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# INFLUENCE OF CONSUMABLES ON THE AMOUNT OF POWER CONSUMPTION OF KINEMATIC VAPOR OF CONFORMAL CONTACT

**Summary:** This paper presents a statistical analysis of the variation of electric power consumption of a tribological station as a consequence of the process of wear of kinematic vapor of conformal contact working in the presence of a consumable of a defined content. It contains the presentation of test conditions and design of a test rig. Tribological tests were carried out at a room temperature for one velocity of relative motion. Determined was the influence of concentration of a selected consumable in SN-150 oil base on the variation of electric consumption of a tribotester. The statistical analysis was carried out on the basis of R software.

**Key words:** surface texture, surface layer, base oil, oil additives, consumable, electric power

## 1. INTRODUCTION

The object of research of this paper is the process of wear of samples with conformal contact ongoing in the presence of a consumable of a defined content. In order to find out its course tests were carried out on a tribological wear test rig. The object of the test were samples in the shape of a cube. A counter sample was in the form of a flat ring-shaped plate.

The fulfilment of set functions by each kinematic vapor in the operating process requires the supply of energy. Part of that energy is used for the implementation of tasks, yet another part constitutes the loss of energy. The efficiency of kinematic vapor depends on the relation between the two parts. Because a defined fixed amount of energy is necessary for the realization of a specific function, hence as a result of monitoring the energy consumption by the system it is possible to observe its loss of energy. Thus, the course of power input is coupled, as it were, with the course of operating temperature of mating elements. Therefore, to describe the impact of tested consumables on the intensity of the wear process, taken was the consumption of electric power and its variation in the function of the path of friction. A smaller power input is equivalent to lower temperatures of the tribological system – the loss of energy resulting from the friction work is smaller. In presented tests, a 3-phase asynchronous cellular electric motor was applied for the drive of a tribotester.

## 2. TEST CONDITIONS

Values, which constitute the set of input factors, were selected on the basis of gathered literature information and preliminary tests:

- average relative motion velocity $V_{śr}$,
- type of lubricating composition.

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The average velocity of relative motion during the tests amounted to: 9.6 m·min$^{-1}$ (0.16 m·s$^{-1}$). Samples with a counter sample were mating at the external load of 600N which – for the contact surface of samples with a counter sample amounting to 300 mm$^2$ – corresponds to the theoretical pressure in the contact zone of 2.0 MPa.

Taking into account the material of samples and counter sample, the following hardness of samples was adopted: 40 HRC, and for a counter sample: 60 HRC.

As additives to SN-150 oil base selected were consumables: Motor Life and Mind M. For their selection the following criteria were used: availability, operations mechanism, purpose. Apart from that no research was found in the analyzed literature as regards testing of a lubricating compound consisting of consumables mentioned above. The first mentioned consumable is widespread in Poland. It causes the modification of the surface layer by creating a boundary layer as a result of physisorption and chemisorption. It contains synthetic base components, anti-wear additives, antioxidants, extreme pressure additives. Whereas Mind M constitutes a hydrocarbon complex which combines chemically with the metal of the base forming a microscopic monomolecular layer which cannot be washed out. It distributes the pressure force on a greater surface thereby increasing the durability of construction materials. It interacts with the metallic base (ferrous or non-ferrous) mainly in places of an increased temperature of the friction process [11, 12].

Producers of consumables mentioned above recommend their 5% concentration in the oil base. In order to learn more about their operation, both lower than this value and higher concentration values were used in this paper. The following concentrations were used: 0% (pure oil base); 0.5%; 1%; 2%; 5% and 7% of tested additive in the oil base. The third consumable was a composition consisting of Motor Life and Mind M in a 1:1 ratio of concentrations: 0.5%; 2%; 5% and 7%.

On the basis of literature information, for the set of output factors taken were values which characterize the wear process, including the power input P [kW] of a tribotester, whose statistical analysis prepared in R software is presented below.

Constant factors in the tests included the construction material of samples, i.e. steel 102Cr6 (NC6). This steel is characterized by, inter alia, a small hardness straggling after heat treatment, therefore in order that hardness of samples be within a narrow range, this material was selected for testing. Samples were in the shape of a cube measuring 10 × 10 × 10 [mm].

The following constant factors were adopted:

- material of a counter sample (steel X210Cr12 – formerly NC11),
- hardness (H) of a counter sample (60±2 HRC),
- state of the surface texture of a counter sample (periodically controlled),
- conditions of treatment of tested elements (ground surface),
- path of friction L = 2000 m,
- operating temperature (the temperature in which transformation of the surface layer proceeded) equal to the ambient temperature: 20ºC,
- pressure force of a counter sample onto samples F = 600 N.

