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CHARACTERIZATION OF THE VISCOSITY OF SAE40 MONOGRADE MOTOR LUBRICANT OIL BY MEANS OF LASER OPTICAL POWER

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Abstract -- This paper presents preliminary results of the characterization of viscosity in SAE40 monograde engine lubricating oil columns by measuring the optical power of a laser obtained by transmission. The technique consists of a 520 nm continuous wave laser diode beam, which passes through a sample of oil column as a function of temperature and is transmitted to a photodetector that records and processes the signal for subsequent analysis. The results show a direct correlation between optical power and liquid viscosity. The correlation is determined from the analysis of absorbance and absorption coefficient using Lambert-Beer's law.

Keywords: Absorbance, Absorption Coefficient, Laser Power, Viscosity.

Abstract -- In this work, preliminary results of the viscosity characterization in columns of SAE40 single-grade motor lubricating oil and the measurement of the laser optical power obtained by transmission are presented. The technique consists of a beam of a 532 nm continuous wave laser diode, which passes through a sample of oil column depending on the temperature and transmitted to a photodetector that registers and processes the signal for subsequent analysis. The results show a direct correlation between optical power and viscosity, which is determined from the analysis of absorbance and absorption coefficient using Lambert-Beer's law.

Key words – Absorbance, Absorption Coefficient, Laser Power, Viscosity.

INTRODUCTION

Viscosity is an important property of fluids, which can be defined as the internal resistance of a fluid to flow. Today, viscosity is an important property for lubricating oils in internal combustion engines. So much so that the analysis of viscosity and other properties has become highly important for establishing the correct functioning and operation of the engine. This is relevant for its determination. Viscosity can be measured using various methods, such as: capillary tube [1][2], rotating cylinder [3], oscillating disc [4], vibrating straight wire [5], ball drop [6][7], among others. On the other hand, optical techniques are relevant in industrial applications because they are non-destructive and non-intrusive, in addition to being able to perform measurements in full field and in real time [8]. Recently, these techniques have been applied to the determination of engine lubricating oil properties. On the one hand, in [9], the nonlinear optical properties of 20W-50 multigrade oil for engines were determined as a function of laser power, estimating values of absorption, refractive index, and electrical susceptibility. In [10], the authors evaluate viscosity properties in dairy products using the speckle image correlation technique. On the other hand, different techniques have been developed for viscosity measurement, such as the one presented in [11], which is based on the principle of laser-induced surface deformation and was tested on standard liquid systems for viscosities from 1 to 10($^{6)}$cSt.

On the other hand, different studies demonstrate the importance of applying optical techniques in different fields of science and engineering. In [12], the effect of temperature on the optical properties of vegetable oils is studied using ultraviolet-visible (UV-VIS) spectroscopy and laser fluorescence. In [13], a study is presented on the correlation between viscosity and visible light absorption for different lubricating oil samples, showing constant absorbance and viscosity values as a function of work cycles. More recently, in [14], the authors present a study and design of a portable laser-based viscometer for viscosity measurements, whose main feature is increased sensitivity and accuracy as viscosity increases.

In this context, the present study aims to determine a correlation between viscosity and laser optical power in columns of SAE40 engine lubricating oil, in a temperature range between 25°C and 100°C. The technique used involves transmitting a laser beam through a column of oil, depending on the temperature, which then strikes a photodetector that records the signal. The analysis is performed using Lambert-Beer's law to obtain the absorption coefficient and absorbance as a function of laser power.

DEVELOPMENT

Samples of SEA40 lubricating oil columns contained in cells of variable width "t," 10 cm long and 7 cm high (10 x t x 7 cm), were used. A 40 W ceramic resistor was used to raise and maintain a constant temperature between 25°C and 100°C, using an NTC 10K/B3950 sensor controlled by an XY-T01 digital module with an accuracy of 0.1°C. The experimental optical setup shown in Figure 1 consists of a light beam from a continuous wave laser diode with a power of ~6 mW and a wavelength (λ) of 520 nm, which passes through a neutral density (ND) filter and strikes the oil column sample maintained at a certain temperature. The laser beam is transmitted to a TSL2568 photodetector (350-1100 nm) for recording. A laser power meter (Thorlabs S20MM) is used as an acquirer, in conjunction with a Hantek 365A data logger, which transmits the data via USB to a personal computer for analysis.

