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EFFECT OF FATTY ACID CONCENTRATION IN THE WORKING FLUID OF MACHINE HYDRAULIC DRIVES ON BOUNDARY LUBRICATING FILM FORMATION

ВПЛИВ КОНЦЕНТРАЦІЇ ЖИРНИХ КИСЛОТ У РОБОЧІЙ РІДИНІ ГІДРОПРИВОДІВ МАШИН НА ФОРМУВАННЯ ГРАНИЧНОЇ МАСТИЛЬНОЇ ПЛІВКИ

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Abstract. An analysis of research regarding the effect of fatty acid additives on enhancing the anti-wear properties of working fluids was conducted. The characteristics and molecular state of the additive within the oil were identified as factors influencing the formation of a boundary lubricating film on friction surfaces. A method for intensifying additive adsorption by subjecting the working fluid to an electric field was proposed. A methodology was developed to experimentally investigate how the concentration of surfactant molecules – specifically the fatty acids under study – affects the formation of a lubricating layer on the friction surfaces of machinery hydraulic drives. Experimental studies were carried out to examine the effect of stearic and oleic acid concentrations on changes in boundary lubricating film thickness when the working fluid undergoes electrostatic treatment. A non-linear relationship between lubricating film thickness and additive concentration was established, and the optimal concentrations of stearic and oleic acids – yielding the maximum boundary lubricating film thickness – were determined.

Keywords: hydraulic drive, working fluid, friction surface, surfactant, lubricating film, electric field, film thickness.

Introduction.

Hydraulic drives and hydraulic transmissions have recently become widespread and are used to drive the working equipment of construction, track, and materials-handling machines. Owing to the high cost of these units and the considerable labor intensity of repair work, there is a need to develop and implement resource-saving technologies aimed at improving the design of these units and the characteristics of working fluids.

One of the most common ways to improve the anti-wear properties of working fluids is to add various additives, most of which are surfactants. Such molecules promote the formation of a more wear-resistant lubricating film, the thickness of which directly depends on their properties, state, and amount in the working fluid. However, because these substances possess an electric dipole moment, at a certain concentration they interact with one another and form supramolecular structures that are unable to form the required lubricating layer effectively. Surfactant molecules are also adsorbed not only on friction surfaces but also on components present in the working fluid (wear products and inorganic particles), which reduces their effective concentration and hinders efficient lubricating-film formation.

An effective method of activating the additive (breaking down aggregates of surfactant molecules) is treatment of the working fluid with an external electric field. Under such a field, the protective function of the working fluid is enhanced by reducing friction and wear losses

in hydraulic drives; wear of friction units in hydraulic machines is reduced, thereby increasing their service life.

However, the effect of fatty-acid concentration (stearic and oleic acids) in the working fluid on lubricating-film formation on the friction surfaces of hydraulic drives of construction and track machines under electrostatic treatment remains insufficiently established. Therefore, elucidating this process is a relevant scientific task.

Literature Review.

Boundary lubricating films of liquid media play an important role during friction between solid surfaces. The mechanism of their formation has been considered in numerous research studies [1–12] because it is of considerable practical interest. Liquid lubricating media that form a lubricating film are inherently multicomponent systems in which surfactants play a decisive role [2–4, 7]. The structure of these molecules is such that all of them possess an electric dipole moment, which enables interaction with metal surfaces. At the same time, the properties of the boundary lubricating film are also influenced by the structure of the metal surface because it forms its force field [3–8]. Thus, formation of the anti-wear layer on hydraulic-drive surfaces in contact with the lubricant depends on two main factors: the force field of the metal surface and the molecular structure of the surfactants.

In [11], a mathematical model (1) was proposed for determining lubricating-film thickness, taking into account the structure of the friction-surface material and the internal state of additive molecules in the working fluid.

$$H = b\sqrt{\frac{\left(1-2ee_0\frac{W_M}{p\sigma}\right)^2}{1-\left(1-2ee_0\frac{W_M}{p\sigma}\right)^2}}, \quad (1)$$

where H is the thickness of the lubricating film on the friction surfaces of machine hydraulic drives, m; W_M is the interaction energy between surfactant molecules depending on their state in the working fluid (monomers, dimers, micelles), J; p is the dipole moment of a surfactant molecule, C·m; σ is the surface charge density, C/m²; ε is the dielectric permittivity of the working fluid; ε_0 is the vacuum permittivity; b is the radius of the friction-surface contact area, m.

