Determining the Main Characteristics of Motor Lubricants Using Color Indices and Prediction Models

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***Abstract* – This paper proposes tools for predicting the main characteristics of motor lubricating oils that can be used to assess their quality. A comparative analysis of four measuring devices, operating on optical principle, was performed to predict the main characteristics of motor lubricating oils. It has been found that the combined use of seven color indices leads to increased accuracy in predicting the value characteristics of motor oils. The two main components are needed to reduce the data volume of the vector containing these features, which leads to a reduction in the volume of data used. It was found that according to colorimeter data, regression models have higher predictive properties than those obtained with a video camera and a digital camera. The proposed research tools can be used with single-board microcomputer systems, which do not require complex computational procedures. The use of the proposed in this article techniques and tools in practice would reduce the effect of the measuring instrument experience.**

***Keywords* - optical sensors, oil production, regression analysis, color components, rheological properties, principal component analysis.**

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1. Introduction

The vehicles mechanisms operation depends to a large extent on the quality of the motor oil used.

It passes through the gaps on the friction surfaces, so it is necessary to create a film that ensures minimal wear of moving parts.

The main characteristics of motor oils such as density, viscosity, color and flame temperature are determined in laboratory conditions. Some of the laboratory methods for analysis are subjective and time consuming. Qualified specialists are required to perform these analyzes. At the current level of development of science and technology, contact and non-contact measuring devices are being developed [1]. These technical devices are low-cost, compact, provide express analysis of motor oils, and are usually based on single-board microcomputers.

Some of the methods used for the analysis of motor oils, based on these devices, are close to the classic laboratory methods [2]. Partial automation is used, which reduces the impact of the meter's experience.

Optical technical devices, such as document cameras, digital cameras, colorimeters, and video sensors for mobile phones and tablets, have the potential to be used for express analysis of the motor oils characteristics. Video sensors have the advantage that are accessible, widespread and the data obtained from them can be used for the creation of models describing the relationship between the characteristics of the analyzed product and color components and indices.

The main stage in the development of recognition systems operating on the optical principle is the assessment of the separability of motor oils from each other by various features that describe them [3]. It is also possible to predict different characteristics of oils, which are usually determined in the laboratory and require specific hardware and trained personnel to use it [4].

From the review of the available literature sources the following issues can be defined, having a partial solution:

- Which available technical means, operating on the optical principle, can provide sufficient accuracy in the motor oils characteristics determination?
- Can the color characteristics of motor oils be used to determine key performance indicators?
- Can the computational procedures studied so far be used with single-board microcomputer systems?

The aim of the present work is to propose a quick method for the non-destructive assessment of the basic characteristics of motor oils, using techniques for the analysis of color indices, which should be used as an indicator to determine their quality.

2. Material and Methods

56 samples of fresh mineral motor lubricating oils of two viscosity classes, marked as xW-30 and xW-40, were analyzed, where "x" is from 5 to 20.

The studied motor oils are formulated by mixing petroleum base oil fractions and additives.

The samples are taken from different batches of motor oils with different applications and operating levels, according to the European Automobile Manufacturers' Association (ACEA).

Three main characteristics of oils have been identified:

- Kinematic viscosity at 100ºC, mm^2/s, KV100, according to BDS EN ISO 3104: 2020 Procedure A;
- Color, Lx, (x=0.5 to 8.0), according to BNS ISO 2049: 2002;
- Total alkalinity by potentiometric titration with perchloric acid, TBN, mgKOH/g, according to ASTM D2896-15.

These characteristics are important in determining the condition of motor lubricants, viscosity and its quality.

The measurements were made in a licensed laboratory. They were performed at room temperature 22±3ºC and relative humidity 50±5% RH.

Table 1. shows the mean values and standard deviation of the measured motor oils characteristics.

Table 1. The characteristics of the tested motor oils

Density class / Characteristic	xW-30	xW-40
KV100, m^2/s	13.59±3.3	11.19±0.7
Color	L2.5 to L5.0	L2.0 to L4.0
TBN, mgKOH/g	8.16±4	8.98±1.3

Two video sensors and a colorimeter were used to determine the optical characteristics of the motor oils, and the test sample of each oil was 5 ml.:

1-Document camera Triumph Board A 405 (TRIUMPH BOARD a.s., Prague, the Czech Republic). The measurements with the video sensor of this camera are in daylight, marked as Dev1. The measurement was made using a Styrofoam box measuring 45x40x35 cm, which is covered on the inside with black foil to avoid light scattering and interference, ensuring uniformity of the captured image. This measurement is referred to as Dev2. The chamber is placed vertically in the center of the box and above the sample holder. The distance between the chamber and the sample holder is 20 cm. The diode lamp built into the document camera, which uses white LEDs with the highest light intensity at 450nm, was used for the recording.