Random, uncontrolled input factors – disturbances include inter alia:

- vibrations resulting from deviations of structure elements of the test rig,
- contamination of the work environment,
- diversification of the surface texture of samples caused for example by the process of wear of tools during the treatment,
- variation of the pressure force resulting from the installation deviation of the spring deflection as well as progressive wear of samples,
- samples hardness straggling caused for instance by segregation of the samples material in its whole volume.

Tests were carried out on the rig presented in Fig. 1. Tested samples were fixed in three grooves every 120° on the face of the bush stabilizing samples in order to ensure a reliable and uniform three-surface pressure of mating elements.

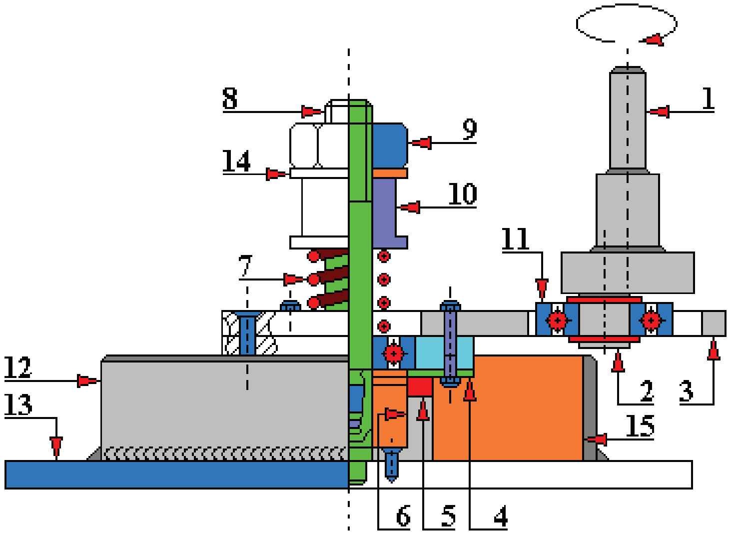


Fig. 1. Structural form of the test rig: 1 – eccentric handle, 2 – eccentric, 3 – lever, 4 – counter sample, 5 – tested samples, 6 – samples stabilizing bush, 7 – spring, 8 – central screw, 9 – nut, 10 – distance bush, 11 – single-row ball bearing, 12 – pipe jacket, 13 – steel plate of the base, 14 – washer, 15 – tested lubricating compound

Rys. 1. Postać konstrukcyjna stanowiska badawczego: 1 – uchwyt mimośrodu, 2 – mimośród, 3 – dźwignia, 4 – przeciwpróbka, 5 – badane próbki, 6 – tuleja ustalająca próbki, 7 – sprężyna, 8 – śruba centralna, 9 – nakrętka, 10 – tuleja dystansowa, 11 – łożysko kulkowe jednorzędowe, 12 – płaszcz rury, 13 – płyta stalowa podstawy, 14 – podkładka, 15 – badana kompozycja smarowa

## 3. TEST RESULTS

For the relative motion velocity $V_1 = 0.16\ m \cdot s^{-1}$, the path of friction L = 2000 m was reached after 200 minutes. The measurement of power input was carried out every one second. Thus, 200 × 60 = 12000 measurements were made for each concentration of a tested consumable. These data were implemented into R software in order to generate a box plot (Fig. 2).

