



Evaluation of tribological characteristics of technical oils with fullerene compositions

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Abstract

The paper presents experimental studies of the tribological characteristics of liquid lubricants of various viscosity classes and various groups of operation when using fullerene compositions. Tribological characteristics were evaluated on a four-ball friction machine according to GOST 9490.

The use of fullerene compositions in the form of a finely dispersed fullerene powder, pre-dispersed (dissolved) in vegetable high oleic oils, for example, rapeseed, with the subsequent addition of the resulting composition to technical oils of various viscosity classes and various groups of operation, leads to the following positive effect. The anti-wear properties of oils, which are assessed by the wear indicator, increase by 20,0...30,7 %, and the critical load on 18,8...25,0%. These indicators significantly exceed similar indicators when using fullerene fine powders without preliminary dispersion in vegetable oils, where the effect is on the border 11,1...15 %.

Fullerene additives do not affect the extreme pressure properties of base oils, which are assessed by the scuffing load. This result makes it possible to state that the way to improve the tribological properties of lubricants by introducing a fine powder of fullerenes into base technical oils is ineffective.

The experimental results obtained confirm the hypothesis about the possibility of the micelle formation mechanism in the lubricant under the action of the electrostatic field of the friction surface. The presence of a surfactant solvent (vegetable oil) allows you to "start" the micelle formation process at lower fullerene concentrations and to obtain the effect of increasing anti-wear properties.

Key words: fullerenes; vegetable oils; four-ball friction machine; tribological characteristics; critical load; welding load; bully index; technical oils.

Introduction

Today, the use of fullerenes is of great interest of C_{60} , as additives to liquid lubricants. In recent years, a number of scientific articles have appeared, where the results of studies of the effect of fullerene additives to lubricants on the processes of friction and wear of metals have been presented and a conclusion has been made about the prospects of using such additives.

An interesting and important feature of fullerene additives is that fullerenes are readily soluble in a wide class of organic and inorganic solvents. At the same time, poor solubility of fullerenes in technical oils was noted (mineral, semi-synthetic and synthetic). To date, the solubility of C_{60} in a large number of liquids has been determined and analyzed. It is shown that the solubility of fullerenes decreases with increasing polarity of the solvent. A number of unusual properties of fullerene solutions have been revealed, so for some solvents the effect of an anomalous dependence of the solubility of fullerene on temperature was found. At a temperature of about 280 °K maximum solubility is observed in these systems C_{60} , after which it starts to decrease.

Another interesting phenomenon observed in fullerene solutions C_{60} , are the processes of formation and growth of clusters, which indicate the proximity of many solutions C_{60} to the class of colloidal systems. The defining moment of this phenomenon is the fact that the size of the fullerene lies on the border of the definition concept of a colloidal particle (according to colloidal chemistry, colloidal particles range in size from one nanometer to several micrometers). The polarity of the solvent also has a great influence on this process.



The use of fullerene additives for technical liquid lubricants raises a number of questions about their effectiveness, i.e. influence on anti-wear and extreme pressure properties. Interest in this phenomenon is of both fundamental and applied nature, which will allow the development of concepts for their application.

Literature review

The authors of the work [1] provide an overview of the literature on lubricants with added nanoparticles. The effect of nanoparticles on the tribotechnical characteristics of oils has been analyzed. The paper notes that the use of nanoadditives to lubricants leads to an increase in the viscosity of the base medium, a high bearing capacity of the interface, a decrease in the friction coefficient, and an increase in wear resistance. Work [2] contains conclusions that the characteristics of a lubricant can be improved by using nanoadditives. Adding nanoparticles to conventional base oils is a promising direction. The work is devoted to an informative review of the application of nanoadditives to liquid lubricants and the prospects for its use in the production of oils. Similar conclusions about the prospects of using nanomaterials in liquid lubricants have been made by the authors of the work. [3].

