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OPTIMIZATION METHOD FOR RHEOLOGICAL MEASUREMENTS APPLIED TO A MULTIGRADE OIL

I. Radulescu[1], A. V. Radulescu[2]
[1] University POLITEHNICA Bucharest, ROMANIA, irina.radulescu@upb.ro
[2] University POLITEHNICA Bucharest, ROMANIA, alexandru.radulescu@upb.ro

Abstract: *The usage of various modern devices and of many types of oils in different industry applications became a challenge for researches to find appropriate methodology for a better description and evaluation of oils rheological behavior. The paper presents an optimization method for measuring the rheological properties for a multigrade oil, using with different cones geometries on a Brookfield viscometer. The analyzed rheological parameters are: soak time, number of points acquired during the measurements, maintenance duration at a speed level and influence of the temperature on the measurements. The proposed optimization method has the effect of decreasing the determination time of the rheological properties, without affecting the precision of the measurements, and implicitly reducing experimentation costs.*
Keywords: *rheology, multigrade oil, optimization*

1. INTRODUCTION

The usage of various modern devices and of many types of oils in different industry applications became a challenge for researches to find appropriate methodology for a better description and evaluation of oils rheological behavior [1].
Rheological modeling of lubricants has always been a subject of great importance when working with oil from different field of interest. The need for predicting the rheological behaviour of the lubricants when experiencing conditions outside the available measuring range for the equipment designed in accordance with API specifications [2, 3] has always been present. Transmission lubricants behave in a non-Newtonian way. They are shear-rate dependent and normally termed as shear-thinning lubricants. Based on these measured values the models should be able to predict the shear-dependent behaviour of the lubricants outside the measured interval of shear rates [4, 5].
The paper presents the experimental design done for measuring the rheological parameters for 75W90 transmission oil [6], by using 4 cones with different geometries on a Brookfield viscometer series CAP 2000+, [7]. The analyzed varying parameters are: soak time, number of points acquired, maintenance duration at a speed level and influence of the temperature on the measurements. The results of the tests and experiments materialize the rheological models for these cases and the dependency of viscosity by the temperature. The results specify the correlation of better information on rheological behavior by using modern technology, in lubricant research domain research.

2. EXPERIMENTAL STAND

The rheological measurements were performed on a Brookfield viscometer CAP2000+ (Figure 1) equipped with four cone-and-plate geometry and using a Peltier system for controlling the temperature. The CAP 2000+ Series Viscometers are medium to high shear rate instruments with Cone Plate geometry and integrated temperature control of the test sample material, [7]. Concerning the technical parameters of the viscometer, rotational speed selection ranges from 5 to 1000 rpm. Viscosity measurement ranges depend upon the cone spindle and the rotational speed (shear rate). Viscosity is selectively displayed in units of centipoise (cP), poise (P), or Pascal seconds (Pa•s). Temperature control of sample is possible between either 5°C (or 15°C below ambient, whichever is higher) and 75°C or 50°C and 235°C depending on viscometer model. The viscometer uses a CAPCALC32 software for complete control and data analysis.

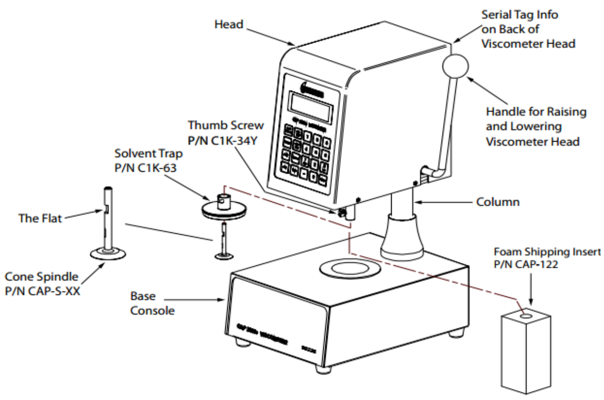


Figure 1: Components of Brookfield viscometer, [7]

A general view of the testing cones is presented in Figure 2. The geometry of testing cones and the viscosity range are described in Table 1.