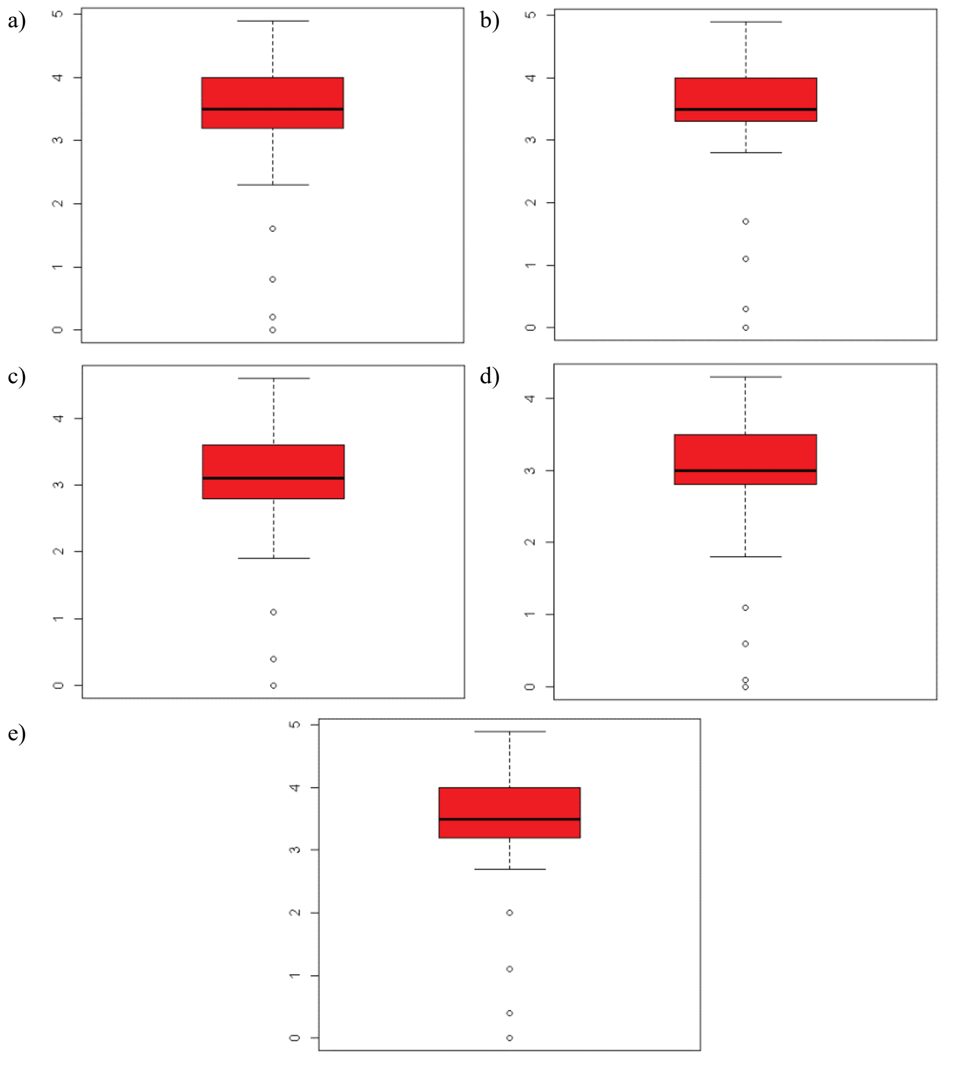


Fig. 2. A box plot generated in R software referring to the power input for the Composition consumable. Relative motion velocity V = 0.16 m·s$^{-1}$, path of friction L = 2000 m; on the vertical axle – power consumption in [kW]: a) 100% SN-150 (pure oil base), b) 0.5% Composition consumable, c) 2% Composition consumable, d) 5% Composition consumable, e) 7% Composition consumable

Rys. 2. Wykres pudełkowy wygenerowany w programie R dotyczący poboru mocy dla PE Kompozycja. Prędkość ruchu względnego V = 0,16 m·s$^{-1}$, droga tarcia L = 2000 m; na osi pionowej – pobór mocy w [kW]: a) 100% SN-150 (czysta baza olejowa), b) 0,5% PE Kompozycja, c) 2% PE Kompozycja, d) 5% PE Kompozycja, e) 7% PE Kompozycja

In order to analyze the obtained results, the following statistical parameters were calculated, using R software, for measured values of the power input:

- Min – minimum value,
- 1stQu. – lower (first) sample quartile ($Q_1$),

- Median – median ('medial value' ($Q_2$),
- Mean – arithmetic mean,
- 3rdQu. – upper (third) sample quartile ($Q_3$),
- Max – maximum value,
- IQR – interquartile range,
- R – sample range,
- s – standard deviation,
- $d_1$ – average deviation from the mean value.

Statistical parameters mentioned above are tabulated in Table 1.

Table 1. List of selected statistical parameters for measured power consumptions for the Composition consumable. Relative motion velocity V = 0.16 m·s$^{-1}$, path of friction L = 2000 m
Tabela 1. Zestawienie wybranych parametrów statystycznych dla zmierzonych poborów mocy dla PE Kompozycja. Prędkość ruchu względnego V = 0,16 m·s$^{-1}$, droga tarcia L = 2000 m

| | Min | 1stQu. | Median | 3rdQu. | Max | IQr | R | s | $d_1$ | Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| 0% | 0.0 | 3.2 | 3.5 | 4.0 | 4.9 | 0.8 | 4.9 | 0.486 | 0.412 | 3.577 |
| 0.5% | 0.0 | 3.3 | 3.5 | 4.0 | 4.9 | 0.7 | 4.9 | 0.434 | 0.367 | 3.621 |
| 2% | 0.0 | 2.8 | 3.1 | 3.6 | 4.6 | 0.8 | 4.6 | 0.478 | 0.408 | 3.187 |
| 5% | 0.0 | 2.8 | 3.0 | 3.5 | 4.3 | 0.7 | 4.3 | 0.444 | 0.383 | 3.146 |
| 7% | 0.0 | 3.2 | 3.5 | 4.0 | 4.9 | 0.8 | 4.9 | 0.469 | 0.404 | 3.500 |

