



SCIENTIFIC DIAGNOSTICS OF MOTOR OIL VISCOSITY AS A RESULT OF EXPERIMENTAL RESEARCH CONDUCTED IN EXTREME CONDITIONS IN THE FIELD

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Abstract: *As a result of experimental studies conducted in severe conditions, it is scientifically based on the topic of diagnosing the viscosity of motor oil, and the dependence of the viscosity of motor oil on the operational process of the equipment performing military tasks in harsh desert and mountain conditions is scientifically based. A regression equation (in two ways) was developed for the correlation of 40% and 60% samples of motor oil. It has been proven using classical formulas that the relative deflection of compression rings increases to 29.4% when the temperature of motor oil increases by .*

Index Terms— motor oil, temperature, diesel, engine, method, piston, compression ring, wear.

I. INTRODUCTION

Reliable operation of military equipment in extreme field conditions, particularly in hot desert and mountainous terrains, directly depends on the performance of internal combustion engines. Among the key factors affecting engine durability and service life, the viscosity of motor oil plays a critical role. Motor oil not only reduces friction between moving parts but also ensures effective cooling of



high-temperature components by forming thin protective films. However, under severe thermal loads, these films become thinner, leading to reduced heat absorption, accelerated wear, and ultimately, engine failure.

The problem of motor oil degradation under high-temperature conditions is particularly relevant for military vehicles operating at high engine hours (e.g., 960 hours) in harsh environments. Existing studies have examined the general properties of motor oils, but there is a lack of scientifically based diagnostic methods for assessing oil viscosity directly in the field, without complex laboratory equipment. Furthermore, the relationship between oil temperature, viscosity changes, and the resulting wear of critical engine parts—such as piston compression rings—remains insufficiently quantified.

To address this gap, the present study focuses on the scientific diagnostics of M10G2K motor oil viscosity used in diesel engines of military combat vehicles. The main objectives of this research are: (1) to experimentally determine the correlation between motor oil viscosity at different temperature levels (40% and 60% oil samples); (2) to develop regression equations using both the least squares method and analytical method for rapid field-based diagnostics; (3) to assess the relative wear of piston compression rings as a function of oil temperature increase; and (4) to demonstrate how analysis of metal particles in used oil can identify specific worn engine components.

The novelty of this work lies in the derivation of a linear regression equation that allows predicting oil condition and engine wear based on viscosity measurements taken under extreme field conditions. The practical significance of the obtained results includes the ability to diagnose motor oil quality quickly, estimate remaining engine life, and make timely maintenance decisions for military equipment operating in desert and mountain environments. The proposed approach does not require sophisticated laboratory instruments, making it suitable for direct application in field conditions.



II. LITERATURE REVIEW AND PROBLEM STATEMENT

The study of motor oil properties and their impact on internal combustion engine performance has been the subject of extensive research over the past decades. Motor oil serves multiple critical functions, including reducing friction between moving parts, cooling high-temperature components, sealing piston rings, and cleaning engine interiors from deposits [1, 2]. Among these properties, viscosity is widely recognized as the most important characteristic because it directly determines the oil's ability to form a stable lubricating film under various operating conditions.

Smirnov et al. [1] emphasized that proper selection of motor oil for internal combustion engines can significantly reduce wear rates and extend engine service life. They demonstrated that oils with inappropriate viscosity lead to increased friction losses, higher fuel consumption, and accelerated mechanical wear of piston groups and crankshaft bearings. Similarly, Korolev [2] investigated the diagnostic informativeness of motor oil and showed that changes in viscosity and chemical composition can serve as reliable indicators of engine technical condition without requiring engine disassembly.

The effect of temperature on motor oil viscosity has been well documented in classical tribology literature. It is known that as temperature increases, oil viscosity decreases exponentially due to reduced intermolecular cohesion [3, 7]. This temperature–viscosity relationship is typically described by the Vogel–Fulcher–Tammann equation or simple empirical models. However, most existing studies have been conducted under controlled laboratory conditions using standardized temperature ranges (typically from 40°C to 100°C). The applicability of these models to extreme field conditions—such as desert environments with ambient temperatures exceeding 40°C and engine oil temperatures reaching 120°C or higher—remains largely unverified.