Figure 2: Geometry of testing cones

Table 1: Geometry and viscosity range of testing cones

Cone number	Cone radius, mm	Cone angle, degree	Viscosity range, Pa.s
3	9.53	0.45	0.083 ... 1.87
5	9.53	1.8	0.333 ... 7.50
6	7.02	1.8	0.833 ... 18.7
8	15.11	3	0.312 ... 3.12

The lubricant used for testing is a 75W90 transmission oil, with physical and chemical properties presented in Table 2 [6]. This is 100% synthetic extreme pressure lubricant, characterised by an efficient anti wear protection, with a better resistance at high temperature and a longer life time. The lubricant is specially designed for racing vehicle gearboxes, synchronised or not synchronised gearboxes, gearbox/differential, transfer gearboxes and hypoïd differentials.

Table 2: Physical and chemical properties of tested lubricant, [6]

Parameter	Catalogue value
Density at 15°C (59°F) ASTM D1298	900 kg/m^3
Viscosity at 40°C (104°F) ASTM D445	72.6 mm²/s
Viscosity at 100°C (212°F) ASTM D445	15.2 mm²/s
Viscosity index VIE ASTM D2270	222
Flash point ASTM D92	200°C
Pour point ASTM D97	-60°C

3. DESIGNING OF THE EXPERIMENT

According to the producer recommendations, the input data for the CAPCALC 32 software are:

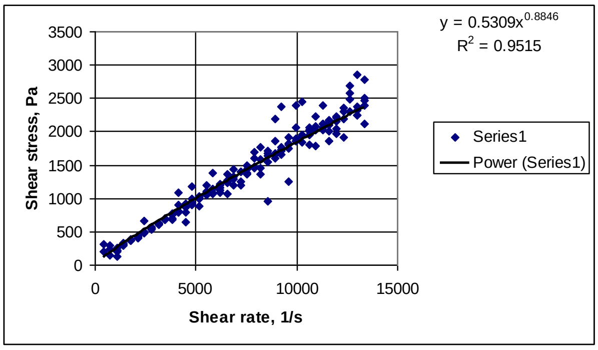
- rheological test type: time to stop; time to torque; dual speed; speed ramp; temperature profile;
- cone number to be used: 1, 2, …, 10;
- range of temperatures: 5 … 75 ^{0}C;

- rotation speed of the cone during soak;
- soak time;
- range of rotation speed for the cone: 5 … 1000 rpm;
- maintenance duration at a speed level of the cone;
- number of points acquired at the same rotation spead of the cone.

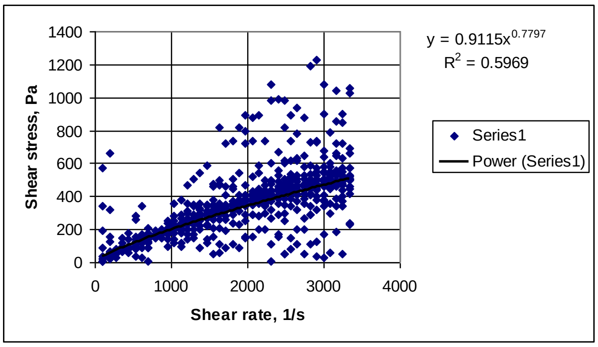
The first step in designing the rheological measurement is to know the properties of the lubricant (see Table 2) and to evaluate the rheological behavior of the sample. Therefore, preliminary tests are imposed in order to choose the proper cones to be used. Figures 3 a, b, c and d show the preliminary testing results for a classic shear rate – shear stress curve, with cone number 3, 5, 6 and 8. For each curve, the numerical data where treated by regression analysis method and the rheological model was obtained, according to the power law model:

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

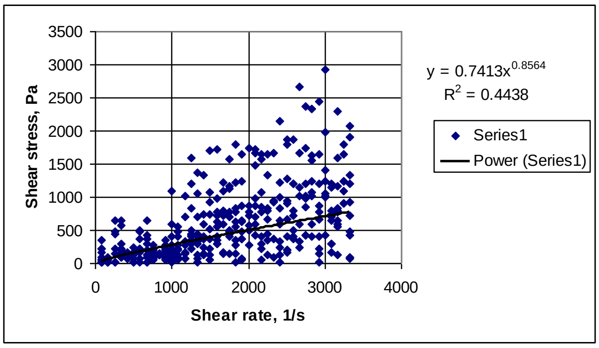
where: m - consistency index (which is equivalent to the Newtonian fluid viscosity);
n - flow index (equal to 1 if the fluid is Newtonian).



