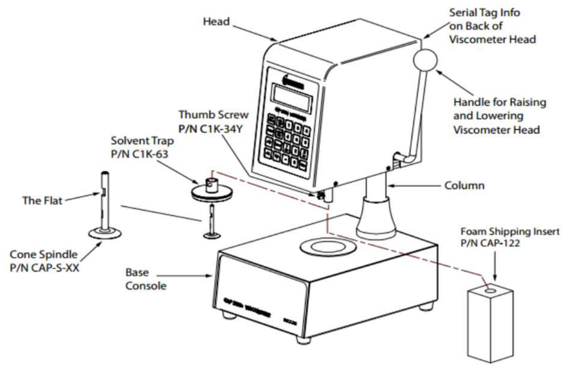


Fig.2. Cone-plate Brookfield viscometer [7]

In Fig. 3., the working geometries used in the Brookfield viscometer are presented. The cone used is number 8, with a cone radius of 15.11 mm and a cone apex angle of 3°.

Fig.3. Work geometries [7]

From a rheological perspective, the proposed models for determining rheological properties and describing their behavior are the Newtonian model (equation 1) and the power-law model (equation 2).

$$\tau = \eta \cdot \dot{\gamma}, \qquad (1)$$
$$\tau = m \cdot \dot{\gamma}^{n}, \qquad (2)$$

Where:

- "m" and "n" are material constants,
- τ-shear stress,
- $\dot{\gamma}$-shear rate,
- m-consistency index,
- n-flow index.

The variation of rheological parameters with temperature, we used the Reynolds model (equation 3), which is an exponential type model.

$$\eta = \eta_{50^\circ} \cdot e^{-m(t-50^\circ)}, \qquad (3)$$

Where:

- η- dynamic viscosity of the fluid at temperature,
- η_{50}- viscosity at the temperature of 50°C,
- m- coefficient of variation of viscosity with temperature,
- t- temperature.

3.2 RESULTS

Fig. 4. shows the rheogram of hydraulic fluids obtained using the rheometer software (CAPCALC 32), where the variation of shear stress with shear rate at a temperature of 20°C can be observed.

The variation of viscosity with temperature at different shear rates for hydraulic oil H46 can be done in the shear rate range from 0 to 800s^{-1}.

For hydraulic oil HETG46, it can be done in the shear rate range from 0 to 1250 s^{-1}, and for hydraulic oil HF-E46, it can be done in the shear rate range from 0 to 900 s^{-1}.

If the shear rate is exceeded for each type of oil, thixotropy becomes much more evident, which means that experimental determinations of viscosity variation with temperature are no longer conclusive.

In Fig. 5., Fig. 6. and Fig. 7. are presented the parameters of the power law rheological model at the temperature of 20°C for the three hydraulic oils. The parameters were obtained by using the numerical regression of the experimental results, using CAPCALC 32 software, to determine the rheological parameters under the hypothesis of power law model variability.