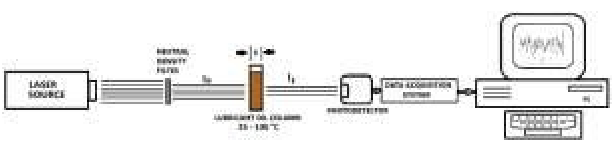

Figure 1. *Experimental optical setup.*
Source: *Own work (2024).*

For data analysis, Lambert-Beer's law is used to determine the absorbance and absorption coefficient of SAE40 oil. Equation No. 1 relates the input and output optical power intensities as a function of the width of the oil column.

$$I_f = I_o e^{-\alpha t} \qquad \text{Eq. (1),}$$

where I_f is the optical power after passing through the oil column, I_o is the input optical power from the laser source, α is the absorption coefficient of the absorbing medium, and t is the width of the oil column.

Figure 2 shows the stability of the measured average optical power [~5.86 mW] of the continuous wave laser diode with a wavelength of 520 nm used.

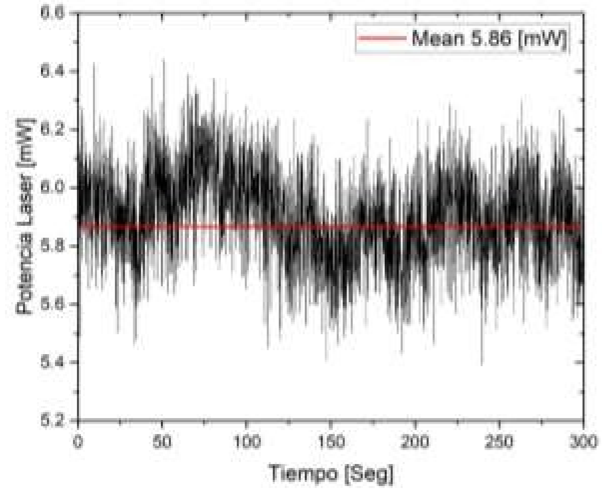

Figure 2. *Average Laser Power.*
Source: *Own elaboration (2024).*

Figure 3 shows the SAE40 viscosity graph as a function of temperature. The red curve represents the adjustment of the data to a third-order polynomial function (equation 2), where an acceptable correlation coefficient of R^2= 0.99983 was obtained, which implies that the model can be used to predict viscosity values.

$$\mu(T) = 0.44283 - 0.04739(T) + 3.89221E - 4(T^2 - 1.48763E - 6(T^3) \qquad \text{Eq. (2).}$$

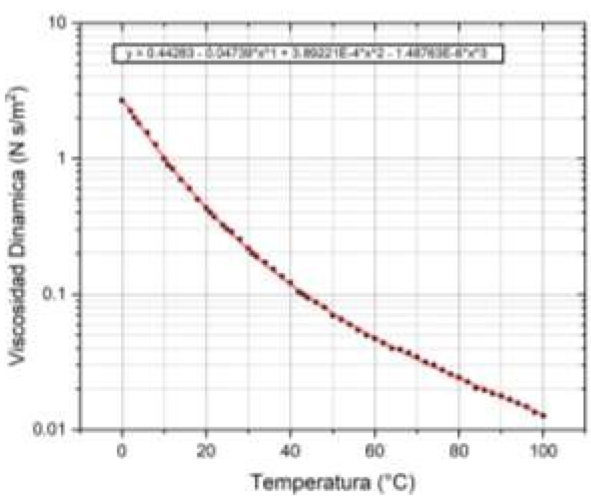

Figure 3. *SAE40 dynamic viscosity vs. temperature.*
Source. *Own elaboration (2024).*

DISCUSSION AND ANALYSIS OF RESULTS

Figure 4 shows the laser optical power as a function of time for an oil column sample with an optical path difference (*ΔL*) of 25 mm, corresponding to the width *t* of the column. The different powers obtained in a temperature range from 30°C to 100°C are shown.

Note how the optical power increases as the temperature in the oil column increases. This may indicate that the viscosity in the oil column is inversely proportional to the optical power transmitted.