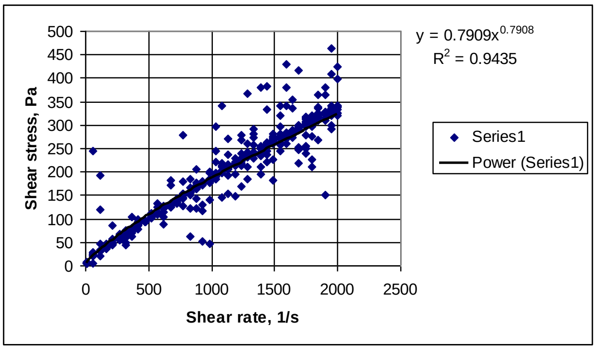
a) cone no. 3



b) cone no. 5



c) cone no. 6



d) cone no. 8

Figure 3: Rheogram for 75W90 oil, for different cones

The rheological paremeters obtained for these preliminary tests are presented in Table 3.

Table 3: The lubricant rheological parameters for preliminary tests

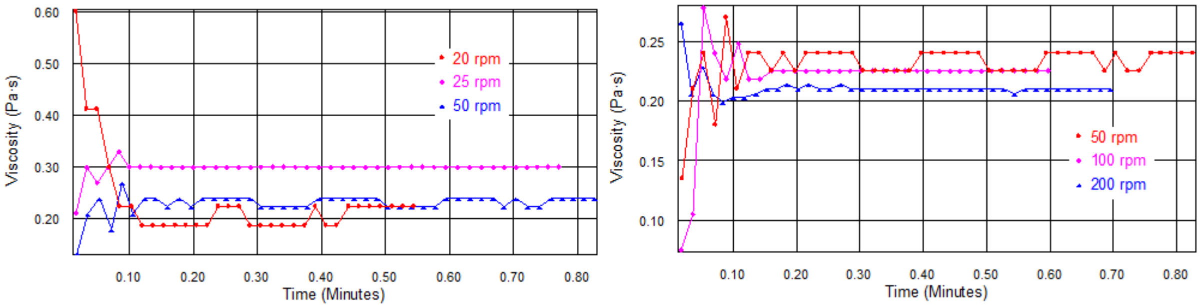
Cone number	Consistency index (m), $Pa\cdot s^n$	Flow index (n)	Correlation coefficient
Cone 3	0.5309	0.8846	95.15%
Cone 5	0.9115	0.7797	59.69%
Cone 6	0.7413	0.8564	44.38%
Cone 8	0.7909	0.7908	94.35%

Analysing these preliminary results, two important conclusions are obtained:

- cones 5 and 6 are not proper for this type of lubricant, because the correlation coefficient for the rheological model is too small, and the results are not significant;
- cones 3 and 8 offer consistent results, with high correlation coefficients.
- there are differencies between the results obtained with cone 3 and 8, because the range of shear rates for these two cones are different:

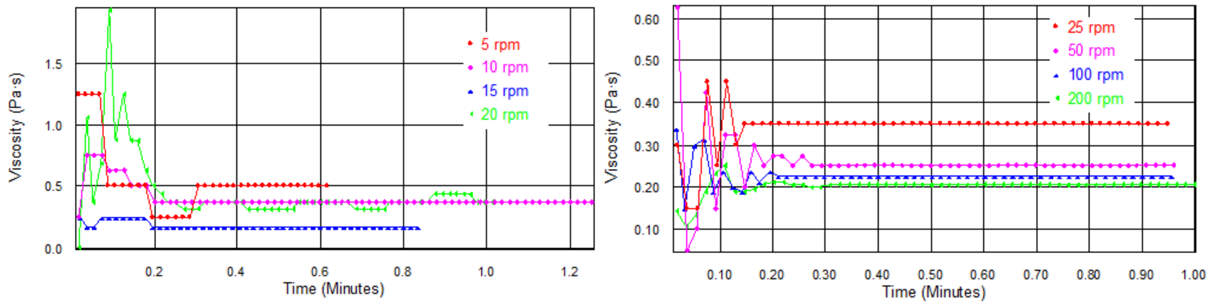
- cone 3: shear rate 67 … 13333 s^{-1};
- cone 8: shear rate 10 … 2000 s^{-1};