However, this mathematical model does not make it possible to construct an actual dependence of the effect of surfactant-molecule concentration on lubricating-layer formation, because the parameter W_M [11], calculated using equation (2), depends only on the critical micelle concentration of fatty-acid molecules (which is a constant for different surfactants) and on temperature.

$$W_M = \frac{RT\ln(CMC)}{N_a}, \quad (2)$$

where R is the Boltzmann constant, J·K⁻¹; N_a is the Avogadro constant, mol⁻¹; T is the fluid temperature, K; CMC is the critical micelle concentration of surfactant molecules, mol/L.

Analysis of studies [10–15] shows that the use of electric fields to control lubricant properties and increase the service life of technical systems is a promising research direction. The theoretical basis of this approach is provided by electrodynamics concepts concerning the interaction of an electric field with matter, polarization processes, and the behavior of matter in an electric field [10]. Application of these principles to technical systems is considered in [13], where electric and magnetic fields are regarded as means of purposefully influencing the processes that determine the service life of machine hydraulic drives.

The results of [11] indicate the difficulty of establishing a universal relationship between additive concentration and the effectiveness of electrical treatment. The optimum concentration is determined by the specific composition of the working fluid, the type of additive, the electrical-treatment mode, and the operating conditions of the hydraulic unit. Therefore, the obtained relationships require additional verification for other lubricants and hydraulic-drive designs.

The effect of liquid-crystal additive concentration and an electric field on the physicochemical properties of a lubricant was investigated in greater detail in [15]. The authors analyzed changes in the kinematic viscosity, viscosity index, and pour point of an industrial oil depending on the concentration of a liquid-crystal additive and exposure to an electric field [15]. The results demonstrate that additive introduction and electrical treatment can change oil characteristics; however, the effect is not unequivocally positive for all properties. Increasing the additive concentration may cause undesirable changes in certain operating characteristics.

A practical assessment of the applicability of electrostatic treatment to engine oil was carried out in [14]. Unlike laboratory studies, the authors conducted operational tests of an electrostatic engine-oil treatment device directly on an engine. This approach is of considerable practical importance because it enables the effectiveness of the technology to be evaluated under actual operating conditions of a technical system [14].

However, the results of operational tests should be considered with due regard to the limitations of the experimental basis. Device effectiveness depends on engine type, oil grade and condition, load mode, temperature, operating duration, and the design parameters of the electrostatic device. Therefore, results obtained for a specific technical system cannot be directly extended to other engine types or lubricants without additional studies [14].

An important complement to these studies is [12], which addresses the mechanisms of tribochemical-film formation on friction surfaces. Unlike [11], [14], and [15], which focus mainly on the effects of the electric field and additives on lubricant characteristics or on the technical system, [12] gives considerable attention to processes occurring directly at the friction surface. Investigation of polymethacrylate components demonstrated the possibility of forming thin tribochemical films on metal surfaces, the characteristics of which are associated with the anti-wear action of the lubricant [12].

This result broadens the understanding of the mechanism of additive action. Improvement in tribological characteristics may be associated not only with changes in viscosity or other bulk properties of the oil, but also with the formation of a protective layer on friction surfaces. At the same time, [12] does not directly investigate the effect of an electric field on lubricating-film formation. Therefore, the possible influence of an electric field on the formation rate, structure, and chemical composition of such films remains insufficiently studied.

Generalization of the results of [11], [12], [14], and [15] suggests a complex interaction among three main factors: lubricant composition, the electric field, and the friction surface. Changes in oil properties under the action of an electric field may affect surface-contact conditions, while the additive may alter the interaction between the lubricant and the metal. In turn, processes at the friction surface determine the actual wear level and service life of the technical unit.