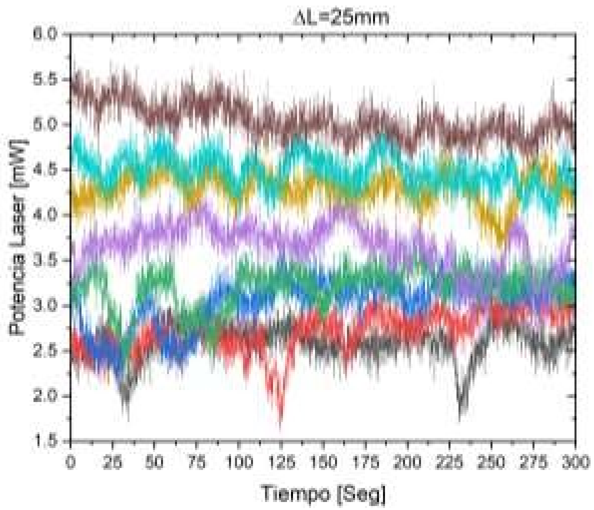

Figure 4. *Laser optical power of an SAE40 oil column (t=25mm) as a function of temperature. 30°C [2.50mW] (Black)-100°C [4.95mW] (Brown).*
Source: *Own work (2024).*

Figure 5 shows the laser optical power obtained for different SAE40 oil columns of width *t* (t=25, 30, 40, and 50 mm) as a function of temperature. Note how the power decreases as the width of the oil column increases.

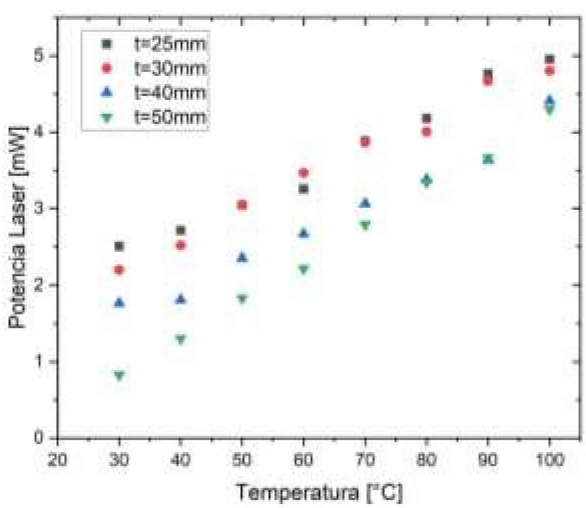

Figure 5. *Laser optical power of different widths of SAE40 oil columns (t=25, 30, 40, and 50 mm).*
Source: *Own work (2024).*

On the other hand, Figure 6 shows the absorbance obtained from the laser power intensities (Eq. 1), which is inversely proportional to the optical path difference ($\Delta L = t$) traveled by the beam.

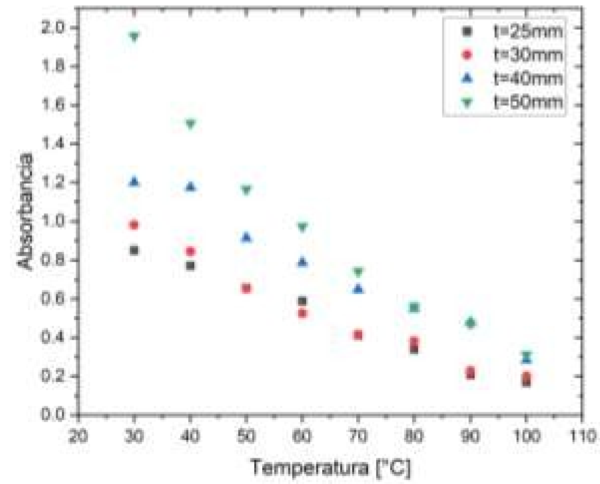

Figure 6. *Absorbance of different widths of SAE40 oil columns (t=25, 30, 40, and 50 mm).*
Source: *Own elaboration (2024).*

Figure 7 shows the trend in dynamic viscosity as a function of absorbance obtained from the intensities of incident and transmitted optical power through the oil columns. An exponential growth behavior is observed as absorbance increases.