Second step for designing the rheological measurement is to determine the soak time and the maintenance duration at a speed level. The rotation speed was established at 5, 10, 15, 20, 25, 50, 100 and 200 rpm, the testing time at 3 minutes, and the results are presented in Figure 4 a and b (cone 3) and Figure 5 a and b (cone 8).



a) speed range: 20, 25 and 50 rpm b) speed range: 50, 100 and 200 rpm

Figure 4: Variation of the viscosity versus time for a constant rotation speed – cone no. 3



a) speed range: 5, 10, 15 and 20 rpm b) speed range: 25, 50, 100 and 200 rpm

Figure 5: Variation of the viscosity versus time for a constant rotation speed – cone no. 8

Analysing Figures 4 and 5, it can observe that the values of the soak time depend on the rotation speed of the cone. The results are synthesized in Table 4, with the observation that for cone 3, at low speed, no consistent results were found..

Table 4: The variation of soak time (in seconds) versus rotation speed of the cone

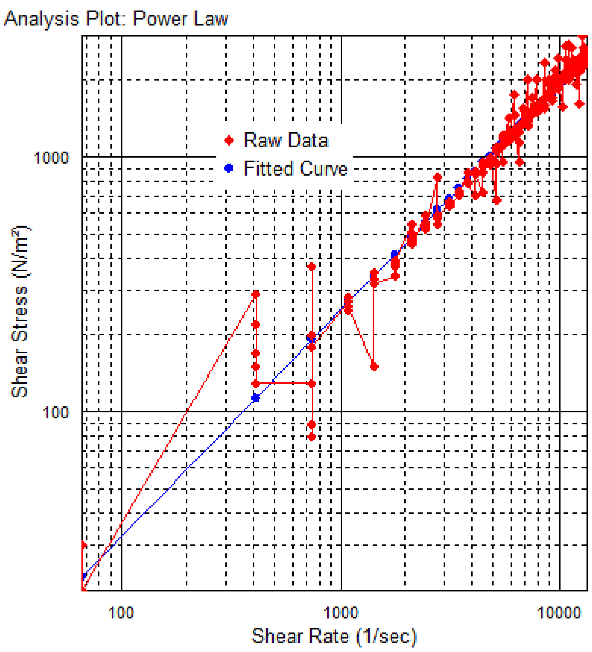
Rotation speed, rpm / Cone number	5	10	15	20	25	50	100	200
Cone 3	-	-	-	12	10	6	4	3
Cone 8	18	12	11	20	8	16	12	18

In conclusion, after these preliminary tests, the following parameters have been choosen for rheological characterization of 75W90 transmission oil:

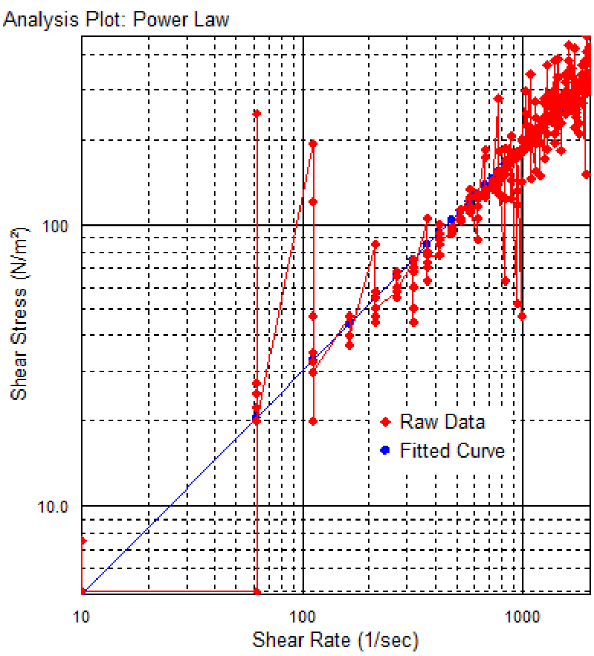
- cone type: number 3 and 8;
- range of shear rate: 10 … 13333 s^{-1};
- soak time:
  - cone 3: 20 seconds;
  - cone 8: 30 seconds;
- range of temperature: 20 … 75 ^{0}C.