At the same time, the reviewed literature does not provide a complete explanation of the mechanism of interaction among these factors. Studies [11] and [15] mainly establish experimental relationships between additive concentration, electrical exposure, and working-fluid characteristics. Study [14] demonstrates the feasibility of practical electrostatic treatment in a real technical system. Study [12] helps explain the role of protective tribochemical films. However, a comprehensive study simultaneously linking electric-field parameters, additive concentration, physicochemical oil characteristics, surface-layer formation processes, and wear intensity requires further development.

Thus, analysis of sources [10–15] indicates that electrical treatment of lubricants can be regarded as a promising means of controlling their physicochemical and tribological properties. At the same time, the effectiveness of such treatment depends substantially on oil composition, additive type and concentration, electric-field parameters, and operating modes of the friction unit [11, 14, 15]. Establishing the mechanism of this interaction requires a combination of physicochemical, tribological, and operational research methods. Particular attention should be paid to the formation of protective surface films and their relationship with electrical-treatment parameters.

The analysis shows that numerous methods for improving the lubricity of working fluids already exist; however, there is a need to refine existing mathematical models or verify them experimentally.

Research Methodology.

The aim of the study is to determine the thickness of the lubricating film formed by surfactant molecules on metal friction surfaces as a function of additive concentration (stearic and oleic acids) in the working fluid when its action is intensified by electrostatic treatment.

To achieve this aim, an experimental methodology was developed for determining lubricating-film thickness on a laboratory test bench. Before the experiments, the ranges of additive concentration were selected: 0–0.35% for stearic acid and 0–2.8% for oleic acid. The working-fluid temperature in both cases was maintained at 80 °C with an error of 0.5 °C. The electrostatic-field strength was 2×10^6 V/m.

Results.

According to earlier studies [2, 12–15], the introduction of additives (fatty-acid molecules) into the working fluid of hydraulic machines results in their adsorption on friction surfaces, accompanied by an increase in the service life of hydraulic-system units. However, these studies did not consider what concentration of molecules in the base oil is rational or how it changes under the influence of an electrostatic field.

In previous studies, thin metal plates wetted with the lubricant under investigation were used to determine lubricating-film thickness. During the experiment, several plates with lubricant applied between them were compressed, after which their total thickness was measured. The resulting value was then compared with the thickness of the dry plates to determine the actual thickness of the lubricating layer.

A drawback of this method was that contaminant particles entered between the plates together with the lubricant. Their size was several orders of magnitude greater than the thickness of the lubricating layer, which increased the error of the experimental results. Therefore, a device developed at the Department of Mechanical Engineering and Technical Service of Machines was used to determine lubricating-film thickness. In this device, balls arranged consecutively one after another are used instead of plates (Fig. 1). With this arrangement, the probability of contaminant particles entering the ball contact point is very low.

The test bench (Fig. 1) consists of frame 1, on which a tube is installed using mounting 6. Thirty metal balls 4 are rolled into this tube. The tube is then closed on one side with mounting bracket 7, while a dial indicator 2 (ИЧЦ-10) is installed on the other side; its stem contacts the first ball through loading mechanism 3. The indicator pointer is thereby displaced by a certain amount.

At the first stage of the study, dry balls were used. They were rolled into tube 5 (Fig. 1) and pressed by the indicator spring. The readings obtained on its scale were taken as the initial values for subsequent measurements.

At the second stage, the mounting bracket was removed, the dry balls were rolled out of the tube, and each ball was successively wetted with I-20 working fluid as supplied and with I-20 containing different concentrations of stearic and oleic acids. Oleic acid is liquid at room

temperature, which allowed it to be introduced into the base oil without difficulty. Stearic acid is solid under normal conditions and has a melting point of 68 °C; therefore, it was preheated to the liquid state. The acids were introduced at the same temperatures, followed by mixing. After wetting in the resulting I-20 oil–acid solution, the balls were rolled into the tube again. Mounting bracket 7 (Fig. 1) was then installed, and the indicator head was pressed with the same force. The indicator reading shifted relative to the first value obtained for the dry balls. The difference between these two values, divided by the number of gaps between the balls, was taken as the thickness of the boundary lubricating layer.

