

# The Mechanism for Improving Anti-Wear Properties of Oils Using Hydrodynamic Dispersion

Ye. Ventsel<sup>a</sup>, O. Orel<sup>a</sup>, O. Shchukin<sup>a,\*</sup>, N. Saienko<sup>a</sup>, S. Kovalevskiy<sup>a</sup>

<sup>a</sup> Kharkiv National Automobile and Highway University, Yaroslava Mudrogo st, 25, Kharkiv, Ukraine, 61002.

## Keywords:

Oil  
Dispersion  
Chemical activity  
Wear  
Free radicals

\* Corresponding author:

Oleksandr Shchukin   
E-mail: [alexhome88@gmail.com](mailto:alexhome88@gmail.com)

Received: 15 June 2020  
Revised: 16 August 2020  
Accepted: 24 October 2020

## ABSTRACT

*It has been established that in the process of hydrodynamic treatment of oil, the size of the particles of contamination decreased to 5 microns or smaller sizes. Such particles can significantly improve the anti-wear properties of the lubricating oil. Besides, during hydrodynamic dispersion, it is significantly heated due to throttling in connection with a sharp transition of the kinetic energy of the oil jet into the thermal energy. It was proved that such heating during hydrodynamic dispersion led to structural transformations of the oil, namely: the number of free radicals and the time of their chemical activity decreased. This resulted in improved antifriction and anti-wear properties of the oil. This was proved quite convincingly by the results of wear tests on the SMC-2 and FBM friction machines: the wear of friction samples decreased on average by 1.34 times.*

© 2020 Published by Faculty of Engineering

## 1. INTRODUCTION

It is known from literature data [1–6] that artificial dispersion of pollution particles (particles of wear and dust) in motor oils and working fluids leads to an increase in their anti-wear properties when used in tribo units of internal combustion engines and hydraulic drives, respectively. The reason for this, according to [1–6], is a positive effect of fine particles with the size of 5 microns or smaller on the anti-wear properties of oils. The latter is explained by the fact that fine particles, having a highly developed specific surface, adsorb the products of oil oxidation, thus separating tribo surfaces from one another.

Besides, highly dispersed particles located in the micro irregularities of rough surfaces, increase

their contact area and thus reduce the possibility of micro seizure. At the same time, being located in the gaps between the tribo surfaces, such particles reduce electrostatic wear when a critical potential difference arises between the friction surfaces, followed up by a breakdown of the lubricating film, its burnout and, as a consequence, direct contact of the tribo surfaces, that is, by the micro seizure.

Taking into account the above, special devices were developed – dispersants of ultrasonic, cavitating, and hydrodynamic types [7–9], intended to artificially intensify the generation of fine particles of pollution in oils during operation.

However, during the research and operation of the hydrodynamic dispersant, in addition to the

direct dispersing of the pollution particles in oils, concomitant phenomena were discovered that contributed to the improvement of anti-wear properties of oils and that had not been previously investigated.

## 2. MAIN HEADING

Establishing the essence of additional phenomena associated with the hydrodynamic dispersion of lubricating oils and leading to an improvement in their anti-wear properties and, based on this, developing a mechanism for reducing the wear of tribo surfaces during hydrodynamic dispersion of lubricating oils.

## 3. PROPOSED MEASURES

Research of the mechanism for improving the oil anti-wear properties.

The results of numerous studies in the laboratory and operational conditions confirmed that a hydrodynamic dispersant (HD) effectively ground particles of wear and dust in the oil, which significantly (at least 1.3–1.4 times) reduced the wear of friction pairs in internal combustion engines and hydraulic drives.

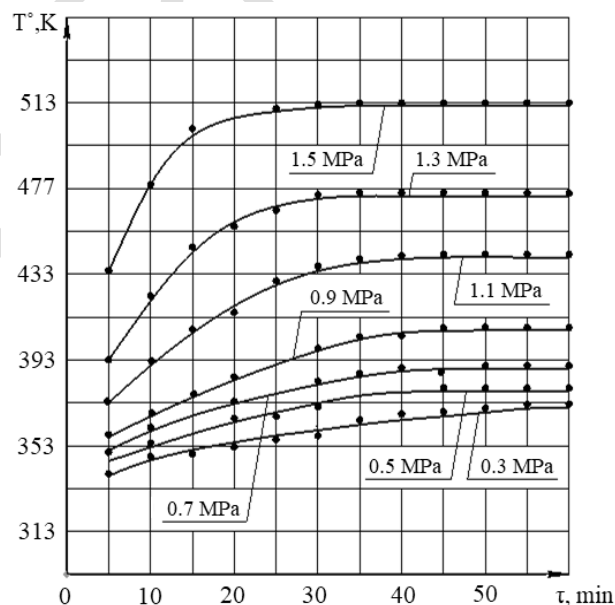
However, during the laboratory studies, it was found that in the process of hydrodynamic treatment of lubricating oils, they heat up to a temperature of 343–353 K. This is explained by the design features of HD, that has a conical nozzle through which the oil throttles under pressure, that is, there occurs a sharp conversion of the kinetic energy of the oil jet moving at a high speed into the heat energy. Such heating of the oil is expected to affect its chemical properties; to confirm this hypothesis, the following research was carried out.