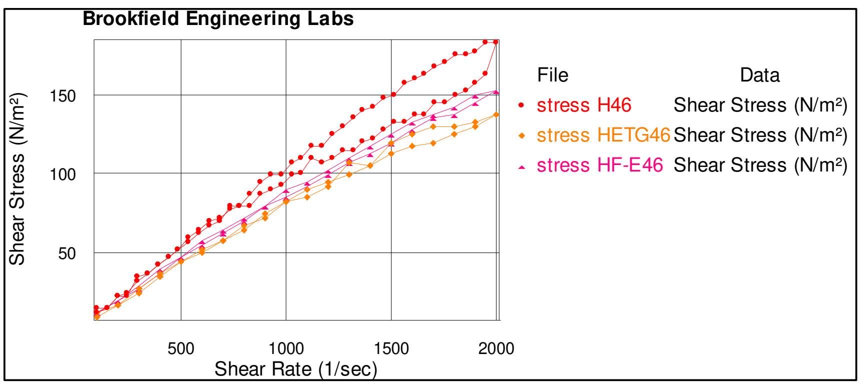


Fig.4. Rheogram of the three hydraulic oils at a temperature of 20°C

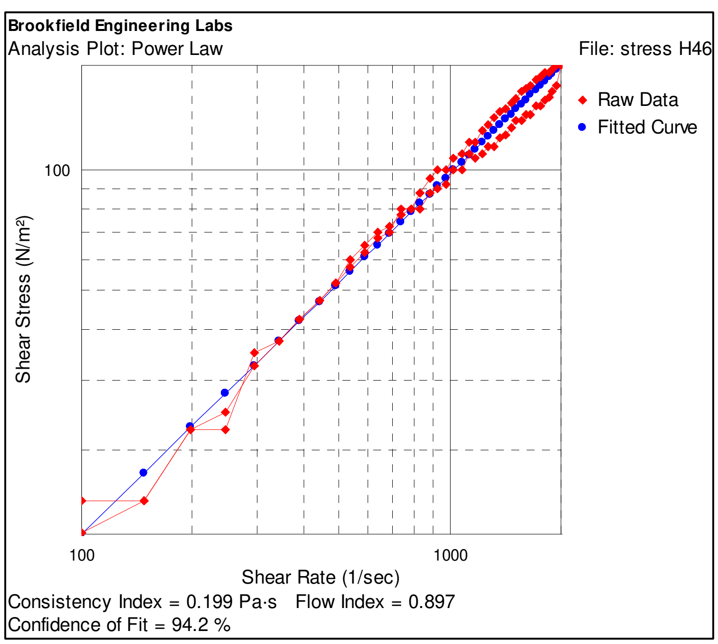


Fig.5. Numerical regression for the results of an H46 hydraulic fluid at 20°C using the power law

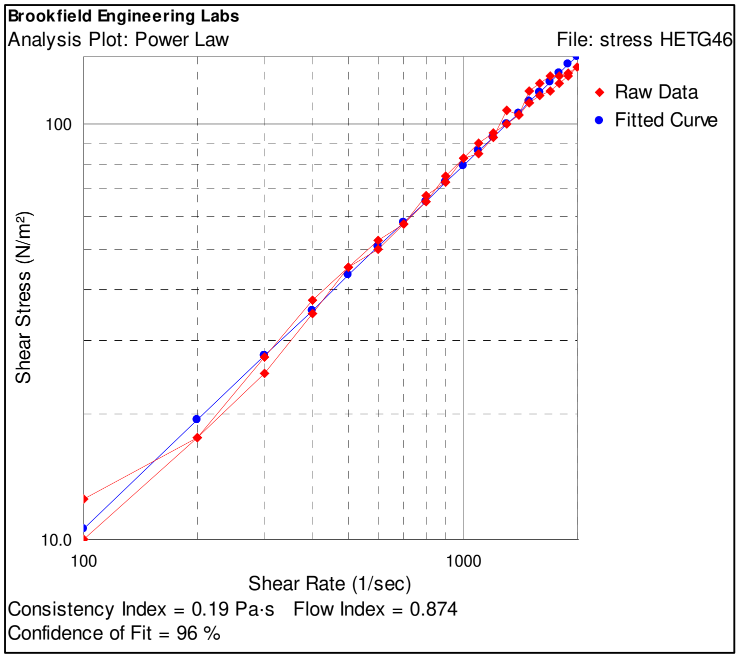


Fig.6. Numerical regression for HETG 46 hydraulic oil results at 20°C using power law