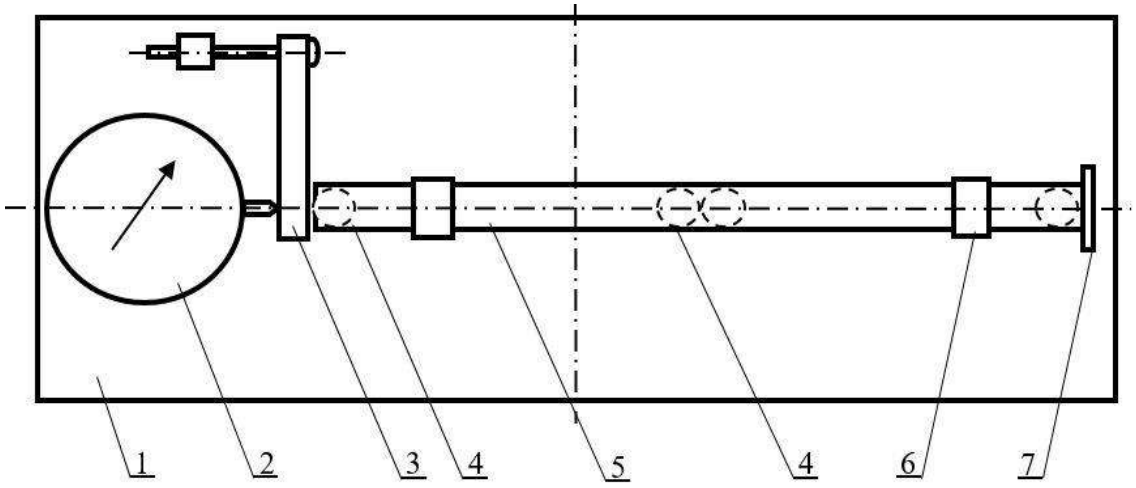


Fig. 1. Test-bench arrangement for determining lubricating-film thickness: 1 – frame; 2 – dial indicator; 3 – loading mechanism; 4 – metal balls; 5 – metal tube; 6 – tube mounting; 7 – mounting bracket

At the third stage, similar tests were conducted; however, in this case the investigated working fluid containing the additive was treated with an electrostatic field. Each lubricating-film thickness value was determined in eight repeated measurements.

The results of the planned experimental studies of the effect of additive concentration under electrostatic treatment of the working fluid are presented in Tables 1 and 2.

Table 1. Experimental results for determining lubricating-film thickness as a function of stearic- and oleic-acid concentration

Additive	Additive concentration in oil, %	Mean lubricating-film thickness (without fluid treatment), µm	Mean lubricating-film thickness (with fluid treatment), µm
Stearic acid	0	0,21	0,42
	0,05	0,33	0,45
	0,1	0,35	0,52
	0,15	0,43	0,62
	0,2	0,42	0,62
	0,25	0,36	0,58
	0,3	0,28	0,56
	0,35	0,27	0,54
Oleic acid	0	0,21	0,42
	0,4	0,25	0,43
	0,8	0,27	0,48
	1,2	0,32	0,48
	1,6	0,31	0,51
	2	0,28	0,49
	2,4	0,27	0,49
	2,8	0,23	0,48

Table 2. Regression equations obtained from the experimental studies

Additive	Working-fluid treatment	Regression equation
Stearic acid	With treatment	$H_1(C) = -4{,}5476C^2 + 1{,}9988C + 0{,}3894$
	Without treatment	$H_2(C) = -5{,}7381C^2 + 2{,}1012C + 0{,}2071$
Oleic acid	With treatment	$H_3(C) = -0.029C^2 + 0.1086C + 0.3992$
	Without treatment	$H_4(C) = -0.0472C^2 + 0.1421C + 0{,}1996$

The graphical representation of the research results shown in Fig. 2 demonstrates that the thickness of the boundary lubricating film between balls lubricated with I-20 oil was 0.2 μm, while electrostatic treatment increased it to 0.4 μm. This indicates the presence of surfactant molecules in the base oil as supplied. With a gradual increase in stearic-acid concentration, the layer thickness first increases and then decreases. This is explained by the transition of fatty-acid surfactant molecules from the monomeric state to an aggregated state. The maximum *H* value corresponds to the rational concentration of stearic acid in the working fluid. Without treatment, the rational concentration is 0.17%, whereas with an electrostatic field it is 0.22%.