To establish the temperature of the oil during its passing through the conical nozzle of HD and the regularities of the change in this temperature in the zone of impact of the oil with the barrier on the reverse side of the latter, a blind hole was drilled at a depth of 5 mm (the thickness of the barrier was 6 mm). Copper, a constantan thermo-couple connected to the PP-64 potentiometer, was inserted into this hole. The fresh I-G-A-32 oil was poured into the hydraulic

tank of the stand, which was previously carefully filtered using the SOG-903A unit.

This oil underwent hydrodynamic dispersion with a pressure difference at HD equal to 0.3; 0.5; 0.7; 0.9; 1.1; 1.3 and 1.5 MPa. The temperature of the oil in the zone of its impact with the barrier was measured every 5 minutes within one hour of dispersion.

The results of the research (Fig. 1) showed that at all pressure differences, after 10 minutes of dispersion, an increase in the temperature of the oil in the zone of its impact with the barrier was observed. Thus, at an oil pressure of 1.5 MPa, its temperature reached almost 500 K. However, after a while, the temperature stabilized, and the higher the pressure difference at HD, the earlier stabilization would occur.



**Fig. 1.** The dependence of the oil temperature in the zone of impact with the barrier of HD on the time of dispersion.

For example, at  $\Delta P = 0.3$  MPa, the oil temperature reaches its maximum value of 367 K after 45–50 min of treatment (heating rate is 1.5 deg/min), and at  $\Delta P = 1.5$  MPa – 507 K after 25–30 min (heating rate is 7 deg/min).

Such local heating of the oil in the conical nozzle of HD does not lead to a decrease in the viscosity of the oil; however, in general, it is expected to lead to its structural transformations and, as a consequence, to a change in the anti-wear properties of the oil.

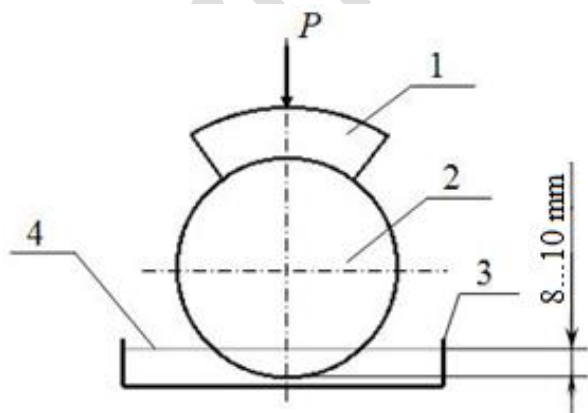
To test this hypothesis, a series of comparative tests was carried out on the SMC-2 friction machine (Figs. 2 and 3) according to the “block-roller” scheme (the materials, were BRAZH9-4 and 20X steel, respectively), as well as on the FBM friction machine (Figs. 4 and 5) (the material of the balls – SHKH15 steel).



**Fig. 2.** The general view of the SMC-2 friction machine.

The test mode on the SMC-2 friction machine was as follows:

- running-in of samples without load - 15 min;
- running-in of samples with a load of 300 N - 2 hours;
- the actual test with a load of 600 N - 4 hours.



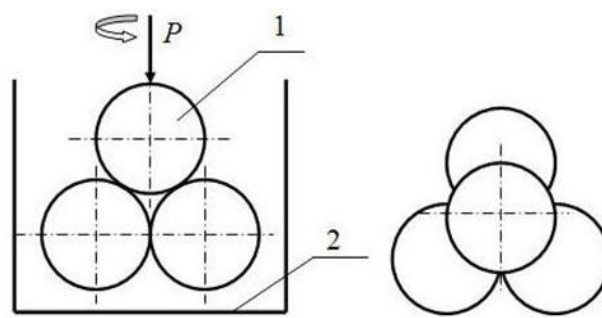
1 - pad; 2 - roller; 3 - cuvette; 4 - the level of oil

**Fig. 3.** The test diagram of the pad and the roller on the SMC-2 friction machine.

The test mode on the FBM friction machine was as follows: the load on the balls was 80 N, the rotation frequency of the upper ball was 1 min<sup>-1</sup>, and the test time was 2 hours.