4. RESULTS AND DISCUSSIONS

The main results of the research are obtained based on the testing parameters obtained above. It was used an “imposed velocity gradient” test, with the variation limits 10 ... 2000 (133333) s^{-1} (depending on the cone number), number of acquired data between 100 … 400 points and temperature range of 20...75°C. Lubricant rheograms for 75W90 oil are presented in Figures 6 a and b, for cone 3 and cone 8. The results for lubricant rheological parameters for both cones are directly obtained by using the rheometer software (Capcalc V3.0). Results are centralized in Tables 5 and 6.



a) cone no. 3



b) cone no. 8

Figure 6: Rheogram for both cones, with number of acquired data 200 points

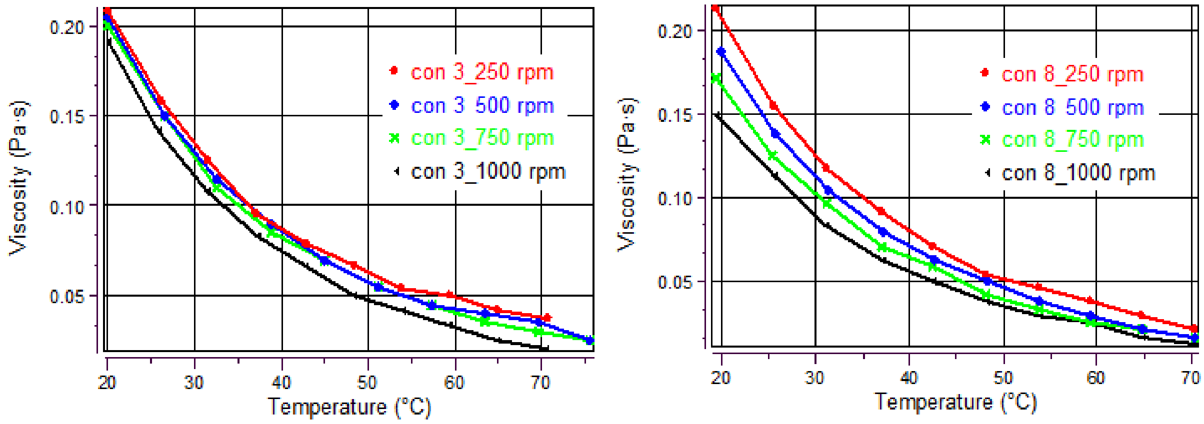
Table 5: The lubricant rheological parameters for cone number 3, function of number of acquired data

Number of acquired data, points	Consistency index (*m*), $Pa{\cdot}s^n$	Flow index (*n*)	Correlation coefficient
100	0.5312	0.8851	91.62%
200	0.5425	0.8914	93.14%
300	0.5481	0.8993	94.20%
400	0.5513	0.9037	95.42%

Table 6: The lubricant rheological parameters for cone number 8, function of number of acquired data

Number of acquired data, points	Consistency index (*m*), $Pa{\cdot}s^n$	Flow index (*n*)	Correlation coefficient
100	0.8832	0.7734	78.42%
200	0.8425	0.7817	84.98%
300	0.8136	0.7896	89.88%
400	0.7909	0.7908	94.35%

Analysing these values, it can observed that the measurements with cone number 3 characterize the rheological behavior of the lubricant on a larger range of shear rate, with a high correlation coefficient. For this cone, it isn’t necessary to increase the number of acquired points, because the precision is high enough even at 100 points.
The cone number 8 characterize the rheological behavior of the lubricant on a smaller range of shear rate, and the correlation coefficient varies with the number of acquired points. Therefore, for this cone it is necessary to have a large number of data points in order to obtain a high precision.
Regarding the thermal behavior of the 75W90 transmission oil, Figures 7 a and b show the variation of the apparent viscosity with temperature, for different speed ratio and for both cones.



a) cone no. 3 b) cone no. 8

Figure 7: Variation of apparent viscosity versus temperature for both cones

It can observed a slight decrease in apparent viscosity with increasing of shear rate for both cones. This shows a certain pseudoplastic behavior of 75W90 transmission oil.

5. CONCLUSIONS

1. In order to perform significant rheological measurements, it is important to know the properties of tested lubricant, to understand the capabilities of the rheometer, to know the rheometer limitations and to correctly design the experiment.
2. In the case of 75W90 transmission oil, on a Brookfield CAP 2000+ viscometer, the using of cone number 3 offers the best results, from the point of view of precision and confidence level.

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