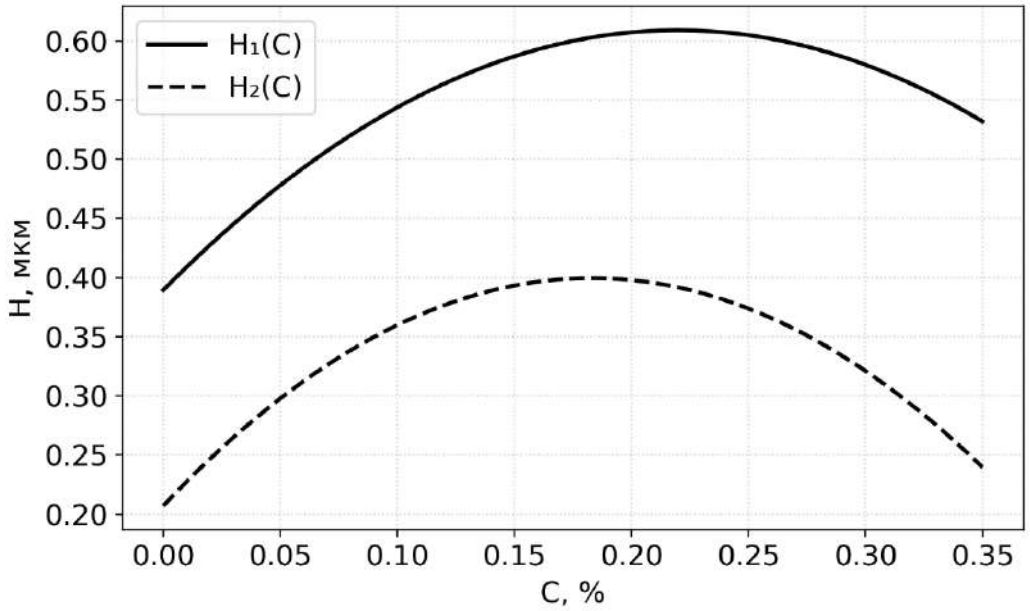


Fig. 2. Dependence of lubricating-film thickness on stearic-acid concentration in I-20 oil at 80 °C

A similar relationship is observed when oleic acid is used in the working fluid (Fig. 3). Without treatment, the rational concentration is 1.5%, whereas with an electrostatic field it is 1.9%.

According to the experimental results, all graphs exhibit a concentration of surfactant molecules at which the maximum lubricating-film thickness is formed. For stearic acid, the thickness increased from 0.2 μm to 0.4 μm without treatment and from 0.4 μm to 0.62 μm with treatment. For oleic acid, it increased from 0.2 μm to 0.32 μm without treatment and from 0.4 μm to 0.51 μm with treatment. This confirms the positive effect of additives in the working fluid and the use of external fields to intensify their action.

The obtained results can be used to verify models for determining lubricating-film thickness and friction-surface wear intensity and for predicting hydraulic-drive service life as a function of fatty-acid concentration in the working fluid.

