Effect of Base Oil Nature on the Operational Properties of Low-Temperature Greases

Yaroslav Porfiryev,* Sergey Shuvalov, Pavel Popov, Dmitry Kolybelsky, Daria Petrova, Evgenii Ivanov, Boris Tonkonogov, and Vladimir Vinokurov

ABSTRACT: Studies of the physicochemical characteristics, group, and fractional composition of low-viscosity base oils with various nature were carried out. The influence of the composition of these oils on their low- and high-temperature characteristics was studied. Studies of the influence of the nature and composition of the dispersion medium on the physicochemical properties of low-temperature greases (LTG) thickened with lithium soap of stearic acid have been carried out. The possibility of expanding the operating temperature range and improving the antiwear properties of low-temperature greases through the combined use of low pour point mineral oil and high-index hydroprocessing oil has been found out. For the first time, the ability to predict the viscosity−temperature and tribological characteristics of lithium LTG based on standard methods for analyzing base oils are established.

1. INTRODUCTION

Global trends in the development of alternative energy sources indicate the preservation of the leading role of hydrocarbon energy carriers until at least the middle of this century. Due to the gradual depletion of deposits in traditional oil and gas basins, special interest is seen in the development of hard-to-recover reserves and exploration of new large deposits. One of the promising underdeveloped regions with high fuel and energy potential is the Arctic. According to various international organizations, at least 15% of the world’s oil reserves and at least 30% of the world’s gas reserves are concentrated in the Arctic zone.1

Ensuring continuous operation of mobile machinery and equipment at extremely low temperatures is impossible without the use of effective lubricants.2 In this regard, the intensification of practical activities for the development of the Arctic region requires additional research in the field of low-temperature greases (LTG) and creation of innovative materials.

The wide range of LTG for specialized friction units, varying by purpose and operating conditions, was developed. The application of these materials is limited due to their narrow specialization. There is an urgent need to create multipurpose greases with a wide range of applications.

To accumulate and systematize the data necessary for the development of multipurpose LTG, the influence of the nature of the base oil on their characteristics has been studied in this paper.

The existing range of mineral base oils includes both high-viscosity residual components, which are well suited for lubricants operated in heavily loaded friction units at high temperatures and shock loadings, and light distillate oils, which are used in lubricants for high-speed lightly loaded units, and these are operated at low temperatures.3

Mineral base oils naturally have a number of beneficial performance properties, such as:

- corrosion prevention of friction units and technological equipment;
- good lubricity and wettability of metal surfaces;
- compatibility with most construction and sealing materials;
- additives acceptance;
- availability and relatively low cost.

Thus, mineral-oil-based greases can provide properties suitable for both general purpose and specific products, thus
maintaining the required balance of productivity and economic efficiency.

Despite the wide range of functional additives and their ability to significantly modify the physical and chemical parameters and operational characteristics, the basic properties of mineral oils due to their fractional and group compositions (for example, evaporation, solvent capacity, propensity to form carbon monoxide, etc.) remain unchanged. Thus, the physical and chemical nature of mineral oils, consisting of a complex mixture of hydrocarbon molecules, imposes a number of restrictions in the field of their operation.

Russian and foreign oil refineries actually do not produce individual grades of oils specifically designed for the production of greases. Oils of the same brand, similar in basic physical and chemical parameters, produced according to the same regulatory document but obtained from different oils or different purification methods, can differ significantly by the group hydrocarbon composition and the structure of their constituent hydrocarbons.

In the dispersion medium of low-temperature greases, the content of aromatic hydrocarbons should be limited, so it is recommended to use naphthenic-paraffin base oils with better multigrade properties. However, the distillation characteristic of these oils significantly limits the upper temperature limit of the operation of lubricants based on them; therefore, the creation of multipurpose LTG, working in a wide range of operating temperatures, significantly increases the requirements for the quality of dispersion media, and these requirements are satisfied with the use of synthetic base oils and oils of hydrocatalytic processes.