In order to determine a possible dependence between individual power inputs of the system (tribotester) for given concentrations of tested Composition consumable, correlations were calculated using the Pearson's and Spearman's method. It was assumed at the same time that results have a normal distribution. If correlation values are close to 1 or –1 value, then variables are dependent. If correlation values are close to 0 value, then we deal with independent variables. Results are presented in Table 2.

Table 2. Results of correlation between individual power inputs of the tribological system for defined concentrations of Composition consumable. Relative motion velocity V = 0.16 m·s$^{-1}$, path of friction L = 2000 m
Tabela 2. Wyniki korelacji pomiędzy poszczególnymi poborami mocy układu tribologicznego dla określonych stężeń PE Kompozycja. Prędkość ruchu względnego V = 0,16 m·s$^{-1}$, droga tarcia L = 2000 m

<table>
<tr><th></th><th colspan="2">Pearson</th><th colspan="2">Spearman</th></tr>
<tr><td>0%</td><td rowspan="2">0.01</td><td></td><td rowspan="2">0.00</td><td></td></tr>
<tr><td>0.5%</td><td rowspan="2">-0.01</td><td rowspan="2">-0.01</td></tr>
<tr><td>2%</td><td rowspan="2">0.00</td><td rowspan="2">0.00</td></tr>
<tr><td>5%</td><td rowspan="2">0.00</td><td rowspan="2">0.00</td></tr>
<tr><td>7%</td><td></td><td></td></tr>
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A similar procedure was adopted for the next consumable – Motor Life. Measured power input data were implemented into R software in order to generate a box plot – Fig. 3.