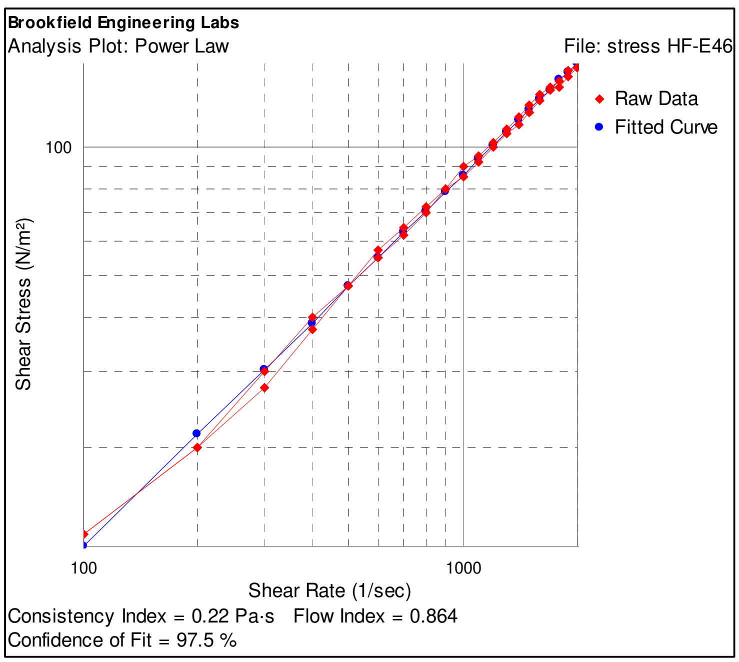


Fig.7. Numerical regression for the results of a HF-E 46 hydraulic oil at 20°C using the power law

In Fig. 8., Fig. 9. and Fig. 10. are presented the parameters of the Newtonian model at the temperature of 20°C for the three hydraulic oils using the numerical regression for experimental data obtained, using the Excell software facilities, to determine the rheological parameters under the assumption of the variability of the Newtonian model.

Fig.8. Numerical regression for the results of an H46 hydraulic fluid at 20°C using the Newtonian model

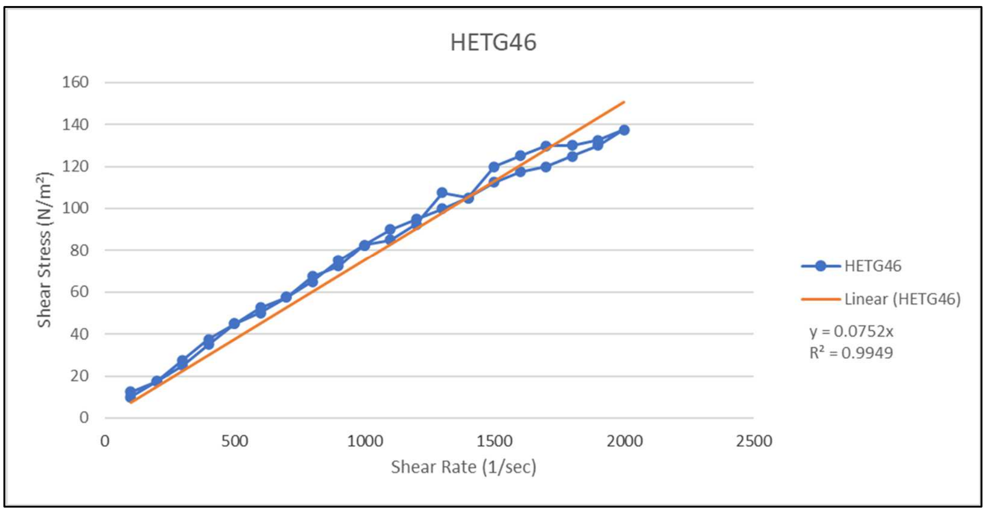


Fig.9. Numerical regression for HETG 46 hydraulic fluid results at 20°C temperature using the Newtonian model

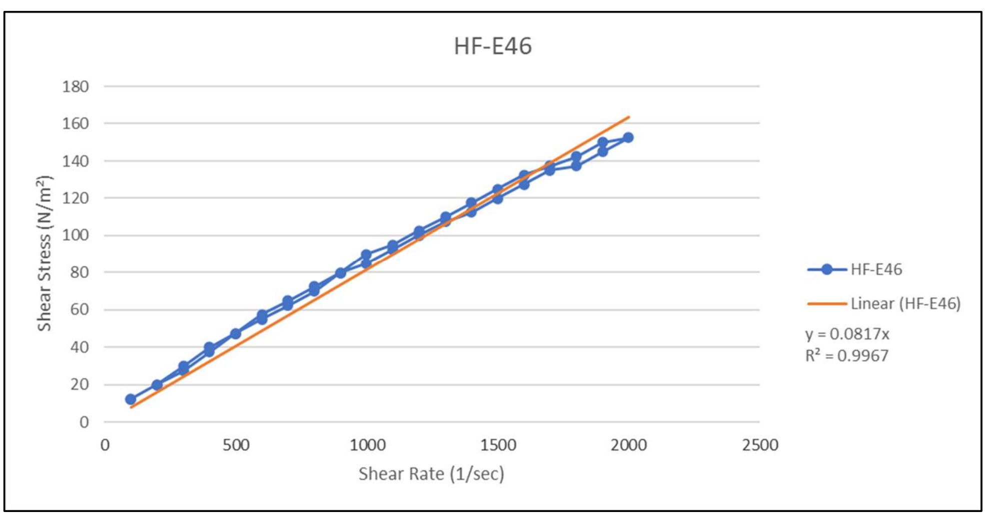


Fig.10. Numerical regression for HF-E 46 hydraulic oil results at 20°C using the model Newtonian