The hydrocatalytic processes for the production of API group III base oils are now becoming more widespread. According to the forecasts, in the period of 2016–2026, the global demand for group III base oils is expected to increase by about 5%, while the demand for the first group base oils is predicted to decrease.

Figure 1 shows the change in demand for base oils in the period of 2005–2010, as well as the forecast for 2020–2030.

![Figure 1. Base oil demand.](image)

The overall picture of the base oil production modernization in Russia is characterized by the transition to hydrocatalytic processes and the gradual abandoning of the classical schemes of solvent refining and dewaxing.

The main purpose of hydrocracking oil is the production of high-viscosity index base oils. Base oils obtained during hydrocracking-hydroisomerization have kinematic viscosity at 50 °C from 2 to 20 mm²/s, viscosity index up to 140, and pour point up to −70 °C. The advantages of these oils in comparison with mineral oils are:

- good chemical stability;
- less loss;
- improved low-temperature properties;
- narrow group composition;
- higher flash point;
- good additives acceptance;
- high viscosity index.

The properties of hydrocracking oils are determined by their narrower fractional and chemical composition. These oils mainly contain high degree of branching isoparaffin hydrocarbons, naphthenic, and monocyclic aromatic hydrocarbons. During the cleaning process of the oil raw materials with selective solvents, unnecessary components are removed; as a result of hydrocatalytic processes, its chemical transformation occurs.

Table 1 shows the main chemical reactions and hydrocarbons formed during hydrocracking of high-viscosity oil raw materials.

As a result of these transformations, the group hydrocarbon-type content of raw material changes greatly in the direction favorable for commercial oils: the content of condensed aromatic hydrocarbons is significantly reduced and those of naphthenic and isoparaffin are significantly increased.

Thus, due to the intensification of the development of oil hydrocracking processes by domestic oil refineries, as well as the existing advantages of oils obtained as a result of these processes in comparison with mineral, and the relatively low cost compared with those of synthetic components, the study of the possibility of using hydrocracking oils as dispersion media in the production of multipurpose low-temperature greases, which show long-term performance in a wide range of operating temperatures (from −50 to +180 °C), is significantly interesting.

Synthetic oils are several (and sometimes ten) times expensive than petroleum oils, so their use is often limited to special-purpose lubricants operated in a wide range of temperatures and speeds, at high specific loads, in high vacuum, in an aggressive environment, etc.; the reliability and long-term performance of these oils compensate the increased expenses associated with their higher price.

Poly-α-olefin oils (PAOs) obtained by oligomerization of α-olefins, as well as various esters, are the most widely used as synthetic dispersion media of greases.

The most widely used low-viscosity base oils with different viscosity indices and pour points were studied as a dispersion medium at the first stage. The analysis of their group and fractional composition was carried out, and the basic dependences of the nature of oils and their low- and high-temperature characteristics were studied.

At the second stage, changes in the properties of low-temperature lithium lubricants were studied depending on the characteristics of the dispersion medium (mineral, hydroprocessing, and poly-α-olefin oils with kinematic viscosity at 100 °C not more than 5 cSt). The content of the dispersion medium in the composition of greases averages 75–95% and therefore the nature, the structure, and the content of various groups of hydrocarbons and the presence of natural surfactants in the base oils have a significant impact on the formation of the structure, performance in a certain temperature range, and other physicochemical, structural–mechanical, and operational characteristics of greases produced on their basis.
The following products were studied: compositions of base oils on their low- and high-temperature characteristics. As part of the study on the influence of group and fractional composition of base oils on low- and high-temperature characteristics, the following products were studied:

- mineral: oil S-9 for chemical fiber manufacturing, base stock oil MS-8, and additive-free spindle oil AU obtained by solvent processes;
- oils obtained by hydroprocesses: hydrocracked transformer oil GK, oil NexBase 3020 (NB 3020), and oil VHVI-4;
- synthetic poly-alpha-olefin oils PAO-2 and PAO-4 based on decen-1 oligomers.