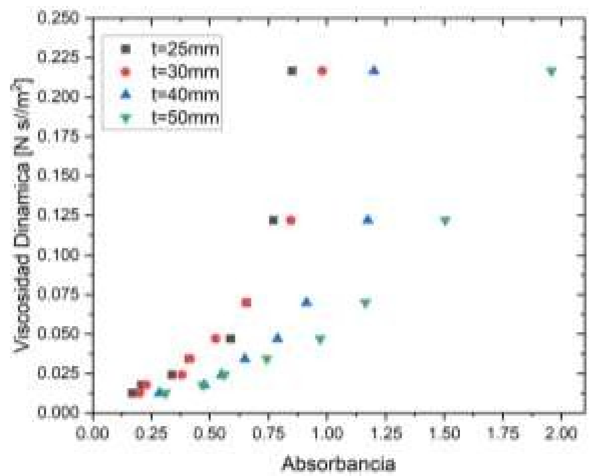

Figure 7. *Dynamic viscosity vs. absorbance of different widths of SAE40 oil columns (t=25, 30, 40, and 50 mm).*
Source: *Own elaboration (2024).*

Figure 8 shows the trend in dynamic viscosity as a function of the absorption coefficient of the different SAE40 oil columns. The absorption coefficient is obtained from the slope of the logarithm of the transmitted power (I_f) for the different column widths (*t*). The red line represents the fit of the obtained second-order polynomial model (Eq. 3), which has an acceptable correlation coefficient (R^2=0.99586) for values of dynamic viscosity as a function of the absorption coefficient (α).

$$\mu(\alpha)=4.10751E\text{-}4+1.03589\alpha+95.53027\alpha^2 \quad \text{Eq. (3).}$$

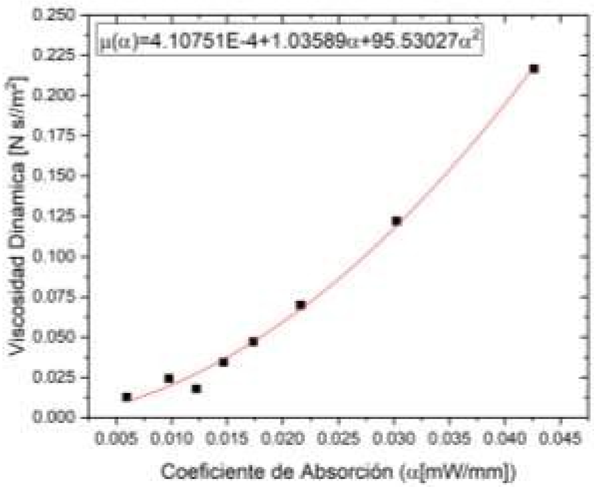

Figure 8. *Dynamic viscosity of SAE40 oil as a function of the absorption coefficient. The red curve represents the data fit (R^2=0.99586).*
Source. *Own elaboration (2024).*

Figure 9 shows the trend in dynamic viscosity as a function of laser power for different widths of SAE40 oil columns. The curves show a similar behavior to that of dynamic viscosity as a function of temperature (Figure 3).

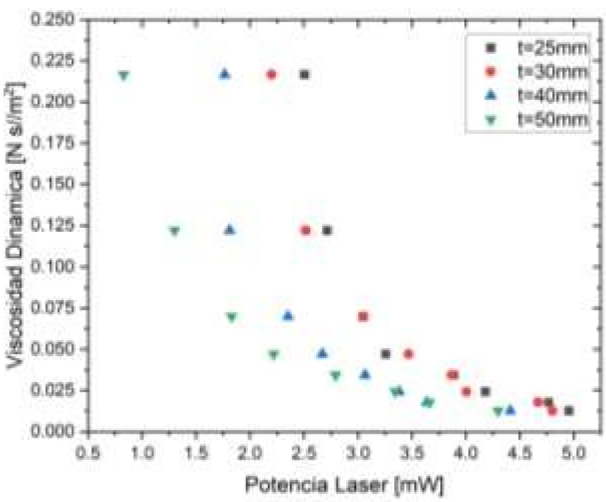

Figure 9. *Dynamic viscosity of SAE40 oil as a function of laser power for different column widths.*
Source: *Own elaboration (2024).*

Table 1. *Dynamic viscosity adjustment models as a function of laser optical power*.

t mm	Model	R^2
50	$\mu(P) = 0.01381 + 0.58372(0.27778)^P$	0.99872
4	$\mu(P) = 0.0416 - (0.02815)\ln(P - 1.7637)$	0.99203
30	$\mu(P) = 3.3488P^{-3.49785}$	0.99442
25	$\mu(P) = (3.13478P^2 + 1.16712P - 17.9744)^{-1}$	0.9981

Source: *Own elaboration (2024).*

Table 1 shows the models obtained from the adjustments of the dynamic viscosity curves as a function of laser power for different widths of SAE40 oil columns (Figure 9). The four models obtained show a correlation fit (R^2)that is more than acceptable, these models being a way of predicting dynamic viscosity as a function of the optical power transmitted through columns of different thicknesses (t*)*.