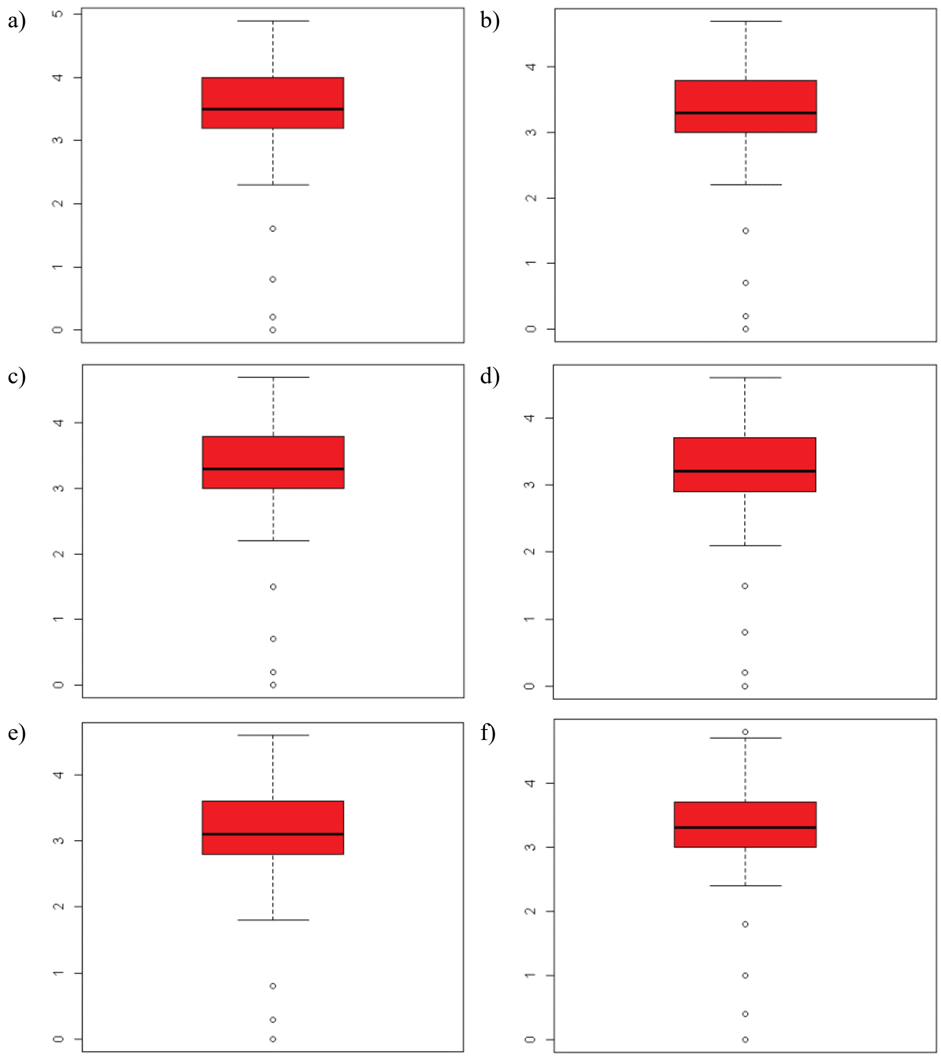


Fig. 3. A box plot generated in R software referring to the power input for Motor Life consumable. Relative motion velocity $V = 0.16\ m \cdot s^{-1}$, path of friction $L = 2000$ m; on the vertical axle – power consumption in [kW]: a) 100% SN-150 (pure oil base), b) 0.5% Motor Life, c) 1% Motor Life, d) 2% Motor Life, e) 5% Motor Life, f) 7% Motor Life

Rys. 3. Wykres pudełkowy wygenerowany w programie R dotyczący poboru mocy dla PE Motor Life. Prędkość ruchu względnego $V = 0{,}16\ m \cdot s^{-1}$, droga tarcia $L = 2000$ m; na osi pionowej – pobór mocy w [kW]: a) 100% SN-150 (czysta baza olejowa), b) 0,5% PE Motor Life, c) 1% PE Motor Life, d) 2% PE Motor Life, e) 5% PE Motor Life, f) 7% PE Motor Life

In order to analyze the obtained results the selected statistical parameters were calculated, using R software, for measured values of the power input. Statistical parameters mentioned above are tabulated in Table 3.

Table 3. List of selected statistical parameters for measured values of power input for Motor Life consumable. Relative motion velocity V = 0.16 m·s$^{-1}$, path of friction L = 2000 m
Tabela 3. Zestawienie wybranych parametrów statystycznych dla zmierzonych wartości poboru mocy dla PE Motor Life. Prędkość ruchu względnego V = 0,16 m·s$^{-1}$, droga tarcia L = 2000 m

| | Min | 1stQu. | Median | 3rdQu. | Max | IQr | R | s | $d_1$ | Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| 0% | 0.0 | 3.2 | 3.5 | 4.0 | 4.9 | 0.8 | 4.9 | 0.486 | 0.412 | 3.577 |
| 0.5% | 0.0 | 3.2 | 3.4 | 3.8 | 4.8 | 0.6 | 4.8 | 0.425 | 0.355 | 3.498 |
| 1% | 0.0 | 3.0 | 3.3 | 3.8 | 4.7 | 0.8 | 4.7 | 0.461 | 0.391 | 3.413 |
| 2% | 0.0 | 2.9 | 3.2 | 3.7 | 4.6 | 0.8 | 4.6 | 0.490 | 0.424 | 3.281 |
| 5% | 0.0 | 2.8 | 3.1 | 3.6 | 4.6 | 0.8 | 4.6 | 0.513 | 0.443 | 3.205 |
| 7% | 0.0 | 3.0 | 3.3 | 3.7 | 4.8 | 0.7 | 4.8 | 0.471 | 0.402 | 3.369 |

In order to determine a possible dependence between individual power inputs of the system (tribotester) for given concentrations of tested Motor Life consumable, correlations were calculated using the Pearson's and Spearman's method. Results are presented in Table 4.

Table 4. Results of correlation between individual values of power inputs of the tribological system for defined concentrations of Motor Life consumable. Relative motion velocity V = 0.16 m·s$^{-1}$, path of friction L = 2000 m
Tabela 4. Wyniki korelacji pomiędzy poszczególnymi wartościami poboru mocy układu tribologicznego dla określonych stężeń PE Motor Life. Prędkość ruchu względnego V = 0,16 m·s$^{-1}$ droga tarcia L = 2000 m

<table>
<tr><th></th><th colspan="2">Pearson</th><th colspan="2">Spearman</th></tr>
<tr><td>0%</td><td rowspan="2">0.04</td><td></td><td rowspan="2">0.03</td><td></td></tr>
<tr><td>0.5%</td><td rowspan="2">0.01</td><td rowspan="2">0.00</td></tr>
<tr><td>1.0%</td><td rowspan="2">0.03</td><td rowspan="2">0.02</td></tr>
<tr><td>2%</td><td rowspan="2">-0.03</td><td rowspan="2">-0.05</td></tr>
<tr><td>5%</td><td rowspan="2">0.01</td><td rowspan="2">0.01</td></tr>
<tr><td>7%</td><td></td><td></td></tr>
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The last consumable for which tests were conducted was Mind M for which measured data of power consumption were implemented into R software in order to generate a box plot – Fig. 4.