The following standard evaluation methods were used to study the basic physical and chemical properties of the tested oils:

- ASTM D 445 “Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids”;
- ASTM D 92 “Standard Test Method for Flash and Fire Points by Cleveland Open-Cup Tester”;
- ASTM D 97 “Standard Test Method for Pour Point of Petroleum Products”;
- ASTM D 1298 “Standard Test Method for Density, Relative Density”;
- ASTM D 5293 “Standard Test Method for Apparent Viscosity of Engine Oils and Base Stocks between −10 and −35 °C using Cold-cranking Simulator”;
- ASTM D 4684 “Standard Test Method for Determination of Yield Stress and Apparent Viscosity of Engine Oils at Low Temperature”;
- ASTM D 5800 “Standard Test Method for Evaporation Loss of Lubricating Oils by the Noack Method”;
- ASTM D 2887 “Standard Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography”. The analysis was performed using hardware and software complex Chromatek Crystal 5000.2 with flame ionization detector and column MXT-2887, 10 m × 0.53 mm × 2.65 μm under control of “Chromatek Analytic” software;
- ASTM D 2501 “Standard Test Method for Calculation of Viscosity-Gravity Constant (VGC) of Petroleum Oils”;
- ASTM D 2140 “Standard Practice for Calculating Carbon-type Composition of Insulating Oils of Petroleum Origin”. Method of calculative determination of group composition of mineral based insulating oils;
- BashNII technique for determination of hydrocarbon-type content by liquid adsorption chromatography with gradient displacement. Activated silica gel ASK was used as an absorbent. The analysis was performed on chromatographic install "Gradient-M", produced by the Institute of Petroleum Refining and Petrochemistry, JSC. The method allows to determine the content of aromatic hydrocarbons of various structures and the total content of paraffin—naphthenic hydrocarbons.

To study the influence of nature and composition of the dispersion medium on the physical and chemical properties of low-temperature greases (LTG), the samples of greases based on the studied base oils and lithium stearate were prepared. The concentration of thickener for each sample was selected individually to obtain the penetration value of 280 ± 5. Sample preparation was carried out in the research reactor with the stirring device equipped with the heating jacket with the thermal fluid (IR).

The following standardized methods were applied to study the physical and chemical characteristics of greases samples:

- ASTM D 217 “Standard Test Methods for Cone Penetration of Lubricating Grease”;
- ASTM D 566 “Standard Test Method for Dropping Point of Lubricating Grease”;
- ASTM D1742 “Standard Test Method for Oil Separation from Lubricating Grease during Storage”;
- GOST 7142-74 “Greases. Methods of determining colloidal stability”;
- GOST 7143-74 “Greases. Method of determining the ultimate strength and homestrengthening ” (method B);
- GOST 7163-84 “Mineral oils. Method of determining the viscosity by automatic capillary viscometer”;
- GOST 9566-74 “Greases. Method of determining of evaporation” for 1 h at a temperature of 120 °C; and
- GOST 9490-75 “Lubricating materials, liquid and plastic. Method of determining the tribological characteristics on a four-ball machine”.

3. RESULTS AND DISCUSSION

3.1. Investigation of the Dependence of Low- and High-Temperature Characteristics of Base Oils on Their Fractional and Group Compositions. The purpose of this stage of research is to study the influence of fractional and group composition of base oils of different nature on their physical, chemical, and operational characteristics.

The fractional composition of petroleum products represents the content of various fractions boiling at the certain temperature range. The peculiarity of low-viscosity base oils
is the presence, along with oil distillates (350–500 °C), of significant amount of hydrocarbons of the diesel fraction (250–350 °C), which is confirmed by the results given in Table 2 and Figures 2 and 3.

The oil S-9 for chemical fiber manufacturing and base stock oil MS-8 have similar fractional composition and are characterized by similar flash point and Noack evaporability because they are produced from the same vacuum gas oil fraction. The feedstock in the production of additive-free spindle oil AU in contrast with oils S-9 and MS-8 is the weighted fraction of vacuum gas oil; therefore, the oil AU is characterized by a higher flash point and a relatively low NOACK evaporability.