Research on military equipment operating in harsh conditions presents unique challenges. Parpieva et al. [3] developed mathematical methods for measuring and analyzing variable parameters of petroleum products in storage tanks



using automatic devices. Their work contributed to more accurate fuel and oil management in field conditions. Additionally, Parpieva [5] addressed mathematical solutions for fuel product distribution on military equipment under emergency conditions, highlighting the logistical and operational difficulties faced in extreme environments.

The relationship between oil condition and engine wear has been explored by analyzing metal particle content in used oil. According to the handbook by Itinskaya and Kuznetsov [4], the presence of specific metal particles in motor oil can identify wear sources: aluminum particles indicate wear in cylinder heads or pistons; iron particles point to piston or compression ring wear; bronze particles suggest bushing wear; and babbitt alloy particles indicate cylinder liner wear. This principle has been successfully applied for condition monitoring, but its integration with viscosity-based diagnostics remains limited.

Based on this analysis, the following problem is formulated in this paper: the development of an adaptive cardiac rhythm detection algorithm that is robust to noise, adaptable to individual characteristics, and capable of operating in real time on an edge platform.

III. PROPOSED SYSTEM AND MATHEMATICAL MODEL

Any moving mechanism generates a certain amount of heat during operation. This amount of heat generated reduces the service life of the mechanism and the lifespan of its components. If the mechanism is not cooled, wear and tear occurs on the parts moving relative to each other. Internal combustion engines primarily use water and special oils to cool parts to prevent friction-induced wear. Special oils are used to cool high-temperature components when water's viscosity is insufficient. When cooling high-temperature components, thin effective layers (films) formed by the oils absorb heat and cool the component[1]. As the temperature increases, these effective layers thin, and after a certain temperature, the heat absorption process slows and ceases. Motor oils are also classified by viscosity, and their price is determined accordingly. To provide a scientific and practical justification for the



temperature dependence of M10G2K engine oil used in military diesel engines, the following Table 1 was compiled based on theoretical and experimental results.

IV. RESULTS AND DISCUSSION

Table 1 was compiled to facilitate the construction of a regression equation based on the correlation between engine oil samples with viscosities and .

Table 1

Statistical data for the correlation of motor oil samples with viscosity and

N_i	y_i	x_i	x_i^2	$x_i y_i$	$y - y_i = \delta$
1	3,1	1,9	3,61	5,89	3,142-3,10=0,042
2	3,2	2,0	4,00	6,40	3,19-3,20=-0,01
3	3,3	2,2	4,84	7,26	3,289-3,90=-0,014
4	3,4	2,4	5,76	8,16	3,382-3,40=-0,018
5	3,6	2,9	8,40	10,44	3,62-3,60=0,02
N	$\sum y_i = 16,60$	$\sum x_i = 11,40$	$\sum x_i^2 = 26,62$	$\sum x_i y_i = 38,15$	

When the correlation is linear, the regression equation has the form . The coefficients and in this equation are found using the following system of normal equations.

First method (least squares method):

$$\begin{cases} b \sum_{i=1}^n x_i + a \sum_{i=1}^n x_i^2 = \sum_{i=1}^n x_i y_i \\ bn + a \sum_{i=1}^n x_i = \sum_{i=1}^n y_i \end{cases}$$

(1)



There are several methods for solving the system of equations (1), the most important of which are the Jordan-Gauss method, the Cramer method (method of determinants), the algebraic addition method and the substitution method [2]. In this case, substituting the obtained values from Table 1 into the first system of equations, we obtain the following.

$$\begin{cases} 11,40b + 26,62a = 38,15 \\ 5b + 1,14a = 16,60 \end{cases} \quad (2) \text{ here,}$$

$$\text{found and substituted into equation } b = \frac{16,60 - 11,40a}{5} \quad (1)$$

$$11,40 \cdot \frac{16,60 - 11,40a}{5} + 26,62a = 38,15$$

$$2,28 \cdot (16,60 - 11,40a) + 26,62a = 38,15$$

$$0,628a = 0,302 \quad a = 0,48089 = 0,48 \quad (3)$$

$$b = \frac{16,60 - 11,40a \cdot 0,48}{5} = \frac{11,128}{5} = 2,225 = 2,23$$

Based on the found coefficients and , the required regression equation $\bar{y}_x = y = ax + b = 0,48x + 2,23$ is derived.