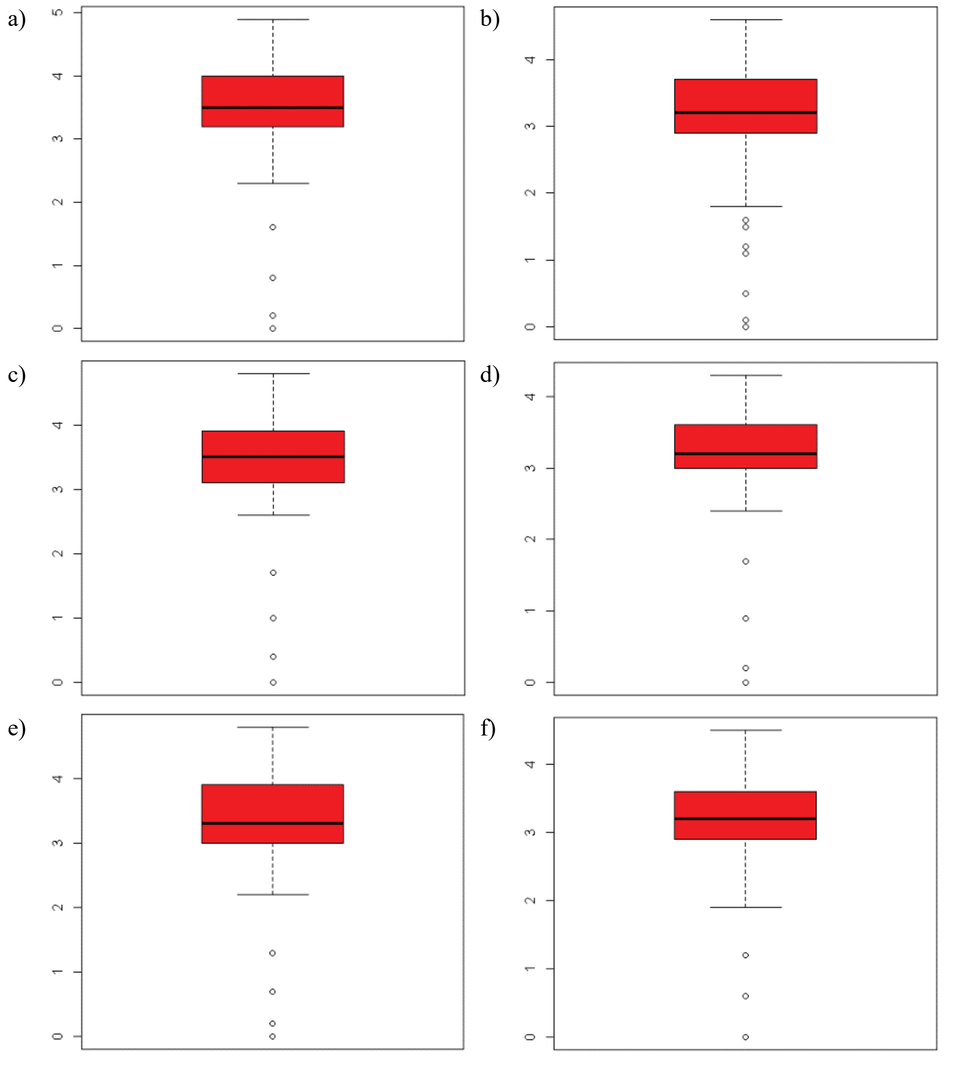


Fig. 4. A box plot generated in R software referring to the power input for Mind M consumable. Relative motion velocity V = 0.16 $m \cdot s^{-1}$, path of friction L = 2000 m; on the vertical axis – electric power [kW]: a) 100% SN-150 (pure oil base), b) 0.5% Mind M consumable, c) 1% Mind M consumable, d) 2% Mind M consumable, e) 5% Mind M consumable, f) 7% Mind M consumable

Rys. 4. Wykres pudełkowy wygenerowany w programie R dotyczący poboru mocy dla PE Mind M. Prędkość ruchu względnego V = 0,16 $m \cdot s^{-1}$, droga tarcia L = 2000 m; na osi pionowej – pobór mocy w [kW]: a) 100% SN-150 (czysta baza olejowa), b) 0,5% PE Mind M, c) 1% PE Mind M, d) 2% PE Mind M, e) 5% PE Mind M, f) 7% PE Mind M

In order to analyze the obtained results the selected statistical parameters were calculated, using R software, for measured values of the power input. Statistical parameters mentioned above are tabulated in Table 5.