The oils GK and NB 3020 are characterized by the highest content of fractions boiling up to 350 °C. However, the oil NB 3020 has a narrow temperature range of boiling.

VHVI-4 oil is characterized by the highest boiling point, narrow fractional composition, the lowest NOACK evaporability, and almost complete absence of hydrocarbons characteristic of diesel fractions.

Regarding the data presented in Table 2 and Figures 2 and 3, it can be concluded that the oils with the lowest boiling point of 50% of the mass are characterized by the highest NOACK evaporability. In addition, the following pattern was observed for low-viscosity mineral and hydroprocessing oils: oil losses from evaporation by the NOACK test correspond to the distillate fraction at 375 ± 10 °C. Thus, the fractional composition of the studied base oils under study has a serious impact on the kinematic viscosity, flash point, and evaporation, while the dependence of other physical and chemical characteristics on the fractional composition in comparison with the influence of the group composition is less expressed.

The results of the studies of the main low-temperature (pour point, apparent viscosity cold-cranking simulator (CCS), and dynamic viscosity minirotary viscometer (MRV)) and high-temperature characteristics (kinematic viscosity at 100 °C, flash point in the open crucible, and evaporation by NOACK), as well as the evaluation of the group composition of base oils by analytical and computational methods are presented in Table 3.

During the analysis of the group chemical composition of base oils by the method of BashNII, it was found that mineral oils S-9, MS-8, and AU contain aromatic compounds of different structures. Hydrocatalytic processes oils GK, NB 3020, and VHVI-4 as well as synthetic poly-α-olefin oils do not contain aromatic hydrocarbons in their composition. To establish the ratio of paraffin and naphthenic hydrocarbons in oils, the ASTM D2140 analysis was performed. This technique allows to obtain the calculated values of the content of paraffin, naphthenic, and aromatic hydrocarbons in low-viscosity oils.

Further, the influence of group composition of base oils on their physical and chemical characteristics is studied on the example of mineral oils S-9, MS-8, and AU and hydrocatalytic oils GK, NB 3020, and VHVI-4.

The mineral oils S-9 and MS-8 are obtained from the same oil fraction at different operating modes of solvent extraction units and dewaxing. The ratio of paraffin and naphthenic compounds in the tested oils is almost the same, but MS-8 oil is characterized by the lower content of heavy and large-light aromatic hydrocarbons and consequently has a higher viscosity index, lower pour point, and lower evaporation by the NOACK test.

The additive-free spindle oil AU is characterized by the lowest content of saturated hydrocarbons and a higher

| parameter/name of base oil | oil S-9 | MS-8 base stock | oil AU | oil GK | NB 3020 | VHVI-4 | PAO-2 | PAO-4 |
|---------------------------|---------|----------------|-------|-------|---------|-------|------|------|
| initial boiling point (°C) | 268     | 260            | 286   | 226   | 260     | 370   | 259  | 372  |
| 25% distillation temperature (°C) | 339     | 338            | 371   | 310   | 324     | 414   | 414  | 422  |
| 50% distillation temperature (°C) | 365     | 374            | 391   | 349   | 349     | 423   | 331  | 427  |
| end boiling point (°C) | 460     | 484            | 499   | 499   | 402     | 485   | 485  | 603  |
| range of start and end boiling (°C) | 192     | 222            | 213   | 273   | 142     | 115   | 173  | 231  |
| distillate fraction at 350 °C (% weight) | 32.709  | 33.447         | 13.546| 50.407| 51.993  | 0.188 | 70.916| 0.000|

Figure 2. Distillate percentage dependence on distillation temperature of mineral oils.