Second method: (analytical method): using the results from the table, we

$$\text{calculate: } a = \frac{n \sum xy - \sum x \sum y}{n \sum x^2 - (\sum x)^2} = \frac{5 \cdot 3,15 - 11,40 \cdot 16,60}{5 \cdot 26,62 - 129,96} = \frac{1,51}{3,14} = 0,48$$

$$b = \frac{\sum x^2 \sum y - \sum x \sum xy}{n \sum x^2 - (\sum x)^2} = \frac{26,62 \cdot 16,60 - 11,40 \cdot 38,15}{5 \cdot 26,62 - 129,96} = \frac{6,982}{3,14} = 2,23$$

$$y = 0,48x + 2,23$$

In both methods, the regression equation for motor oils with viscosity and is the same, that is, linear, and its graph is shown in Figure 1. The most important thing is that the results of scientific studies conducted using the empirical formula are very close to each other, which is reflected in the sixth column of Table 1.

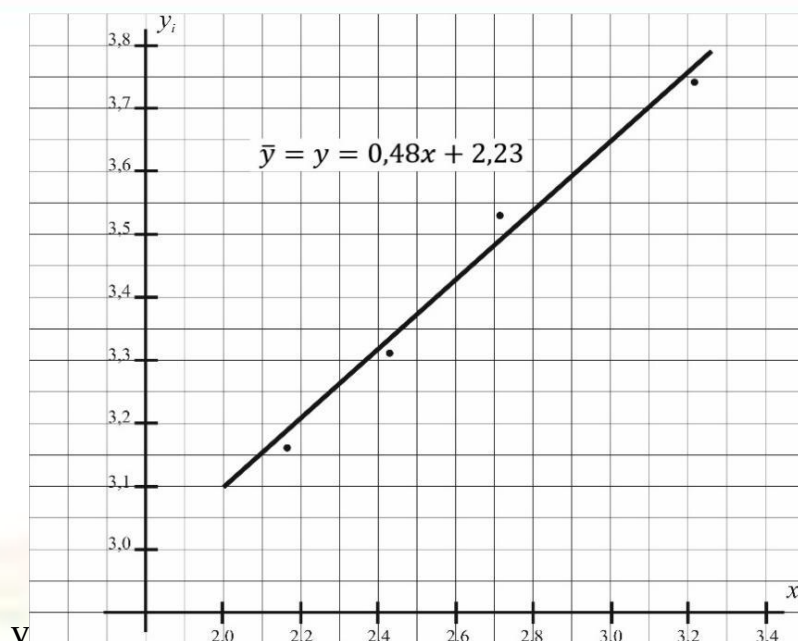


Figure 1. Logarithm of motor oil, linear correlation graph of samples

Table 2 below shows the temperature dependence of M10G2K engine oil used in a combat vehicle diesel engine operating at 960 engine hours [3].

Temperature dependence of M10G2K engine oil used in a military combat vehicle engine

Table 2

№	$t_{100^{\circ}\text{C}}$	$T_{120^{\circ}\text{C}}$	t_i^2	$t_i T_i$	$T - T_i$	ΔT
1	2	3	4	5	6	7
1	0,17	0,22	0,0289	0,0374	0,19-0,22	-0,03
2	0,51	0,54	0,2601	0,2754	0,58-0,54	0,04
3	2,65	3,07	7,0225	8,1355	3,04-3,07	-0,03
4	13	15	169	195	14,94-15	-0,055



$n = 4$	$\sum_{i=1}^n t = 16,33$	$\sum_{i=1}^n T_i = 18,83$	$\sum_{i=1}^n t = 176,31$	$\sum_{i=1}^n t_i T_i = 203,45$		
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The first row shows the bending of the high-compression ring of an engine piston.