Works [4-6] are devoted to fullerenes as additives to lubricants. The authors note that the use of fullerenes reduces the coefficient of friction and increases the wear resistance of mates. In work [6] it is noted that the concentration of the fullerene additive should be within 0,5...2,0% masses. In work [7] the result of using fullerene is given C_{60} . The authors note a positive effect, however, they conclude that the mechanism of the senergism of fullerenes with base oil is unclear and requires further research. At the same time, it was noted in the work that a decrease in the friction coefficient with the addition of fullerenes to oils can reach 90% compared to the base oil.

Analysis of works devoted to the use of fullerenes as additives to lubricants allows us to conclude that fullerenes are not dispersed (dissolved) in all technical oils [8-10]. This conclusion has been confirmed by the author of the work [11]. The introduction of fullerene additives in the form of a finely dispersed powder into technical oils of various viscosity classes and various groups of operation improves the anti-wear properties of oils, which are estimated by the wear indicator (increase by 11,1...15 %) and critical load (increase by 11,8...17,4%). Fullerene additives do not affect the extreme pressure properties of base oils, which are assessed by the scuffing load. This result makes it possible to state that the way to improve the tribological properties of lubricants by introducing a fine powder of fullerenes into base technical oils is ineffective. As follows from the above analysis of scientific works, such an insignificant effect is typical due to the intense clustering of fullerene molecules in the environment of industrial oils containing surfactants. Technical oils act as a highly polar solvent.

The experimental results presented allow us to conclude that it is necessary to develop other, more technological techniques and methods for introducing fullerene additives into technical lubricants, the theoretical justification of which has been developed in the works [12, 13]. In the presented works, a mathematical model of the interaction of electrically active heterogeneous fine-dispersed systems at the interface friction surface - lubricant has been developed. From the analysis of the solution of the differential equation, which describes the process of interaction of electric fields, it has been found that the introduction of fullerenes into the base lubricant does not bring a large effect.

It has been theoretically established that the use of fullerene "solvents", which can be high oleic vegetable oils, you can "start" the process of micelle formation, where the nucleus of the micelle is a fullerene molecule surrounded by molecules, for example, oleic or stearic acid. In work [12] theoretical studies that have shown, that the number of micelles is 50 times higher than the number of clusters in the base lubricating medium at the same concentration of fullerenes, and the dipole moment of micelles is an order of magnitude higher than the dipole moment of clusters. At the same time, micelles are more effective, where a single fullerene molecule acts as a nucleus, rather than a cluster of fullerene molecules, which affects the size of the formed micelles. The role of the friction surface on the formation of clusters and micelles in the lubricant film at the friction surface is established. It is shown that under the action of the stress-strain state of the surface layers, the friction surface acts as "Generator of electrostatic force field", which affects the formation of an electric field in the volume of the oil film. Expressions are obtained for calculating the value of the total electric field strength of the system "friction surface + lubricant".

In works [12, 13] it has been theoretically established that the electrostatic field of the friction surface is the driving force for the formation of an electrostatic field in the volume of the oil film, which is adsorbed on the friction surface. It shows that the process of cluster formation from fullerene molecules and micelles from fullerene molecules and fullerene solvent molecules affects the magnitude of the electrostatic field in the volume of liquid. Based on the review of publications and the performed modeling, it has been found that high oleic vegetable oil can act as a "strong solvent" of fullerenes.

Purpose

The purpose of this work is to carry out experimental studies of the tribological characteristics of liquid lubricants in the presence of fullerene compositions in their composition, which contain a fine powder of fullerenes, previously dispersed (dissolved) in vegetable high oleic rapeseed oil in various concentrations.

Methods

The tribological characteristics were assessed on a four-ball friction machine according to the method described in GOST 9490.

1. Fullerene compositions were prepared in the following mass concentrations. Base oils free from fullerene compositions.

2. Fullerene supplement 50 g/kg. It contains 0,5 g of fullerenes and 49,5 g of vegetable rapeseed oleic oil. Mass addition 50 g is introduced in 1000 g of base oil.