Figure 3. Distillate percentage dependence on the distillation temperature of hydroprocessing.
Table 3. Physical and Chemical Characteristics of Lubricating Oils

| no. | parameter                              | oil S-9  | MS-8 base stock | oil AU | oil GK | NB 3020 | VHVI-4 | PAO-2 | PAO-4 | oil GK 82% + VHVI-4 18% | NB 3020 63% + VHVI-4 37% | oil S-9 50% + VHVI-4 50% |
|-----|----------------------------------------|----------|-----------------|--------|--------|---------|--------|-------|-------|-------------------------|--------------------------|--------------------------|
| 1   | kinematic viscosity at 40 °C (cSt)     | 10.88    | 11.27           | 17.40  | 9.44   | 7.65    | 21.02  | 5.60  | 18.20 | 10.79                   | 10.80                    |                           |
| 2   | kinematic viscosity at 100 °C (cSt)    | 2.74     | 2.82            | 3.40   | 2.54   | 2.24    | 4.43   | 1.90  | 4.06  | 2.78                    | 2.83                     |                           |
| 3   | viscosity index                        | 86       | 90              | 41     | 94     | 99      | 123    | 124   | 98    | 108                     |                          |                           |
| 4   | pour point (°C)                        | −50      | −55             | −48    | −60    | −54     | −24    | −70   | −68   | −36                     | −28                      |                           |
| 5   | open-cup flash point (°C)              | 176      | 175             | 189    | 162    | 148     | 227    | 172   | 222   | 170                     | 176                      |                           |
| 6   | density at 15 °C (kg/m³)               | 854.2    | 857.2           | 867.1  | 858.2  | 836.3   | 838.2  | 801.5 | 820.4 | 855.5                   | 837.2                    |                           |
| 7   | density at 20 °C (kg/m³)               | 849.4    | 854.4           | 863.4  | 854.4  | 835.4   | 837.4  | 799.4 | 817.4 | 850.4                   | 835.4                    |                           |
| 8   | refractive index                       | 1.4684   | 1.4708          | 1.4762 | 1.4684 | 1.4602  | 1.4628 | 1.4668| 1.4568| 1.4684                  | 1.4628                   |                           |
| 9   | CCS, −35 °C (mPax-s)                   | 1076     | 1266            | 3903   | 1036   | 331     | 3634   | 238   | 1555  | 840                      | 1815                     |                           |
| 10  | MRV, −40 °C (mPax-s)                   | 2005     | 2390            | 7667   | 1916   | 794     | 23061  | 1040  | 2683  | 3166                     | 3430                     |                           |
| 11  | NOACK test (%)                         | 62.97    | 58.56           | 35.67  | 68.10  | 82.32   | 12.36  | 94.14 | 15.62 | 61.49                    | 54.25                    |                           |
| 12  | group composition BashNII test,        |          |                 |        |        |         |        |       |       |                          |                          |                           |
|     | hydrocarbon content (wt %):            |          |                 |        |        |         |        |       |       |                          |                          |                           |
|     | paraffin-naphthenes                    | 91.3     | 89.1            | 85.8   | 100.0  | 100.0   | 100.0  | 100.0 | 100.0 | 100.0                   | 96.0                     |                           |
|     | light aromatic                         | 4.4      | 7.6             | 7.2    | 0.0    | 0.0     | 0.0    | 0.0   | 0.0   | 0.0                      | 0.0                      |                           |
|     | medium aromatic                        | 1.5      | 1.7             | 1.5    | 0.0    | 0.0     | 0.0    | 0.0   | 0.0   | 0.0                      | 0.0                      |                           |
|     | heavy aromatic                         | 2.8      | 1.5             | 5.5    | 0.0    | 0.0     | 0.0    | 0.0   | 0.0   | 0.0                      | 0.0                      |                           |
| 13  | carbon-type composition ASTM D2140,     |          |                 |        |        |         |        |       |       |                          |                          |                           |
|     | hydrocarbon content (wt %):            |          |                 |        |        |         |        |       |       |                          |                          |                           |
|     | paraffins                              | 63.0     | 62.0            | 63.0   | 55.0   | 64.0    |        |       |       |                          |                          |                           |
|     | naphthenes                             | 34.0     | 35.0            | 32.0   | 45.0   | 36.0    |        |       |       |                          |                          |                           |
|     | aromatic                               | 3.0      | 3.0             | 5.0    | 0.0    | 0.0     |        |       |       |                          |                          |                           |