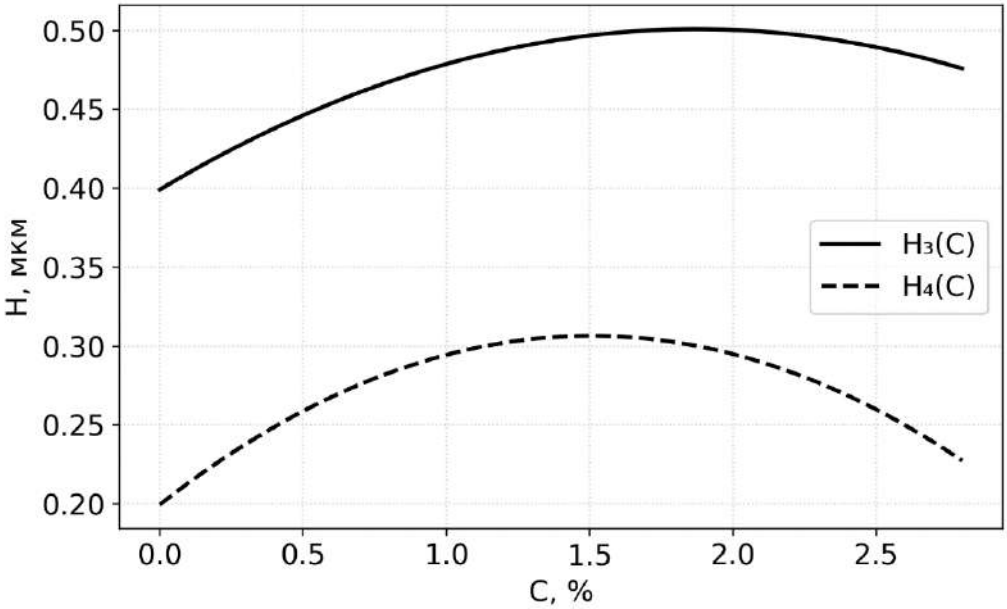


Fig. 3. Dependence of lubricating-film thickness on oleic-acid concentration in I-20 oil at 80 °C

However, future work should separately determine the contributions of the additive itself and the electric field. For this purpose, comparative experiments should be conducted in at least four modes: base oil without additive and without an electric field; oil with additive but without electrical exposure; base oil after electrical treatment; and oil with additive after electrical treatment. This methodology will make it possible to determine the contribution of each factor and establish whether an additional effect arises from their simultaneous application.

Conclusions.

Based on the analysis of scientific studies, it was established that the effectiveness of boundary lubricating-film formation is determined not only by the presence of surfactants in the working fluid, but also by their concentration and molecular state. As additive concentration increases, aggregated structures may form, as a result of which some surfactant molecules lose the ability to adsorb effectively on friction surfaces. One way to intensify additive action is to apply an external electric field.

A non-monotonic dependence of boundary lubricating-film thickness on fatty-acid concentration in I-20 oil was established experimentally. For both additives studied, increasing the concentration initially increased the lubricating-film thickness; after the maximum value was reached, the thickness decreased. This indicates the existence of a rational additive concentration that provides the greatest thickness of the formed lubricating film. For stearic acid, the rational concentration is approximately 0.17% without electrostatic treatment and 0.22% with electrostatic treatment of the working fluid. For oleic acid, the corresponding values are approximately 1.5% and 1.9%. The results indicate that the electrostatic-treatment mode must be taken into account when determining the rational additive concentration.

Electrostatic treatment was found to increase boundary lubricating-film thickness under the investigated conditions. The maximum film thickness was 0.62 μm for stearic acid and 0.51 μm for oleic acid, whereas without electrostatic treatment the corresponding maximum values were 0.43 μm and 0.32 μm. The experimental results support further investigation of electrostatic treatment of working fluids as a means of intensifying the action of surfactants. At the same time, the established dependence of lubricating-film thickness does not directly determine hydraulic-drive service life; therefore, additional tribological and operational

studies are required to establish a quantitative relationship among additive concentration, film thickness, wear intensity, and technical-system service life.

The research results can be used to refine and experimentally verify mathematical models for determining lubricating-film thickness and as input data for subsequently establishing relationships among working-fluid parameters, electrostatic-treatment conditions, friction-surface wear, and hydraulic-drive service life.

Future Research Directions

Further research should focus on establishing a quantitative relationship between fatty-acid additive concentration, the parameters of electrostatic treatment, boundary lubricating film formation, friction-surface wear, and the service life of hydraulic drive components. The results obtained in the present study characterize the change in lubricating film thickness; however, this parameter alone does not provide a direct quantitative assessment of wear intensity or hydraulic-system durability.