According to the calculation programs, we observe that for each type of oil, the power-law model has a lower correlation coefficient than the Newtonian model, which means that the

Newtonian model best approximates the rheological behavior of these hydraulic oils at a temperature of 20°C. These results are highlighted in Table 1.

Tabel 1

The rheological parameters of hydraulic oil H46 at a temperature of 20°C

Type of oil	Rheological models				
	Newtonian		Power law		
	η, [Pa·s]	Corr. coeff, [%]	m, [Pa·s^n]	n	Corr. coeff, [%]
H46	0,0936	99,29	0,1991	0,8971	94,2
HETG46	0,0752	99,49	0,19	0,874	96
HF-E46	0,0817	99,67	0,22	0,864	97,5

In Fig. 11., Fig. 12. and Fig. 13., the variation of viscosity with temperature at four different shear rates (250, 500, 750, 1000 s^{-1}) is represented. Based on this variation, using the exponential function, the following parameters were determined:

- η_{50}-viscosity variation at the temperature of 50°C,
- m-coefficient of variation of viscosity with temperature,
- ρ-the correlation coefficient.

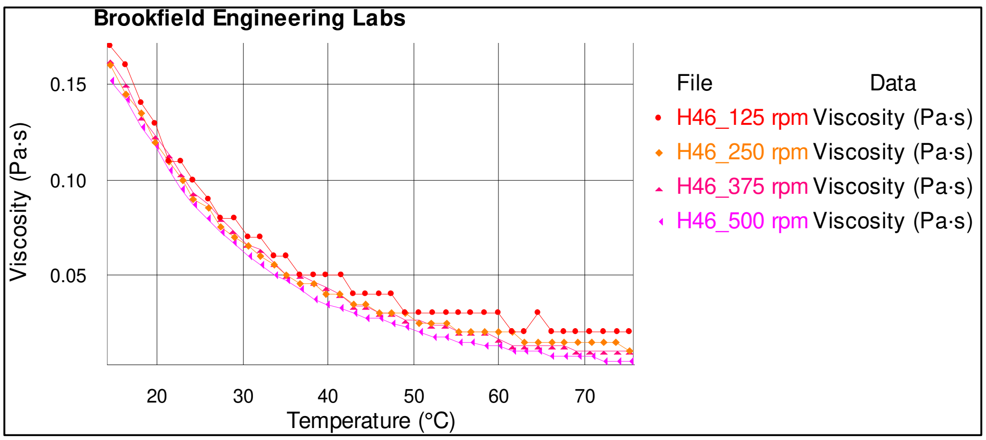


Fig.11. Variation of viscosity depending on temperature for hydraulic oil H46, at four different shear rates (250, 500, 750, 1000 s^{-1})

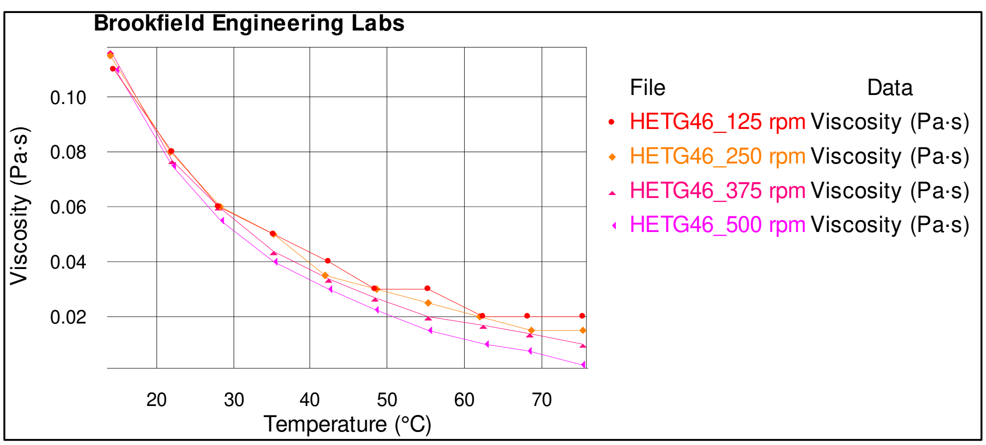


Fig.12. Variation of viscosity depending on temperature for hydraulic oil HETG 46, at four different shear rates (250, 500, 750, 1000 s^{-1})