On the one hand, the four previous models have the disadvantage of depending on the thickness (*t*) of the oil column, so it is important to consider this when selecting the model. On the other hand, this limitation does not affect the model obtained from viscosity as a function of the absorption coefficient, Figure 8 (Eq. 3), because it implicitly considers the thickness (t*)* of the different columns in the calculation of the absorption coefficient (*α)*, which is why it is perhaps a very good option for determining dynamic viscosity (*μ)*.

The results obtained in this study reinforce previous work highlighting the potential of optical methods for determining properties in oils. The correlation between laser optical power, absorption coefficient, and oil viscosity (Figures 5, 8, and 9) is an example of this. For example, in [9], the authors determined a relationship between nonlinear absorption coefficients and incident laser power in 20W-50 multigrade oil, presenting an exponential decay relationship, unlike the one presented in this work (Figure 8). On the other hand, in [15], an experimental arrangement is proposed for determining the dynamic viscosity of oils based on the Mach Zehnder digital holographic interferometer in conjunction with a ball drop viscometer, which is a relatively more complex technique compared to the one used in this work (Figure 1), which is simpler and easier to implement. Furthermore, in [16], an electronic circuit is proposed for measuring the viscosity of vegetable oils in terms of voltage, obtaining a linear relationship between kinematic viscosity and voltage, which, when compared to the behavior between oil temperature and laser power (Figure 5), presents a similar relationship. Finally, the behavior of absorbance as a function of temperature shows an exponential decay very similar to that of viscosity as a function of laser power (Figures 6 and 9, respectively), which also resembles that reported in [17], but with the variation of using biodiesel as the absorbing medium.

CONCLUSIONS

This paper reports preliminary results of the characterization of viscosity in columns of SAE40 monograde engine lubricating oil by measuring the optical laser power obtained by transmission. A clear correlation was determined between dynamic viscosity and optical laser power of columns for a temperature range of 30°C to 100°C. In addition, a significant correlation was obtained as a function of the absorption coefficient without depending on the width *t* of the column. The simplicity of the experimental optical technique suggests its application in viscosity studies as an alternative to conventional methods.

Furthermore, in the future, a portable prototype for laser viscosity measurement could be implemented, with the advantage of instantaneous measurement.

On the other hand, it is important to use optical techniques that are non-intrusive and non-destructive, facilitating the identification of correlated parameters for the recognition of patterns or trends in data, as in [13], the authors used three types of oil samples, placed in special spectrophotometer cells and subjected to visible radiation with wavelengths from 400 nm to 600 nm. The percentages of visible light absorbance of the different oil samples were measured, and viscosity measurements were performed on them. It is reported that the percentages of absorbance of all samples are inversely proportional to the viscosity of the oil sample at the same wavelength of visible light, which is similar to what is reported in this work with viscosity as a function of laser power (Figure 9). In one of their conclusions, the authors mention that the visible light absorbance factor can be used as an indicator of motor oil quality. Another advantage of using optical technology is to irradiate and modify properties, as in [18], which compares selected properties of conventional motor oil and irradiated motor oil during two exchange intervals. The oil properties examined were physical and physicochemical in nature and mainly included kinematic viscosity and viscosity index, among others. The authors compare the oil attribute with its original value, demonstrating that its application improves the properties of motor oil.

Based on the above, the results presented in this paper show the advantage of using non-intrusive, non-destructive methods, as well as being able to perform full-field, real-time measurements that can help interpret, obtain, and/or complement the processes that occur using conventional methods.

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Contribution roles table.

Contribution Role	Author(s)
Conceptualization	Oscar Sarmiento Martínez
Data curation	
Methodology	
Project management	
Visualization	
Resources	Oscar Sarmiento Martínez "same" Rosember Ovando Castelar "same"
Supervision	Oscar Sarmiento Martínez "equal" Rosember Ovando Castelar "equal"

Validation	Oscar Sarmiento Martínez "same" Rosember Ovando Castelar "same"
Drafting (Original draft)	Oscar Sarmiento Martínez
Draft (Revision - Editing)	Oscar Sarmiento Martínez "equal" Rosember Ovando Castelar "equal"