“For these oils, the calculation method for determining the group composition is not applicable.”
Table 4. Dependence of the Physical and Chemical Parameters of the LTG on the Composition of the Dispersion Medium

| no. | parameter                                      | base oils                                           |
|-----|-----------------------------------------------|----------------------------------------------------|
|     |                                               | oil S-9    | MS-8 base stock | oil AU | oil GK | NB 3020 | VHVI-4 | PAO-2 | PAO-4 | oil GK + VHVI-4 | NB 3020 + VHVI-4 | oil S-9 + VHVI-4 |
|     | amount of thickener (%)                       | 11.00      | 10.50           | 10.00  | 9.25  | 8.50    | 9.25   | 10.50 | 10.50 | 8.25            | 8.25            | 10.00            |
| 1   | penetration at 25 °C (mm⁻¹)                    | 285        | 281             | 276    | 283   | 285     | 281    | 285   | 277   | 283             | 284             | 285              |
| 2   | yield stress at 50 °C (Pa)                     | 220        | 200             | 260    | 320   | 140     | 320    | 260   | 190   | 310             | 330             | 260              |
| 3   | colloidal stability (% separated oil)         | 25.5       | 24.6            | 22.3   | 26.3  | 36.6    | 25.6   | 24.5  | 20.8  | 27.1            | 26.8            | 23.1             |
| 4   | oil separation during storage (%)             | 9.6        | 7.9             | 7.6    | 12.1  | 17.3    | 6.4    | 6.2   | 12.6  | 12.5            | 9.5             |
| 5   | dropping point (°C)                            | 196        | 198             | 198    | 192   | 200     | 211    | 205   | 205   | 194             | 198             |
| 6   | vaporability at 120 °C 1 h (%)                 | 5.5        | 5.8             | 2.4    | 13.7  | 8.3     | 0.6    | 7.4   | 19    | 12.7            | 6.2             |
| 7   | wear scar diameter (mm)                        | 0.90       | 0.88            | 0.82   | 0.63  | 0.71    | 0.66   | 0.81  | 0.57  | 0.60            | 0.69            |
| 8   | effective viscosity at:                        |            |                 |        |       |         |        |       |       |                 |                 |
|     | −20 gradient 10 s⁻¹                             | 107        | 100             | 123    | 103   | 42      | 100    | 64    | 88    | 126             | 113             | 105              |
|     | −30 gradient 10 s⁻¹                             | 155        | 151             | 159    | 113   | 63      | 229    | 93    | 162   | 150             | 180             | 147              |
|     | −40 gradient 10 s⁻¹                             | 210        | 159             | 355    | 142   | 109     | 398    | 128   | 190   | 207             | 278             | 394              |
|     | −50 gradient 10 s⁻¹                             | 593        | 421             | 743    | 291   | 217     | 992    | 162   | 337   | 334             | 483             |
|     | −60 gradient 10 s⁻¹                             | 1384       | 962             | 807    | 492   | 2351    | 257    | 879   | 790   | 889             | 1733            |
|     | +20 gradient 100 s⁻¹                            | 10.5       | 10.5            | 15.3   | 9.8   | 15.9    | 8.9    | 9.8   | 11.0  | 10.7            |

ACS Omega http://pubs.acs.org/journal/acsodf

https://dx.doi.org/10.1021/acsomega.9b04087
concentration of heavy aromatic compounds, which is probably due to the deep degree of dewaxing and weighing of the original oil fraction. The group composition of AU oil determines its poor viscosity—temperature characteristics (viscosity index, CCS, MRV) while providing the low pour point.

The hydrocatalitic oils GK and NB 3020 differ in the ratio of paraffin and naphthenic hydrocarbons. The highest content of naphthenic hydrocarbons (45%) was established for GK oil, which explains its worse viscosity—temperature characteristics compared with those of NB 3020 oil, which contains 36% naphthenic compounds. This also explains the higher density of GK oil, lower pour point, and lower evaporation by the NOACK test.