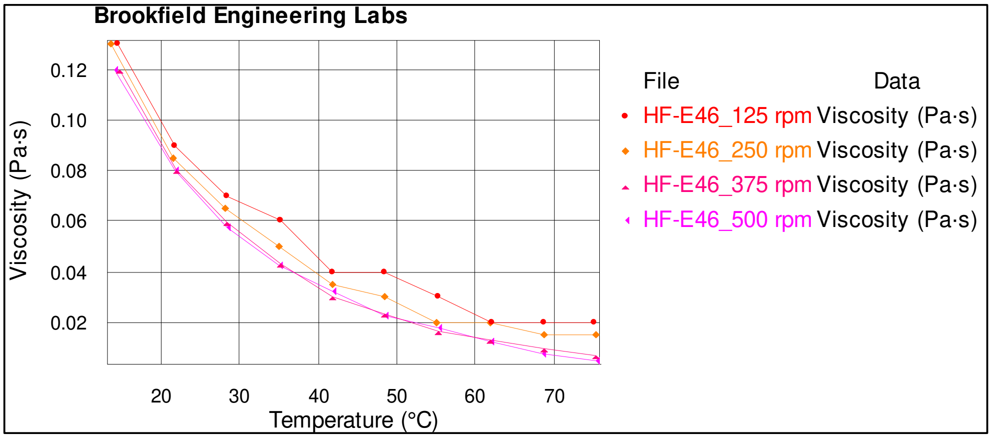


Fig.13. Variation of viscosity depending on temperature for hydraulic oil HF-E 46, at four different shear rates (250, 500, 750, 1000 s^{-1})

In Fig. 11., Fig.12., Fig. 13. it can be seen that the viscosity of the three hydraulic oils decreases while the shear rate increases, thus indicating a pseudoplastic behavior.

Table 2 shows the experimental results obtained using the Reynolds model for the three hydraulic oils. An analysis of these results reveals that the viscosity at 50°C ($\eta_{50°}$) decreases as the velocity gradient increases, while the coefficient of variation of viscosity with temperature (m) increases.

Tabel 2

The characteristic parameters for the variation of viscosity with temperature using the Reynolds model for hydraulic oil H46

Shear rate, [s^{-1}] \ Parameter	H46		
	η_{50} [$Pa \cdot s$]	m, [$°C^{-1}$]	Corr. Coeff. [%]
250	0,0300	0,039	96,71
500	0,0250	0,045	98,40
750	0,0266	0,048	99,51
1000	0,0200	0,057	99,89
	HETG46		
250	0,0300	0,031	96,62
500	0,0250	0,036	98,96
750	0,0199	0,042	99,52
1000	0,0150	0,058	99,36
	HF-E46		
250	0,0300	0,035	98,18
500	0,0200	0,041	99,00
750	0,0166	0,050	99,89
1000	0,0175	0,052	99,84

4. DISCUSSIONS

In Fig. 14., the comparative rheograms of the three tested hydraulic oils are presented.

Analyzing the three curves, the following observations can be made:

- the H46 hydraulic oil has a higher slope compared to the two biodegradable oils, HETG46 and HF-E46, which indicates that its viscosity is higher than that of the biodegradable oils, where the slopes and thixotropy are less obvious;
- the biodegradable oil HF-E46 compared to the biodegradable oil HETG46, has a higher slope, thus indicating that the viscosity of HF-E46 is higher than that of HETG46, where the slope is lower and the thixotropy is more pronounced.

Based on the above two observations, it can be concluded that:

- hydraulic oil H46 does not show stability, because it exhibits a significant thixotropy;
- biodegradable oil HF-E46, on the other hand, shows better stability due to a very low thixotropy.