3. Fullerene supplement 100 g/kg. It contains 0,75 g of fullerenes and 99,25 g of vegetable rapeseed oleic oil. Mass addition 100 g is introduced in 1000 g of base oil.

4. Fullerene supplement 150 g/kg. It contains 1,0 g of fullerenes and 149,0 g of vegetable rapeseed oleic oil. Mass addition 150 g is introduced in 1000 g of base oil.

5. Fullerene supplement 200 g/kg. It contains 1,5 g of fullerenes and 198,5 g of vegetable rapeseed oleic oil. Mass addition 200 g is introduced in 1000 g of base oil.

6. Fullerene supplement 250 g/kg. It contains 2,0 g of fullerenes and 248,0 g of vegetable rapeseed oleic oil. Mass addition 250 g is introduced in 1000 g of base oil.

Experimental studies included the determination of tribological characteristics on a four-ball machine of liquid lubricants of the following operation groups:

- hydraulic mineral oil, by classification ISO corresponds to NM, viscosity class 10, trade mark MGP-10;
- engine oil, according to SAE 30 classification, API CC operation group, trade mark M-10G_{2k};
- gear oil, SAE 75W90 classification, API GL-5 service group, trade mark VALVOLINE.

Fullerenes in the form of fine powder of various concentrations $F=0,5\dots2,0$ grams "dissolved" in high oleic rapeseed oil and added to the above-listed technical base oils in the form of a fullerene composition (FK).

Results

In the process of experimental studies, the following tribological characteristics have been determined:

- wear rate, D_w , mm;
- critical load, P_{cr} , N;
- welding load, P_{weld} , N;
- bully index, I_b , N.

Experimental results for hydraulic oil MGP-10 are presented in the table 1, for engine oil M-10G_{2k} in the table 2, for transmission oil VALVOLINE GL-5 in the table 3.

The experimental results were checked for reproducibility by Cochran's criterion according to the formulas (1), (2):

$$G_p = \frac{S_{\max}^2}{\sum_{i=1}^N S_i^2}, \quad (1)$$

where S_{\max}^2 - maximum value of variance for D_w , P_{cr} , P_{weld} , I_b in accordance;

S_i^2 - the value of the variance of the i - th experiment for D_w , P_{cr} , P_{weld} , I_b in accordance.

The hypothesis was tested:

$$G_p < G_{tab}, \quad (2)$$

where G_{tab} - tabular value of the Cochran's criterion, with a given confidence interval $q = 0,90$.

During the statistical processing of the experimental results, the number of repetitions of the same type was determined, which make it possible to ensure the experimental error at the level of confidence equal to $q = 0,90$.

The obtained experimental values allow us to conclude that tests on a four-ball machine of liquid lubricants for various purposes with different concentrations of fullerene compositions are reproducible and reliable under the condition of three repeats of the same type.

In tables 1 - 3 the arithmetic mean values of three repetitions of tribological characteristics are given.

Analysis of the data given in the tables 1 - 3 allows us to draw the following conclusions.

Wear indicator D_w increases by 20,0...30,7 %, at the same time, the larger value refers to the MGP-10 hydraulic oil, and the lower value refers to the transmission oil VALVOLINE GL-5. It follows from the tables that improvements in anti-wear properties for all oils are characteristic up to a concentration 150 g/kg in the base lubricant. If we compare with the data presented in the work [11], where a finely dispersed fullerene powder was

used as an additive, then the wear index D_w increases by 11,1...15 %, at the same time, the improvement of anti-wear properties begins with a concentration of 0.2% masses, fullerenes in the lubricant.