**Fig. 4.** The general view of the FBM friction machine.



1 - ball; 2 - cuvette with oil

**Fig. 5.** The diagram of testing balls on the FBM friction machine.

The wear of the pads and rollers after testing on the SMC-2 machine was determined by their weight loss during the test period with the help of the VLA -200-M analytical balance and the diameter of the ball wear scar after testing on the FBM with the help of the MBS-9 microscope. To carry out the research, two portions of the fresh I-G-A-32 oil from the same batch were used. They were preliminarily filtered carefully from particles of pollution with the use of the CLG-903A plant to maximally eliminate the effect of this pollution on the oil anti-wear properties. The first portion of the oil remained unchanged, while the second one passed through the conical nozzles of HD, where it was heated to a temperature of 373 K and then cooled down to room temperature.

The test results (Tables 1 and 2) showed that heating the oil in the conical nozzle of HD up to a temperature of 373 K improved its antifriction and anti-wear properties. Thus, the coefficient of friction of the samples on the SMC-2 machine decreased 1.34 times, and on the FBM friction machine – 2.44 times. At the same time, the total wear of the samples on the SMC-2 machine decreased 1.35 times. Accordingly, the diameter of the wear scar on the balls decreased 1.33 times when testing them on the FBM machine.

**Table 1.** The results of testing the I-G-A-32 oil on the SMC-2 friction machine.

Oil condition	Coefficient of friction	Wear, g		
		Pad	Roller	Total
Fresh	0.047	0.1895	0.0069	0.1964
Fresh, artificially heat-treated to T = 373 K	0.035	0.1305	0.0049	0.1459

**Table 2.** The results of testing the I-G-A-32 oil on the FBM friction machine.

Oil condition	Coefficient of friction (in conventional units)	The diameter of the wear scar, mm
Fresh	51.6	0.284
Fresh, artificially heat treated to T = 373 K	23.1	0.213

Note. Tables 1 and 2 present the average values by the results of five tests on the oil in each state,

which ensured an error of not more than 0.2 with a confidence factor of 0.9.

Studies [9–10] show that oils contain paramagnetic compounds in small quantities – free radicals (FR), which have a decisive effect on the chemical activity of oils.

In this regard, it can be expected that the improvement of the antifriction and anti-wear properties of the oils when they are heated due to their passing through the conical nozzle of HD is associated with a change in the content or chemical activity of FR.

Studies of the FR chemical activity were carried out by the method of electron paramagnetic resonance, which allowed to determine the quantity of FR in the oil and evaluate their chemical activity quite reliably.

The Rubin EPR spectrometer was used, and silicon monoxide served as a standard of reference.

The I-G-A-32 oil was studied in its following conditions:

- fresh, free from contaminants;
- fresh, free from contaminants oils dispersed by HD, with the oil temperature 373 K in the conical nozzle of HD and then cooled down to room temperature.

Samples of oil in each condition (~ 100 mg) were placed in a tube of resonantly pure glass, after which the tube was filled with oxygen and sealed. Then, the quantity of FR was determined in each sample. By changing the quantity of FR in each sample, their chemical activity was determined.

The results of the research are given in Table 3, which shows that due to dispersion there is a slight decrease in the quantity of FR (1.33 times and on average 1.18 times when thermostated) compared to the fresh oil. At the same time, there is a significant decrease (by 1.48 times) in the chemical activity of FR as a result of hydrodynamic dispersion.

The phenomena noted above can explain the mechanism for improving the anti-wear properties of oils during hydrodynamic dispersion.

**Table 3.** The research results of FR chemical activity.

Oil condition	Quantity of FR $\ln \cdot 10^{-16}$ , spin / g	Quantity of FR thermostated at 473 K, $\ln \cdot 10^{-16}$ , spin / g							FR mass lifetime $W_g \cdot 10^{-13}$ deg / g * s
		2.5	5	10	15	20	25	30	
Fresh	0.72	3.47	2.69	2.21	2.04	1.91	1.88	1.69	22.6
Fresh, dispersed to T = 373 K	0.54	2.51	2.04	1.59	1.48	1.40	1.45	1.32	15.6

Based on the results of previously known research and the above one, it can be assumed that the improvement of anti-wear properties of oils during their hydrodynamic dispersion is caused by the following two processes:

- grinding pollution particles (products of wear and dust);
- mechanochemical activation of oil.

The role of fine particles of pollution in increasing anti-wear properties of oils is conclusively demonstrated in [1–5].