Fig. 15. presents comparative diagrams of viscosity variation with temperature for the three tested hydraulic oils at four different velocity gradients.

Analyzing these diagrams, the following can be observed:

- the three hydraulic oils show a decrease in viscosity with increasing temperature and velocity gradient;

- at a temperature of 40°C, at the four velocity gradients, the three hydraulic oils have the same viscosity;
- for the two biodegradable oils (HETG46 and HF-E46), there are no significant differences in viscosity variation with temperature;
- as the velocity gradient increases, the curves of the biodegradable oils tend to have the same shape;
- with increasing velocity gradient, the differences in the rheological behaviors of the oils disappear at temperatures above 40°C.

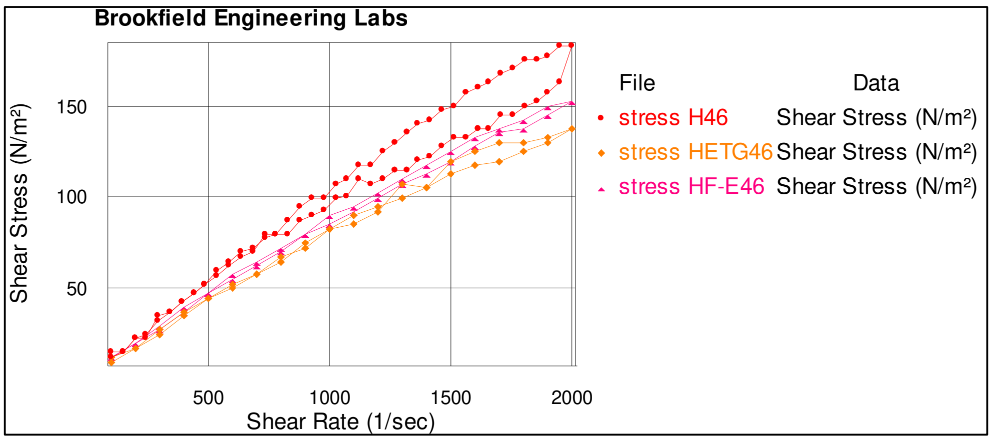
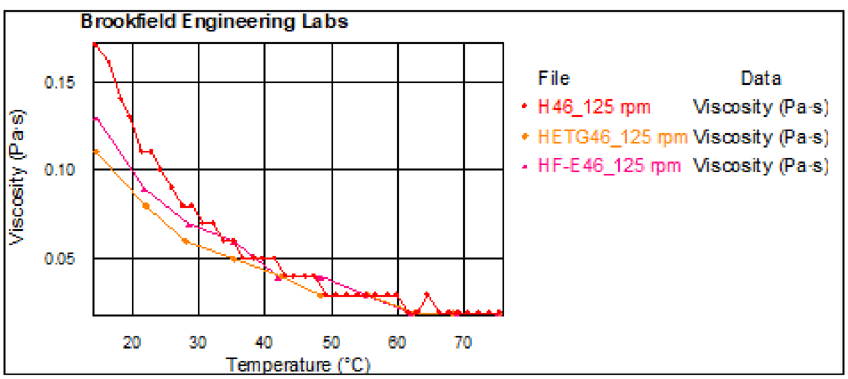
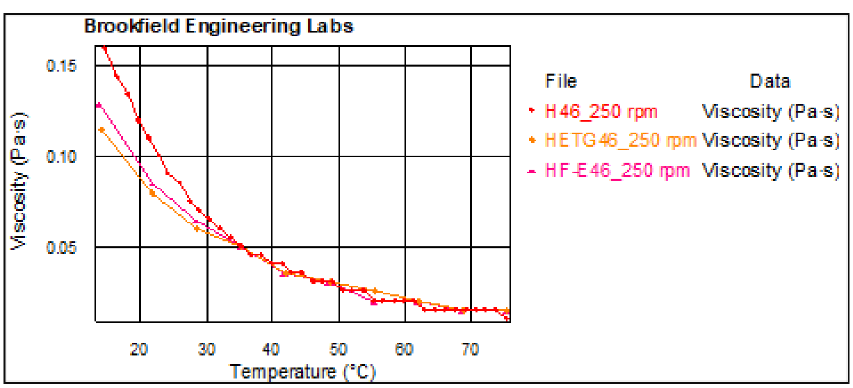