Table 5. List of selected statistical parameters for measured power inputs for Mind M consumable. Relative motion velocity V = 0.16 m·s$^{-1}$, path of friction L = 2000 m

Tabela 5. Zestawienie wybranych parametrów statystycznych dla zmierzonych wartości poboru mocy dla PE Mind M. Prędkość ruchu względnego V = 0,16 m·s$^{-1}$, droga tarcia L = 2000 m

| | Min | 1stQu. | Median | 3rdQu. | Max | IQr | R | s | $d_1$ | Mean |
|---|---|---|---|---|---|---|---|---|---|---|
| 0% | 0.0 | 3.2 | 3.5 | 4.0 | 4.9 | 0.8 | 4.9 | 0.486 | 0.412 | 3.577 |
| 0.5% | 0.0 | 2.9 | 3.2 | 3.7 | 4.6 | 0.8 | 4.6 | 0.523 | 0.443 | 3.298 |
| 1% | 0.0 | 3.1 | 3.5 | 3.9 | 4.8 | 0.8 | 4.8 | 0.479 | 0.401 | 3.527 |
| 2% | 0.0 | 3.0 | 3.2 | 3.6 | 4.3 | 0.6 | 4.3 | 0.355 | 0.300 | 3.320 |
| 5% | 0.0 | 3.0 | 3.3 | 3.9 | 4.8 | 0.9 | 4.8 | 0.498 | 0.429 | 3.453 |
| 7% | 0.0 | 2.9 | 3.2 | 3.6 | 4.5 | 0.7 | 4.5 | 0.419 | 0.356 | 3.260 |

In order to determine a possible dependence between individual power consumptions of the system (tribotester) for given concentrations of tested Mind M consumable, correlations were calculated using the Pearson's and Spearman's method, similarly as for Composition and Motor Life consumables. Results are presented in Table 6.

Table 6. Results of correlation between individual values of power inputs of the tribological system for defined concentrations of Mind M consumable. Relative motion velocity V = 0.16 m·s$^{-1}$, path of friction L = 2000 m

Tabela 6. Wyniki korelacji pomiędzy poszczególnymi wartościami poboru mocy układu tribologicznego dla określonych stężeń PE Mind M. Prędkość ruchu względnego V = 0,16 m·s$^{-1}$, droga tarcia L = 2000 m

<table>
<tr><th></th><th colspan="2">Pearson</th><th colspan="2">Spearman</th></tr>
<tr><td>0%</td><td rowspan="2">0.05</td><td></td><td rowspan="2">0.04</td><td></td></tr>
<tr><td>0.5%</td><td rowspan="2">0.02</td><td rowspan="2">0.01</td></tr>
<tr><td>1.0%</td><td rowspan="2">0.06</td><td rowspan="2">0.05</td></tr>
<tr><td>2%</td><td rowspan="2">0.04</td><td rowspan="2">0.03</td></tr>
<tr><td>5%</td><td rowspan="2">-0.01</td><td rowspan="2">-0.03</td></tr>
<tr><td>7%</td><td></td><td></td></tr>
</table>

If the value of power input for SN-150 pure oil base is taken as:

$$P_{100\%SN-150} = 1.0 \text{ (lub 100\%)}$$

then the values of power consumption for individual concentrations of tested consumables shall be as those presented Tables 7–9.

Table 7. Presentation of relative variations of power input for individual concentrations of Composition consumable against pure oil base. Relative motion velocity V = 0.16 m·s$^{-1}$, path of friction L = 2000 m

Tabela 7. Zestawienie względnych zmian poboru mocy dla poszczególnych stężeń PE Kompozycja względem czystej bazy olejowej. Prędkość ruchu względnego V = 0,16 m·s$^{-1}$, droga tarcia L = 2000 m

| | Mean [kW] | $x/P_{100\%SN-150}$ | [%] |
|---|---|---|---|
| 0% | 3.577 | 1.0 | 100% |
| 0.5% | 3.621 | 1.012 | 101.2% |
| 2% | 3.187 | 0.891 | 89.1% |
| 5% | 3.146 | 0.879 | 87.9% |
| 7% | 3.500 | 0.978 | 97.8% |