Due to the heating of the oil as it passes through the conical nozzle of HD the chemical activity of FR decreases. The latter are less vigorously adsorbed on tribo surfaces, reducing the work function of electrons and, consequently, the wearing. On the other hand, a decrease in the chemical activity of FR cuts the proportion of corrosive wear.

The chemical activity of FR decreases due to an increase in the rate of chemical reactions with increasing temperature, and therefore, during hydrodynamic dispersion, some of the active FR lose their properties. At the same time, more associated FR emerge, that strengthen the polymolecular boundary layers and improve their lubricating effect, which results in a wear decrease.

#### 4. CONCLUSION

In the process of oil treatment using HD two parallel phenomena occur:

- grinding pollution particles in the oil (products of wear and dust) to the sizes of 5 microns or smaller;

- mechanochemical activation of the oil due to its heating when it passes through the HD conical nozzle. This reduces the quantity of short-period free radicals.

As a result of heating the oil, more associated free radicals appear in it, thus, strengthening the polymolecular boundary layers and improving their lubricating effect.

The above phenomena reveal the mechanism for a positive effect on anti-wear properties of oils when they are treated with a dispersant of a hydrodynamic type.

#### REFERENCES

- [1] Ye.S. Ventsel, *Improving the performance properties of lubricants and fuels*, Kharkov: KhNADU, 2010. (in Russian)
- [2] Ye. Ventsel, O. Orel, O. Shchukin, N. Saienko, A. Kravets, *Dependence of Wear Intensity on Parameters of Tribo Units*, Tribology in Industry, vol. 40, no. 2, pp. 195-202, 2018, doi: [10.24874/ti.2018.40.02.03](https://doi.org/10.24874/ti.2018.40.02.03)
- [3] A. Akchurin, R. Bosman, P.M. Lugt, M. Drogen, *Analysis of wear particles formed in boundary-lubricated sliding contacts*, Tribology Letters, vol. 63, iss. 16, pp. 1-14, 2016, doi: [10.1007/s11249-016-0701-z](https://doi.org/10.1007/s11249-016-0701-z)
- [4] E. Hu, XI. Hu, T. Liu, L. Fang, K. Dearn, H. Xu, *The role of soot particles in the tribological behavior of engine lubricating oils*, Wear, vol. 304, iss. 1-2, pp. 152-161, 2013, doi: [10.1016/j.wear.2013.05.002](https://doi.org/10.1016/j.wear.2013.05.002)
- [5] M.K.A. Ali, F.M.H. Ezzat, K.A.Abd El-Gawwad, M.M.M. Salem, *Effect of lubricant contaminants on tribological characteristics during boundary lubrication reciprocating sliding*, Minia journal of engineering and technology, vol. 32, pp. 90-102, 2013.

- [6] M.M. Marcia, K.D. Tanaka, *Influence of loading, contamination and additive on the wear of a metallic pair under rotating and reciprocating lubricated sliding*, Journal of the Brazilian society of mechanical sciences and engineering, vol. 28, no. 3, pp. 278-285, 2006, doi: [10.1590/s1678-58782006000300005](https://doi.org/10.1590/s1678-58782006000300005)
- [7] L.R. Rudnick *Lubricant additives: chemistry and applications*, Boca Raton: CRC Press, 2009, doi: [10.1201/9781420059656](https://doi.org/10.1201/9781420059656)
- [8] M.I.H. Chua, M.F.B. Abdollah, H. Amiruddin, N. Tamaldin, N. Mat Nuri, H.H. Masjuki, S. Rafeq, *Improving engine oil properties by dispersion of hBN/Al<sub>2</sub>O<sub>3</sub> nanoparticles*, Applied Mechanics and Materials, vol. 607, pp. 70-73, 2014, doi: [10.4028/www.scientific.net/amm.607.70](https://doi.org/10.4028/www.scientific.net/amm.607.70)
- [9] M. Torbacke, R.Å. Kassman, E. Kassfeldt, *Lubricants: introduction to properties and performance*, Chichester: John Wiley & Sons, 2014, doi: [10.1002/9781118799734](https://doi.org/10.1002/9781118799734)
- [10] G.S. Shimonae, A.B. Vipper, A.F. Penchul, M.A. Lisovskaya, I.I. Proskurina, *Investigation of active part of motor oil additives*, Chemistry and Technology of Fuels and Oils, vol. 12, pp. 218-221, 1976, doi: [10.1007/bf00718816](https://doi.org/10.1007/bf00718816)
- [11] Influencing oil degradation, Insight from infineum international limited, available at: [www.infineuminsight.com/en-gb/articles/passenger-cars/influencing-oil-degradation](http://www.infineuminsight.com/en-gb/articles/passenger-cars/influencing-oil-degradation) accessed: 30.04.2020.