2-Digital camera (Dev3), with a 25-megapixel video sensor Nikon D5300, DLSR (Nikon Inc., New York, USA) with a sensor size of 23.5x15.6 mm.

When measuring with video sensors, a 1x1 cm region of interest is selected from the obtained color digital image.

Colorimeter (Dev4), model PCE-RGB-2 (PCE Holding GmbH, Germany). Manufactured according to DIN 5033. The device measures 10-bit RGB color.

When measuring with a colorimeter, the color was determined at three points of the sample and their average value was accepted.

Table 2. summarizes the data on the measuring devices used.

Table 2. Measurement devices used for test

Designation	Device	Measurement conditions
Dev1	Document camera Triumph Board A 405	Day light
Dev2	Document camera Triumph Board A 405	Homogeneous lighting
Dev3	Digital camera Nikon D5300	Day light
Dev4	Colorimeter PCE-RGB-2	Device light source

The 8-bit values of the color components of the RGB color model measured by video sensors are converted to Lab, in the ranges L = [0, 100]; "a" and b = [-100, 100]. The conversion is to CIE L* a* b* 1976. Computational functions at D65 illuminance were used.

The 10-bit values of the RGB color components obtained by the colorimeter are converted to 8-bit, according to the formula:

$$RGB_8 = \frac{RGB_{10}}{1023}.255 \quad (1)$$

Table 3. shows data for RGB and Lab color components for both classes of motor oils. Their mean values and standard deviation are given.

Table 3. Color component values for the motor oils used

DC	xW-30			
D / CC	Dev1	Dev2	Dev3	Dev4
R	175±15	174±16	75±24	44±12
G	142±17	142±17	71±22	50±13
B	30±24	29±24	40±18	2±0
L	60,5±5,8	60,3±5,8	29,8±9,3	19,8±4
a	1,9±6,3	2±6,3	-3,5±2	-9,2±12,7
b	57,4±8,8	57,7±8,8	19,2±7,4	26,8±4,4
DC	xW-40			
D / CC	Dev1	Dev2	Dev3	Dev4
R	175±12	173±12	66±7	40±12
G	146±14	144±14	64±7	54±13
B	48±25	46±25	36±12	2±0
L	61,6±4,8	61±4,9	26,5±3,1	20,6±4,3
a	0,5±4,8	0,5±4,9	-3,8±1,2	-13,1±12,4
b	52,4±8,1	52,3±8,1	17±7,2	27,5±4,6
DC- Density class; D-Device; CC-Color component				

The values of the chrome (C) and hue (h) from LCh color model are determined by the formula:

$$C = \sqrt{a+b} \qquad h^o = atan\left(\frac{b}{a}\right) \tag{2}$$

These values are used in the calculation of color indices. The indices are determined by formulas summarized by Pathare and team [5].

$$YI = \frac{142.86b}{L} \tag{3}$$

$$WI = 100 - \sqrt{(100-L)^2 + a^2 + b^2} \tag{4}$$

$$BI = \frac{x-0{,}31}{0.17} \text{ where } x = \frac{a+1{,}75L}{5.645L+a-0.012b} \tag{5}$$

$$SI = \sqrt{a^2+b^2} \tag{6}$$

$$CIRG = \frac{180-h}{L+C} \tag{7}$$

$$COL = \frac{2000a}{LC} \tag{8}$$

$$CI = \frac{a}{b} \tag{9}$$

$$ECB = \frac{a}{b} + \frac{a}{L} \tag{10}$$

$$FCI = L - b \tag{11}$$

$$WL = \frac{L}{b} \tag{12}$$

$$PACI = \frac{1000a}{L+h} \tag{13}$$

Informative color indices have been selected using the method of consistently improving estimates, which reduces the number of combinations of traits obtained. The method is used to select regression traits by analyzing neighboring components, FSRNCA [6]. The weight of the traits is determined by diagonally adapting the method of analysis of adjacent components (NCA). Those color indices that have weight coefficients with a value greater than or equal to 0.6 are considered informative.

The data of the obtained vector of traits were reduced by the principal components analysis (PCA) method. The required number of principal components (PCs) to describe the variance in the data has been determined.

One of the approaches to evaluate the performance of various optical devices is based on predictive models [7], [8], for which there are developed algorithms for single-board microcomputers [9]. The models are suitable for software implementation in such devices.