Table 8. Presentation of relative variations of power input for individual concentrations of Motor Life consumable against pure oil base. Relative motion velocity V = 0.16 $m \cdot s^{-1}$, path of friction L = 2000 m

Tabela 8. Zestawienie względnych zmian poboru mocy dla poszczególnych stężeń PE Motor Life względem czystej bazy olejowej. Prędkość ruchu względnego V = 0,16 $m \cdot s^{-1}$, droga tarcia L = 2000 m

| | Mean [kW] | $x/P_{100\%SN-150}$ | [%] |
|---|---|---|---|
| 0% | 3.577 | 1.0 | 100% |
| 0.5% | 3.498 | 0.978 | 97.8% |
| 1% | 3.413 | 0.954 | 95.4% |
| 2% | 3.281 | 0.917 | 91.7% |
| 5% | 3.205 | 0.896 | 89.6% |
| 7% | 3.369 | 0.942 | 94.2% |

Table 9. Presentation of relative variations of power input for individual concentrations of Mind M consumable against pure oil base. Relative motion velocity V = 0.16 $m \cdot s^{-1}$, path of friction L = 2000 m

Tabela 9. Zestawienie względnych zmian poboru mocy dla poszczególnych stężeń PE Mind M względem czystej bazy olejowej. Prędkość ruchu względnego V = 0,16 $m \cdot s^{-1}$, droga tarcia L = 2000 m

| | Mean [kW] | $x/P_{100\%SN-150}$ | [%] |
|---|---|---|---|
| 0% | 3.577 | 1.0 | 100% |
| 0.5% | 3.298 | 0.922 | 92.2% |
| 1% | 3.527 | 0.986 | 98.6% |
| 2% | 3.320 | 0.928 | 92.8% |
| 5% | 3.453 | 0.965 | 96.5% |
| 7% | 3.260 | 0.911 | 91.1% |

## 4. SUMMARY

The following conclusions can be formulated upon the analysis of obtained characteristics of variations of electric power consumption during the process of friction:

- A reduction of power input, in relation to pure oil base, by ca. 12% was noted for 5% Composition consumable concentration (Table 7);
- A reduction of power input, in relation to pure oil base, by ca. 10% was noted for 5% Motor Life consumable concentration (Table 8);
- A reduction of power input, in relation to pure oil base, by ca. 9% was noted for 7% Mind M consumable concentration (Table 9);
- For Composition, Motor Life and Mind M consumables there are few outliers (Fig. 2, 3 and 4), mainly during the start-up (power-up) of tribotester;
- If the power consumption variation is accepted as a certain feature of tested consumables, then it should be concluded that for a relative motion velocity V = 0.16 m/sec there is a beneficial synergism between Motor Life and Mind M consumables. This is reflected by the reduction of power consumption for Composition consumable by as much as ca. 12% for 5% concentration (Table 7);
- The analysis of results of correlation between individual values of power consumption (Table 2, 4 and 6) proves there is no dependence between them.

The analysis of power input by frictional vapor is an important feature of a lubricant. In literature, mainly the variations of the surface layer or changes of surface texture of mating elements are analyzed, which of course is important. However, the analysis of power input by tribological systems practically cannot be found, which seems to be some kind of oversight while assessing tribological properties of a given lubricant. Of course, there will be different power inputs for different tribotesters, but there will always be a certain extremum (minimum or maximum) for tested concentrations.
This lubricant has better lubricating properties in given conditions, for which the smallest electric power inputs were observed.

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## WPŁYW PE NA POBÓR MOCY PARY KINEMATYCZNEJ O STYKU KONFOREMNYM

**Streszczenie:** W artykule przedstawiono analizę statystyczną zmiany poboru mocy elektrycznej stanowiska tribologicznego w wyniku procesu zużywania pary kinematycznej o styku konforemnym, pracującej w obecności preparatu eksploatacyjnego PE o zdefiniowanym składzie. Omówiono warunki badań oraz budowę stanowiska badawczego. Badania tribologiczne wykonano w temperaturze pokojowej dla jednej prędkości ruchu względnego. Określono wpływ stężenia wybranego PE w bazie olejowej SN-150 na zmianę poboru mocy elektrycznej tribotesteru dla wybranej prędkości ruchu względnego. Analizę statystyczną wykonano w oparciu o program R.

**Słowa kluczowe:** struktura geometryczna powierzchni, warstwa wierzchnia, olej bazowy, dodatki do olejów, preparat eksploatacyjny, moc elektryczna