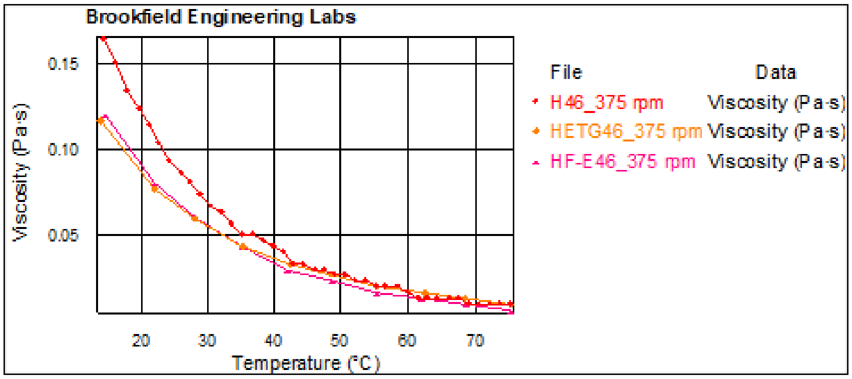
Fig.14. Comparative rheogram between mineral fluid (H46) and biodegradable oils (HETG 46, HF-E46)



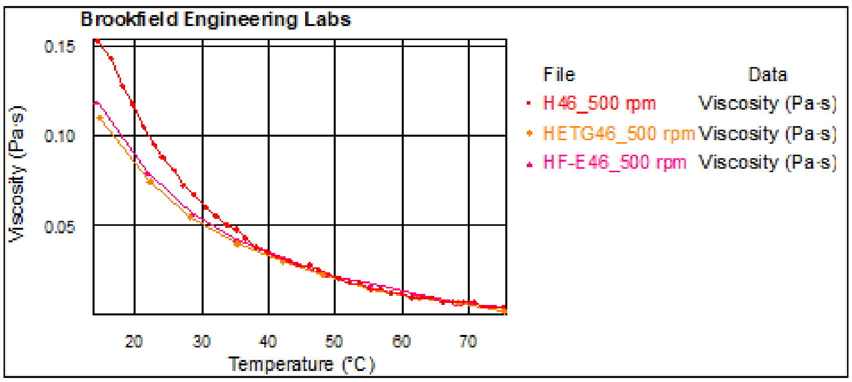
a) Shear rate 250 s^{-1}



b) Shear rate 500 s^{-1}



c) Shear rate 750 s^{-1}



d) Shear rate 1000 s^{-1}

Fig.3.15. Comparative diagrams regarding the variation of viscosity depending on temperature for the three hydraulic oils

5. CONCLUSIONS

Based on these hydraulic oils, their results were comparatively analyzed, noting that:

- the biodegradable oils HF-E46 and HETG46 exhibit very low thixotropy compared to the hydraulic oil H46, where its thixotropy is very high;
- the biodegradable oil HF-E46 has a higher viscosity than the biodegradable oil HETG46 and lower than the hydraulic oil H46, where its slope is higher, indicating a higher viscosity;
- the three hydraulic oils show a decrease in viscosity with increasing temperature and velocity gradient;
- for the two biodegradable oils (HETG46 and HF-E46), there are no significant differences in the variation of viscosity with temperature;
- as the velocity gradient increases, the curves of the biodegradable oils tend to have the same shape or trend.

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Analiza experimentală a proprietăților reologice ale uleiurilor hidraulice

În această lucrare este prezentat comportamentul reologic al uleiului hidraulic mineral H46 și al celor doua uleiuri hidraulice biodegradabile HETG46 și HF-E46. Acestea au fost testate din punct de vedere reologic utilizând modelul Newtonian si modelul legea puterii, iar din punct de vedere termnal utilizând modelul Reynolds. Testare uleiurilor s-a realizat pe vîscozimetrul BROOKFIELD CAP 2000+, care este controlat de un software denumit CAPCALC 32 prin intermediul căruia s-a realizat prelucrarea numerică a datelor, precum și setarea generală a parametrilor de lucru a vîscozimetrului. Scopul lucrării este de a observa care dintre uleiurile hidraulice prezintă comportament reologic bun și ulterior poate fi utilizat în instalațiile hidraulice de putere.

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