Regression prediction models of the type Z=f (X, Y) make it possible to determine the value of a characteristic at any point in time, including future moments.

An initial model was used, describing the relationship between selected characteristics of motor oils of the type:

$$z = b_0 + b_1x + b_2y + b_3x^2 + b_4xy + b_5y^2 \tag{14}$$

where b are the coefficients of the model; x and y are the independent variables; z the dependent variable corresponding to the characteristic of the engine oils.

The accuracy of the predictive models was assessed on the basis of statistical parameters: coefficient of certainty, standard deviation, errors in order to obtain information through analysis and interpretation of empirical data.

The coefficients of the model, their standard error (SE), t-statistics (tStat), p-value are determined.

For each of the models, an analysis of the model coefficients was made, depending on the value of p,. Non-informative coefficients are rejected by the model.

An analysis of the residues is made, which is determined by the difference between the actually measured values and those of the model.

Matlab 2017b (The Mathworks Inc.) and Statistica 12 (Stat Soft Inc.) software products were used to process the experimental data.

All data were processed at significance level α=0.05.

3. Results and Discussion

A selection of informative color indices and characteristics has been made for each variant of the measuring device. The weighting factors are averaged. Those indexes, that are most informative, have been selected.

Figure 1. shows summarized results from this selection. Two components "L" and "a" are selected from the Lab color model. It can be seen that the brown and yellow indices are also informative for motor oils, as well as those that depend on the components of the Lab model. The COL and PACI indices, which depend on the "L", "a" and "C", "h" color components, also have weighting coefficients above 0.6.

A vector of features is formed, containing a total of seven color indices. It has the form:

$$FV=[L\ a\ YI\ BI\ COL\ FCI\ PACI] \tag{15}$$

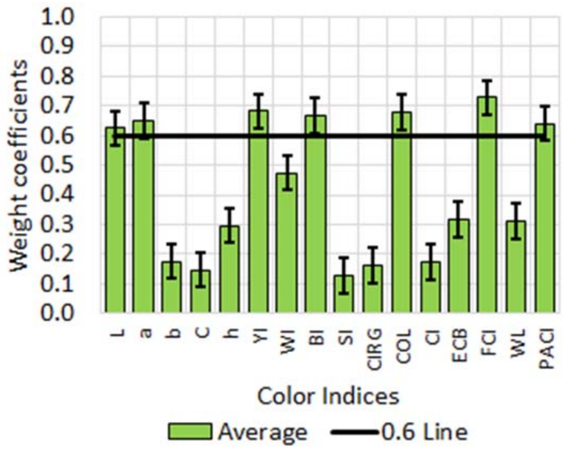

Figure 1. Selection of informative color indices

The required number of principal components to describe 95% of the variance in the data of the feature vector, containing color indices from each of the four analyzed devices, was determined. It has been found that two main components are needed to describe these data in all cases. The main components were used as independent variables in the compilation of regression prediction models for the three characteristics of motor oils.

Insignificant coefficients with a p-value> 0.05 have been removed from the basic model. The obtained models for Dev1 have the form:

$$\begin{gathered}KV=f(PC_1,PC_2)\\ z = 13.92 - 0.72x - 1.27y + 0.15y^2 + 0.18xy\end{gathered} \tag{16}$$

$$\begin{gathered}L=f(PC_1,PC_2)\\ z = 4.03 - 0.62y + 0.01x^2 + 0.07y^2\end{gathered} \tag{17}$$

$$\begin{gathered}TBN=f(PC_1,PC_2)\\ z = 10.99 - 0.04x - 1.19y + 0.1y^2\end{gathered} \tag{18}$$

Table 4. shows the values of the criteria for evaluation of the models obtained from Dev1 data. The values of the coefficient of certainty are lower than 0.5, and the error rates are high. This shows that the obtained models do not describe the experimental data with sufficient accuracy. Although in the p <0.01 models the value of the Fisher criterion is much higher than the critical one (F >> Fcr), this proves that the models are not suitable for describing the experimental data.