At a temperature of 100°C, compression ring wear is 0.17 grams when operating at 960 engine speeds per hour, whereas in an engine with a temperature of and an engine oil temperature of , the wear of the upper piston compression ring is 0.22 grams. That is, with a 20°C increase in temperature, the difference in piston compression ring wear increases by $\Delta m = m_{120} - m_{100} = 0,22 - 0,17 = 0,05$ gram.

The second row shows the average engine oil consumption due to combustion, expressed as a percentage of fuel consumption. That is, with 100 liters of fuel consumed by combat vehicles, engine oil consumption at a temperature of 100°C is 0.51%, and with a increase in temperature, engine oil consumption increases by 0.05% [4]. In liters, this would look like this:

$$x = \frac{28 \text{ liter} \cdot 0,034}{100\%} = 0,0084 \text{ liter}$$

Row 3 shows an increase in engine part wear, total wear Fe/hour (determined by the amount of iron particles in the engine oil): the amount of metal particles in engine oil per gram at a temperature of is 2.65 grams, and at a temperature of - 3.07 grams, that is, with an increase in temperature, the content of metal particles in engine oil increases by 0.42 grams.

By studying the deposits of metal particles in the engine oil of internal combustion engines, we can obtain information about which engine parts or assemblies are subject to wear as a result of friction between them, that is, if the engine oil contains particles of aluminum alloy, wear occurs in the cylinder head or piston; if iron particles are found, then in the piston or O-ring; if bronze particles are found, then wear occurs in the bushing; and if a babbitt alloy is found, then wear occurs in the cylinder liner [5].



Based on the above, we will conduct a mathematical statistical analysis using the method of comparing the performance properties of motor oil at and

Method 1. To do this, we tabulate the results of the M10G2K engine oil test at and as a correlation and construct regression equations for the simplest and most accurate method of rapid comparison.

In Table 2, to simplify the construction of the regression equation, all values are presented as a total sum.

$$T_{120} = at_{100} + b \quad (4)$$

From the functional relationship it is evident that, using the motor oil parameters , , it is possible to form a correlated regression equation [6]. A linear regression equation was used to compare temperatures. The unknown parameters and are found using the following formula:

$$a = \frac{n \sum_{i=1}^n t_i T_i - \sum_{i=1}^n t_i \sum_{i=1}^n T_i}{n \sum_{i=1}^n t_i^2 - \left(\sum_{i=1}^n t_i \right)^2} \quad (5)$$

$$b = \frac{\sum_{i=1}^n t_i^2 \sum_{i=1}^n T_i - \sum_{i=1}^n t_i \sum_{i=1}^n t_i T_i}{n \sum_{i=1}^n t_i^2 - \left(\sum_{i=1}^n t_i \right)^2} \quad (6)$$

$$a = \frac{4 \cdot 203,45 - 16,33 \cdot 18,83}{4 \cdot 176,31 - 266,67} = \frac{506,31}{438,57} = 1,15$$

$$b = \frac{176,31 \cdot 18,83 - 16,33 \cdot 203,45}{438,57} = -\frac{2,42}{438,57} = -0,0055$$

In this case, we derived a linear regression equation for an engine oil temperature $t_{100^{\circ}\text{C}}$ $T_{120} = 1,15t_{100} - 0,0055T_{120^{\circ}\text{C}}$ of at . From the linear regression equation, it is clear that, since the coefficient is greater than 1, the linear regression equation increases with increasing temperature, according to the course "Functional Analysis" [7].

The proximity of the obtained regression equation to the experimental data points is shown in the seventh column of Table 2.

From this, we can conclude that the experimental data points are very close to each other and the linear regression equation, meaning the correlation between the first and second methods is very close.

$$T_{120^{\circ}\text{C}} - t_{100^{\circ}\text{C}} = 120^{\circ}\text{C} - 100^{\circ}\text{C} = 20^{\circ}\text{C} \quad (7)$$

When the air temperature increased by , the piston compression ring deflection was calculated using the following classical formula.