A priority task is to separate the individual and combined effects of the additive and the electric field. For this purpose, comparative experiments should be carried out under four conditions: base oil without an additive and without electrostatic treatment; oil containing an additive without electrostatic treatment; base oil subjected to electrostatic treatment; and oil containing an additive subjected to electrostatic treatment. Such an experimental design will make it possible to determine the contribution of each factor and to identify a possible interaction effect between fatty-acid additives and electrostatic treatment.

Further experimental studies should also extend the ranges of operating conditions. In particular, the effects of working-fluid temperature, electric-field strength, treatment duration, contact pressure, sliding velocity, and contamination level should be investigated. Particular attention should be paid to verifying whether the rational concentrations determined for stearic and oleic acids remain stable when the operating conditions of hydraulic friction units change.

Another important direction is the tribological verification of the established relationships using friction pairs representative of hydraulic machines. Measurements of friction coefficient, wear rate, surface roughness, and changes in the morphology and chemical composition of the formed boundary films would allow the experimentally determined film-thickness relationships to be linked with the actual anti-wear performance of the working fluid.

The resulting experimental data can subsequently be used to refine and validate mathematical models describing boundary lubricating film formation and wear processes. A combined model incorporating additive concentration, molecular state, electrostatic-treatment parameters, lubricating film thickness, and wear intensity could provide a basis for predicting the durability of hydraulic drive friction units and for selecting rational working-fluid treatment conditions.

References

1. Meng Y., Xu J., Ma L., Jin Z., Prakash B., Ma T., Wang W. A review of advances in tribology in 2020–2021. *Friction*, 2022. 10 (10). 1443–1595. https://doi.org/10.1007/s40544-022-0685-7

2. Charoo M. S., Akhter F., Hanief M., Shafi W. K., Nissar M. Effect of Saturated Fatty Acids on the Antiwear and Rheological Properties of Olive Oil. *Tribology in Industry*, 2023. 45 (1). 121–128. https://doi.org/10.24874/ti.1404.11.22.02

3. Li H., Yin Z., Jiang D., Jin L., Cui Y. A study of the tribological behavior of transfer films of PTFE composites formed under different loads, speeds and morphologies of the counterface. *Wear*, 2015. Vol. 328–329. P. 17–27. https://doi.org/10.1016/j.wear.2015.01.028

4. Ligier J.-L., Noel B. Friction Reduction and Reliability for Engines Bearings. *Lubricants*, 2015. 3 (3). 569–596. https://doi.org/10.3390/lubricants3030569

5. Zhao J., Huang Y., He Y., Shi Y. Nanolubricant additives: A review. *Friction.* 2021. 9. 891–917. https://doi.org/10.1007/s40544-020-0450-8

6. Minkin V. I., Osipov O. A., Zhdanov Y. A. Dipole Moments in Organic Chemistry. New York: Springer Science+Business Media, 1970. XII, 288 p. https://doi.org/10.1007/978-1-4684-1770-8

7. Dou P., Jia Y., Zheng P., Wu T., Yu M., Reddyhoff T., Peng Z. Review of ultrasonic-based technology for oil film thickness measurement in lubrication. *Tribology International*, 2022. 165. 107290. https://doi.org/10.1016/j.triboint.2021.107290

8. Gu H., Hirayama T. Effect of surfactant self-assembly on lubrication performance in oil-based systems: the role of reverse micelles and vesicles. *Frontiers in Mechanical Engineering*, 2025. 11. 1608716. https://doi.org/10.3389/fmech.2025.1608716

9. Zangwill A. Physics at Surfaces: monograph. – New York: Cambridge University Press, 1988. 454 p.

10. Purcell E.M., Morin D. J. Electricity and magnetism: textbook. New York: Cambridge University Press, 2013. 839 p.

11. Стефанов В. О. Вплив концентрації присадки на ресурс гідроагрегатів засобів транспорту в умовах електрообробки робочої рідини. *Енергозбереження. Енергетика. Енергоаудит*, 2014. № 7 (125). С. 2–11.