Table 4. Criteria for evaluating the obtained models for Dev1

	R^2	F	p-value	SE
$KV=f(PC_1,PC_2)$	0.39	F(4,53)=8.31 Fcr=2.54	<0.00	2.24
$L=f(PC_1,PC_2)$	0.40	F(3,54)=11.77 Fcr=2.78	<0.00	0.46
$TBN=f(PC_1,PC_2)$	0.23	F(3,54)=5.23 Fcr=2.78	<0.01	1.68

The obtained models for Dev2 have the form:

$$\begin{gathered}KV=f(PC_1,PC_2)\\ z = 8.72 - 0.17x - 1.91y - 0.13y^2\end{gathered} \tag{19}$$

$$\begin{gathered}L=f(PC_1,PC_2)\\ z = 2.92 - 0.08x - 0.11y - 0.01y^2\end{gathered} \tag{20}$$

$$\begin{gathered}TBN=f(PC_1,PC_2)\\ z = 9.2 - 0.01x^2 + 0.06xy\end{gathered} \tag{21}$$

Table 5. shows the values of the criteria for evaluating the models obtained from Dev2 data. The high error rates and low R^2 values indicate that the obtained models do not describe the experimental data with sufficient accuracy. Although for the models p <0.01, the value of the Fisher test is much higher than the critical one (F >> Fcr), which also proves that the models are not suitable for describing the experimental data.

Table 5. Criteria for evaluating the obtained models for Dev2

	R^2	F	p-value	SE
$KV=f(PC_1,PC_2)$	0.33	F(3,54)=8.96 Fcr=2.78	<0.00	2.31
$L=f(PC_1,PC_2)$	0.44	F(3,54)=14.26 Fcr=2.78	<0.00	0.44
$TBN=f(PC_1,PC_2)$	0.11	F(2,55)=3.37 Fcr=3.17	<0.04	1.78

The obtained models for Dev3 have the form:

$$\begin{gathered}KV=f(PC_1,PC_2)\\ z = 7.71 - 1.21x - 5y - xy\end{gathered} \tag{22}$$

$$\begin{gathered}L=f(PC_1,PC_2)\\ z = 3 + 0.1y - 0.1y^2 + 0.2xy\end{gathered} \tag{23}$$

$$\begin{gathered}TBN=f(PC_1,PC_2)\\ z = 8.21 - 0.1x - 0.1x^2 - 0.1y^2\end{gathered} \tag{24}$$

Table 6. shows the values of the criteria for evaluation of the models obtained from Dev3 data. When predicting kinematic viscosity and total alkalinity, the values of the coefficient of determination are lower than 0.5. High error rates indicate that the obtained models do not describe the experimental data with sufficient accuracy. Although for the models p <0.01, the value of the Fisher test is much higher than the critical one (F >> Fcr), which also proves that the models are not suitable for describing the experimental data. In the model for

predicting the motor lubricating oils color, the coefficient of certainty is above 0.5. The low value of errors indicates that the color of the samples can be predicted with this device, with an accuracy of up to 69%.

Table 6. Criteria for evaluating the obtained models for Dev3

Model	R^2	F	p-value	SE
$KV=f(PC_1,PC_2)$	0,46	F(3,54)=15.46 Fcr=2.78	<0.00	2.07
$L=f(PC_1,PC_2)$	0,69	F(3,54)=41.42 Fcr=2.78	<0.00	0.33
$TBN=f(PC_1,PC_2)$	0,11	F(3,54)=2.15 Fcr=2.78	<0.1	1.81

The obtained models for Dev4 have the form:

$$KV=f(PC_1,PC_2)$$
$$z = 10.89 + 0.03x + 0.1y^2 - 0.001xy \quad (25)$$

$$L=f(PC_1,PC_2)$$
$$z = 3.14 + 0.1y - 0.1x^2 + 0.1y^2 \quad (26)$$

$$TBN=f(PC_1,PC_2)$$
$$z = 7.93 + 0.02x + 0.05y - 0.01x^2 \quad (27)$$

Table 7. shows the values of the criteria for evaluating the models obtained from Dev4 data. In the three models for predicting the three main characteristics of motor oils, the coefficient of certainty is above 0.5. The Fisher's criterion is close to its critical values for the respective degrees of freedom. This shows that the data obtained with the device are suitable for characteristics prediction with an accuracy of 75-84%.

Table 7. Criteria for evaluating the obtained models for Dev4

Model	R^2	F	p-value	SE
$KV=f(PC_1,PC_2)$	0.77	F(3,54)=6.82 Fcr=2.78	<0.00	1.35
$L=f(PC_1,PC_2)$	0.84	F(3,54)=9.07 Fcr=2.78	<0.00	0.24
$TBN=f(PC_1,PC_2)$	0.75	F(3,54)=5.82 Fcr=2.78	<0.00	0.95

The obtained results show that the models obtained from camera document data, when shooting with homogeneous light (Dev2), and those, obtained with a colorimeter (Dev4), describe with sufficient accuracy the experimental data. The images taken in ambient light and the color indices obtained from them are greatly affected by ambient noise. This is evidenced by the predictive models obtained and the lack of accuracy with which the experimental data and their poor predictive power are described.