Table 1

Tribological characteristics of hydraulic oil MGP-10 with the addition of fullerenes (F) and with fullerene composition (FC)

Lubricant	D_w, mm	P_{cr}, N	P_{weld}, N	I_b, N
MGP-10, HM	0,65	784	1568	24
MGP-10 + 0,05% F	0,6	784	1568	24
MGP-10 +50 g/kg FC	0,55	823	1568	26
MGP-10 + 0,1% F	0,6	823	1568	24
MGP-10 +100 g/kg FC	0,5	921	1568	28
MGP-10 + 0,15% F	0,6	872	1568	26
MGP-10 +150 g/kg FC	0,45	980	1568	30
MGP-10 + 0,2% F	0,55	921	1568	27
MGP-10 +200 g/kg FC	0,45	980	1568	30
MGP-10 + 0,3% F	0,55	921	1568	27
MGP-10 +250 g/kg FC	0,45	980	1568	30

Table 2

Tribological characteristics of M-10G_{2k}, API CC engine oil with the addition of fullerenes (F) and with fullerene composition (FC)

Lubricant	D_w, mm	P_{cr}, N	P_{weld}, N	I_b, N
M-10G _{2k} , API CC	0,45	1235	2450	28
M-10G _{2k} + 0,05% F	0,45	1235	2450	28
M-10G _{2k} + 50 g/kg FC	0,40	1235	2450	30
M-10G _{2k} + 0,1% F	0,45	1235	2450	29
M-10G _{2k} + 100 g/kg FC	0,35	1303	2450	32
M-10G _{2k} + 0,15% F	0,45	1235	2450	30
M-10G _{2k} + 150 g/kg FC	0,34	1381	2450	34
M-10G _{2k} + 0,2% F	0,4	1303	2450	31
M-10G _{2k} + 200 g/kg FC	0,33	1381	2450	34
M-10G _{2k} + 0,3% F	0,4	1381	2450	31
M-10G _{2k} + 250 g/kg FC	0,33	1381	2450	34

Table 3

Tribological characteristics of VALVOLINE GL-5 gear oil with the addition of fullerenes (F) and with fullerene composition (FC)

Lubricant	D_w, mm	P_{cr}, N	P_{weld}, N	I_b, N
GL-5	0,45	1960	4900	76
GL-5 + 0,05% F	0,45	1960	4900	76
GL-5 + 50 g/kg FC	0,40	2067	4900	82
GL-5 + 0,1% F	0,45	1960	4900	78
GL-5 + 100 g/kg FC	0,38	2195	4900	84
GL-5 + 0,15% F	0,45	2067	4900	80
GL-5 + 150 g/kg FC	0,36	2323	4900	88
GL-5 + 0,2% F	0,4	2195	4900	82
GL-5 + 200 g/kg FC	0,36	2323	4900	88
GL-5 + 0,3% F	0,4	2195	4900	82
GL-5 + 250 g/kg FC	0,36	2323	4900	88

The results obtained allow us to conclude that the concentration limit for the fullerene composition in industrial oils can be 100...150 g/kg. A further increase in concentration does not bring a positive effect.

The positive effect is also characteristic of the indicator – critical load P_{cr} , which characterizes the range of performance of anti-wear additives. The critical load is increased by 18,8...25,0%, the larger value refers to the hydraulic oil and the lower value refers to the transmission oil. At the same time, an increase in the critical load for all oils is characteristic up to a concentration 150 g/kg, in the base lubricant. If we compare with the data presented in the work [11], where a finely dispersed powder of fullerenes was used as an additive, then the critical load increases by 11,8...17,4%.

Changes in the value of the welding load P_{weld} during the experiments were not recorded, this allows us to conclude that the fullerene composition obtained by dissolving a fine powder of fullerenes in vegetable high oleic rapeseed oil does not improve the extreme pressure properties of liquid lubricants, but is only an antiwear additive.

Bully index I_b , which characterizes the integral tribological characteristic of the lubricant increases by 15,7...25,0%, the larger value refers to the hydraulic oil and the lower value refers to the transmission oil. In work [11], where a finely dispersed fullerene powder was used as an additive, it was noted that the bully index I_b increases by 7,8...12,5%.