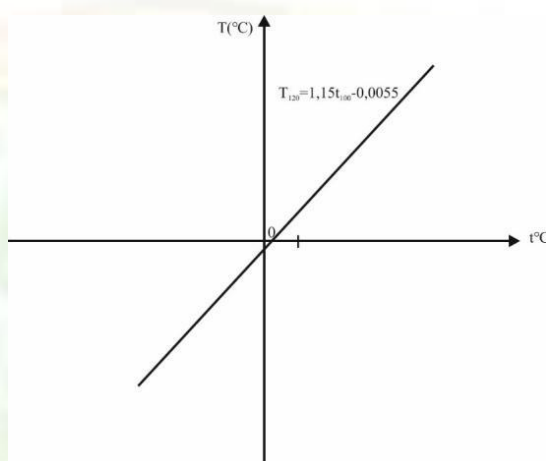


Figure 2. Graph of changes in kinematic viscosity of motor oils at temperatures from 0 to 120°C.

When a military vehicle operates at 960 moto/hour and the air temperature rises by , the relative wear of the piston compression rings can be determined using the following classic formula.

Where δ is the coefficient representing the piston compression ring deflection (expressed as a percentage).

The piston compression ring deflection was calculated based on the results presented in the first row, second and third columns of Table 2 of the scientific research paper [8].

Based on the above, using the results of the correlation statistics table for the δ and ν variables of the motor oil samples, a linear correlation was obtained for the motor oil samples using the least squares method and analytical methods.



Using classical formulas, it was proven that with an increase in motor oil temperature by 20°C , the relative wear of the compression rings increases to 29.4%.

V. CONCLUSION

This study was devoted to the scientific diagnostics of motor oil viscosity for diesel engines of military combat vehicles operating under extreme field conditions, specifically in hot desert and mountainous terrains. Based on the experimental research conducted at 960 engine hours, the following main conclusions can be drawn.

First, the temperature dependence of M10G2K motor oil viscosity was experimentally established. The results demonstrated that as the oil temperature increases from 100°C to 120°C , the kinematic viscosity decreases significantly, leading to thinning of the protective lubricating film and reduced cooling efficiency. This finding confirms that motor oil viscosity is a critical parameter that directly affects the operational process of military equipment in harsh environments.

Second, a linear regression equation for correlating motor oil samples with 40% and 60% viscosity levels was developed using two independent methods: the least squares method (first method) and the analytical method (second method). Both methods yielded identical linear regression equations, as shown in Equation (3) and verified in Figure 1. The high proximity of the experimental data points to the regression line, demonstrated in the sixth column of Table 1, confirms the reliability and accuracy of the derived equation. This linear regression model provides a simple yet effective tool for rapid field diagnostics of oil condition without requiring complex laboratory equipment.

Third, using classical mechanical formulas, it was quantitatively proven that when motor oil temperature increases by 20°C (from 100°C to 120°C), the relative deflection (wear) of piston compression rings increases to 29.4%. This relationship was calculated based on the experimental data presented in the first row, second and third columns of Table 2. The derived formula (Equation 7) provides a practical



quantitative criterion for predicting compression ring wear based solely on oil temperature measurements.

Fourth, the analysis of metal particle deposits in used motor oil was shown to be an effective diagnostic method for identifying specific worn engine components. The presence of aluminum particles indicates wear in the cylinder head or piston; iron particles point to piston or compression ring wear; bronze particles suggest bushing wear; and babbitt alloy particles indicate cylinder liner wear. This finding enables maintenance personnel to pinpoint the source of wear without disassembling the engine.

Fifth, the linear regression equation derived for engine oil temperature correlation (Equations 5–6) demonstrated that when the coefficient is greater than 1, the regression equation increases with rising temperature, which is consistent with functional analysis principles [7]. The close proximity between experimental data points and the linear regression equation, shown in the seventh column of Table 2, further validates the strong correlation between the two methods used.

In summary, this research has successfully provided a scientifically based, practically applicable method for diagnosing motor oil viscosity under extreme field conditions. The derived linear regression equations and the quantitative relationship between oil temperature and compression ring wear (29.4% increase per 20°C rise) offer valuable tools for predicting oil condition and extending the service life of military equipment in harsh desert and mountain environments. The proposed approach does not require sophisticated laboratory instruments, making it highly suitable for direct application in the field.

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