Models obtained with a document camera in homogeneous lighting (Dev2) are about 5% more accurate than those obtained with the same device, but in daylight (Dev1).

Among the compared devices, the colorimeter (Dev4) shows the highest accuracy and repeatability of the results. An additional analysis of the models obtained from data gathered with this device was made.

Figure 2. shows a general view of the models obtained from data generated with Dev4 – colorimeter.

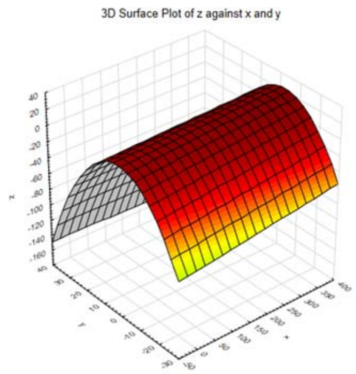

Figure 2. a) $KV=f(PC_1, PC_2)$

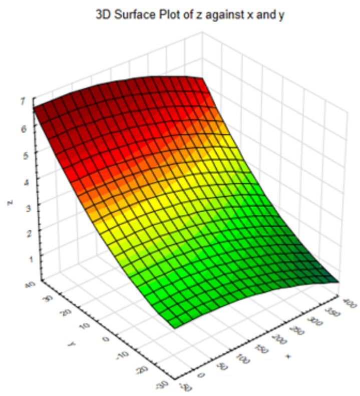

Figure 2. b) $L=f(PC_1, PC_2)$

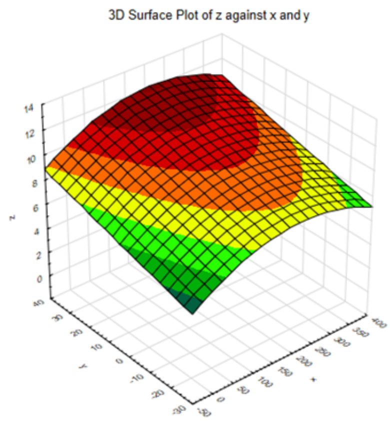

Figure 2. c) $TBN=f(PC_1, PC_2)$

Figure 2. Models obtained from Dev4 data – general view

The independent variables x and y plotted on the horizontal axis represent the first and second principal components. The dependent variable z is the predicted characteristic of motor oils.

The analysis of the residues of these models showed that they have a normal distribution and are close to the normal probability graph. According to this criterion, it can be judged that the requirements of the regression analysis are met.

In the present work, the advantage of using optical sensors in determination of motor oils basic characteristics has been proven. Sensors based on dielectric permittivity measurements often show low sensitivity in determining the characteristics of motor lubricants, as they are complex media [10].

The obtained better results for determining the color of motor oils, using a colorimeter, reaches 84%, compared to other devices used in the same analysis (video camera and digital camera). The results obtained complement the data found in the available literature. Kanyathare et al. [4] successfully apply a device developed by them, working on the same principle in the determination of contaminants in machine oil.

Spectrophotometric instruments operating on the principle of light transmission have been proposed for determining the color of a transformer Hadi et al. [3] and Heredia-Cancino et al. [11], whose accuracy reaches 99%. An advantage of the method, proposed in the present work for determining the color of the oil, is its accuracy of 84% and the lack of necessity of specialized equipment and cuvettes.

4. Conclusion

In the present work are proposed instruments for predicting the main characteristics of motor lubricating oils, such as color, viscosity, and total alkalinity, which are based on a set of ratios between color indices.

It has been found that the combined use of color indices leads to an increase in the accuracy of predicted values of the motor oils characteristics. It has been shown that seven color indices can be used to predict these characteristics. Reducing the amount of data of the vector containing these features requires two main components, which significantly reduce the amount of used data.

Analytical models have been created for automated prediction of the main characteristics of motor oils. The obtained data can be used to predict a change in their properties in a laboratory.

A comparative analysis of the predictive regression models for the main characteristics of motor lubricating oils was made. It was found that according to colorimeter data, these models have higher predictive properties than those obtained with a video camera and a digital camera.

In order to predict the characteristics of motor oils using a video camera, it is recommended to use homogeneous lighting.

The proposed methods of analysis can be used with single-board microcomputer systems because they do not require complex computational procedures.

The use of the methods and tools proposed in this study in the laboratory, offering partial automation, would reduce the influence of the subjective factor in conducting experiments.

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