The obtained experimental results confirm the [12, 13] hypothesis about the possibility of the mechanism of micelle formation in the lubricant under the action of the electrostatic field of the friction surface. The presence of a surfactant solvent (vegetable oil) allows «start» process of micelle formation at lower concentrations of fullerenes and to obtain the effect of increasing anti-wear properties on 20,0...30,7 %, while the dissolution of fullerenes in the base oil without the use of a solvent has the effect of increasing the anti-wear properties on 11,1...15%.

The obtained values of the improvement of antiwear properties coincide with the values obtained by other researchers, whose work is reviewed above.

Conclusions

The use of fullerene compositions in the form of a finely dispersed powder of fullerenes, previously dispersed (dissolved) in vegetable high oleic oils, for example, rapeseed, with the subsequent addition of the resulting composition to technical oils of different viscosity classes and different groups of operation, leads to the following positive effect. The anti-wear properties of oils, which are assessed by the wear indicator, increase by 20,0...30,7 %, and the critical load on 18,8...25,0%. These indicators significantly exceed similar indicators when using fullerene fine powders without preliminary dispersion in vegetable oils, where the effect is on the border 11,1...15 %.

Fullerene additives do not affect the extreme pressure properties of base oils, which are assessed by the bully load. This result makes it possible to state that the way to improve the tribological properties of lubricants by introducing a finely dispersed powder of fullerenes into base technical oils is ineffective. As follows from the above analysis of scientific works such an insignificant effect is typical due to the intense clustering of fullerene molecules in the environment of industrial oils containing surfactants. Technical oils act as a highly polar solvent.

The obtained experimental results confirm the [12, 13] hypothesis about the possibility of the mechanism of micelle formation in the lubricant under the action of the electrostatic field of the friction surface. The presence of a surfactant solvent (vegetable oil) allows you to «start» the micelle formation process at lower fullerene concentrations and to obtain the effect of increasing anti-wear properties.

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Кравцов А.Г. Оцінка трибологічних характеристик технічних олиव з фулереновими композиціями

В роботі представлені експериментальні дослідження трибологічних характеристик рідких мастильних матеріалів різного класу в'язкості і різних груп експлуатації при використанні фулеренових композицій. Трибологічні характеристики оцінювалися на чотирьохкульковій машині тертя згідно ГОСТ 9490.

Використання фулеренових композицій у вигляді дрібнодисперсного порошку фулеренів, попередньо диспергированого (розчиненого) в рослинних високоолеїнових оліях, наприклад, ріпакової, з подальшим додаванням отриманої композиції в технічні оливи різних класів в'язкості і різних груп експлуатації, призводить до наступного позитивного ефекту. Протизносні властивості оливи, які оцінюються показником зносу, збільшуються на 20,0 ... 30,7%, а критичне навантаження на 18,8 ... 25,0%. Дані показники значно перевищують аналогічні показники при застосуванні фулеренових дрібнодисперсних порошоків без попереднього диспергування в рослинних оліях, де ефект знаходиться на межі 11,1 ... 15%.

На протизадирні властивості базових технічних оливи, які оцінюються навантаженням зварювання, фулеренові композиції не впливають. Такий результат дозволяє констатувати, що шлях поліпшення трибологічних характеристик мастильних матеріалів шляхом введення фулеренових композицій в базові технічні оливи є малоефективним.

Отримані експериментальні результати підтверджують гіпотезу про можливість механізму міцелоутворення в змащувальному матеріалі під дією електростатичного поля поверхні тертя. Наявність поверхнево-активного розчинника (рослинна олія) дозволяє «запустити» процес міцелоутворення при більш низьких концентраціях фулеренів і отримати ефект підвищення протизносних властивостей.

Ключові слова: фулерени; рослинні олії; чотирьохкулькова машина тертя; трибологічні характеристики; критичне навантаження; навантаження зварювання; індекс задира; технічні оливи.