12. Erck R. A., Song M., Li D., Cosimbescu L. Investigations of polymethacrylate tribochemical films using X-Ray spectroscopy and optical profilometry. *Tribology Letters*, 2021. 69 (1), № 1. 26. https://doi.org/10.1007/s11249-020-01388-5

13. Александров Є. Є., Кравець І. А., Лисіков Є. М. Підвищення ресурсу технічних систем шляхом використання електричних та магнітних полів : монографія. Харків : НТУ «ХПІ», 2006. 544 с.

14. Воронін С. В., Стефанов В. О., Харківський О. С. Експлуатаційні випробування пристрою для електростатичної обробки моторної оливи. *Збірник наукових праць Українського державного університету залізничного транспорту*. Харків : УкрДУЗТ, 2022. Вип. 200. С. 11–24. https://doi.org/10.18664/1994-7852.200.2022.262678

15. Воронін С. В., Сафонюк І. Ю., Аношкіна Н. М., Харківський О. С. Дослідження впливу концентрації рідкокристалічної присадки та електричного поля на фізико-хімічні властивості індустріальної оливи. *Вісник Національного авіаційного університету*. 2020. № 2 (83). С. 70–76. https://doi.org/10.18372/2306-1472.83.14654

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ВПЛИВ КОНЦЕНТРАЦІЇ ЖИРНИХ КИСЛОТ У РОБОЧІЙ РІДИНІ ГІДРОПРИВОДІВ МАШИН НА ФОРМУВАННЯ ГРАНИЧНОЇ МАСТИЛЬНОЇ ПЛІВКИ

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Анотація

У цьому дослідженні вивчається вплив концентрації присадок на основі жирних кислот на формування граничної мастильної плівки на металевих поверхнях тертя під час електростатичної обробки робочих рідин гідравлічних машин. Особливу увагу приділено молекулярному стану присадки, оскільки підвищення її концентрації може сприяти утворенню надмолекулярних агрегатів і, як наслідок, зменшувати частку молекул, доступних для адсорбції на поверхнях тертя. Зовнішнє електричне поле розглядається як засіб інтенсифікації адсорбції присадок та модифікації молекулярного стану поверхнево-активних речовин у робочій рідині. Було розроблено експериментальну методику визначення товщини граничної мастильної плівки з використанням випробувального стенда, що містить 30 послідовно розміщених металевих кульок. Така конфігурація зменшує ймовірний вплив забруднювальних частинок на результати вимірювань. Експерименти проводили з використанням базової оливи І-20 за

температури 80 °С. Досліджували концентрації стеаринової кислоти в діапазоні 0–0,35 % та олеїнової кислоти — 0–2,8 % як за умов електростатичної обробки, так і без неї. Результати експериментів продемонстрували нелінійну залежність між концентрацією присадки та товщиною граничної плівки. Для обох жирних кислот товщина плівки спочатку зростала зі збільшенням концентрації присадки, а після досягнення максимального значення — зменшувалася. Для стеаринової кислоти раціональна концентрація становила приблизно 0,17 % без електростатичної обробки та 0,22 % — з обробкою. Для олеїнової кислоти відповідні значення становили приблизно 1,5 % та 1,9 %. Максимальна товщина плівки для стеаринової кислоти становила 0,43 мкм без обробки та 0,62 мкм з електростатичною обробкою, тоді як для олеїнової кислоти ці показники дорівнювали 0,32 мкм та 0,51 мкм відповідно. Отримані результати свідчать про те, що як концентрація присадки, так і електростатична обробка впливають на формування граничної мастильної плівки за досліджуваних умов. Отримані експериментальні залежності можуть бути використані для уточнення та верифікації математичних моделей, що описують формування мастильної плівки, а також для подальшого вивчення взаємозв’язку між складом робочої рідини, молекулярним станом присадки, зношуванням і ресурсом гідравлічних систем. Висновки дослідження створюють підґрунтя для вибору раціональних концентрацій присадок на основі жирних кислот з урахуванням застосування електростатичної обробки.

Ключові слова: гідравлічний привід, робоча рідина, поверхня тертя, поверхнево-активна речовина, мастильна плівка, електричне поле, товщина плівки.