VHVI-4 oil consists of branched paraffin hydrocarbons, the main part of which boils in the temperature range of 400–460 °C. This explains a high pour point (−24 °C) and the worst low-temperature properties (CCS, MRV). However, isoparaffin hydrocarbons provide a high viscosity index and the introduction of a small number of depressor additives allows them to achieve viscosity—temperature characteristics comparable to those of poly-α-olefin oils.

Thus, the group composition of base oils is the decisive factor, which determines the value of their dynamic viscosities at negative temperatures, which is clearly shown in the results of the CCS tests of VHVI-4 oil mixtures with GK oil and NB 3020 oil. Oil mixture oil-based on NB 3020 oil, despite relatively high temperature of solidification (−28 °C), has significantly lower CCS viscosity at −35 °C than the mixture based on GK oil (the pour point at −36 °C) and S-9, MS-8, and GK oils (pour points −50, −55, and −60 °C, respectively).

**3.2. Investigation of the Dependence between Physical and Chemical Properties of LTG and the Dispersion Medium.** An analysis of the samples of greases with penetration of 280 ± 5 prepared by thickening the studied base oils with lithium stearate revealed that their thickening capacity is maximal for hydiprocessing oils having similar group composition. In addition, smaller amount of thickener in lubricants based on hydiprocessing oils provides higher yield stress value in comparison with the samples of LTG based on other base oils (Table 4).

Colloidal stability according to GOST 7142, which characterizes the ability of the structural frame of the thickener to retain the dispersion medium, is 24 ± 3% of the extracted oil for all prepared samples of the OPS (except for the sample on oil NB 3020). In this case, the oil separation during storage (ASTM D1742 method) is 2–3 times lower in absolute value and decreases with increasing viscosity of the base oil, and for lubricants prepared on a mixture of base oils, it corresponds to the value determined for oil with higher density and therefore depends on the group composition.

Evaporation rates of LTG samples at 120 °C are directly dependent on the fractional composition and for low-viscosity mineral and hydprocessing oils correspond to the proportion of distillate at 300 ± 10 °C. The comparative analysis of the tribological characteristics of grease samples showed that lubricants based on mineral oils C-9, MS-8, and AU, containing aromatic hydrocarbons of various structures, as well as RAO-2 synthetic oil, which is a decene-1 oligomer, have the worst antiwear properties. Samples based on hydiprocessing oils and PAO-4 oil showed the best antiwear properties. The pattern is confirmed,77,28 that poly-α-olefin-based greases have better lubricity compared to greases based on mineral base oils with similar viscosity. It should be noted that for LTG samples, unlike for greases based on mineral base oils with medium and high viscosity,29 dependence of the wear scar on the amount of naphthenic hydrocarbons in the composition of their dispersion medium is more typical than dependence on its viscosity. The different effect of aromatic and naphthenic hydrocarbons on the antiwear properties of LTG is most likely due to the peculiarities of the adsorption interaction of base oil molecules with the metal surface of friction pairs, which results in the formation of boundary chemosorption films of different strengths and thicknesses.

The main distinguishing feature of greases from oils is the viscosity anomaly, which does not obey Newton’s law and depends not only on temperature but also on the strain rate. This feature of plastic lubricants as colloidal dispersed systems explains the absence of a model that describes the dependence of effective viscosity on temperature.

**Figure 4** shows the viscosity—temperature characteristics of the LTG based on mineral oils S-9 and MS-8, as well as on mixtures of hydiprocessing oils GK + VHVI-4 and NB 3020 + VHVI-4 in ratios that provide kinematic viscosity at 100 °C similar to the viscosity of oils S-9 and MS-8. Greases based on mixtures of hydiprocessing oils provide the best viscosity—temperature properties despite the relatively high pour points.
Greases based on hydroprocessed oil GK and synthetic poly-
α-olefin oil PAO-4 have similar viscosity–temperature proper-
ties in the studied temperature range (Figure 5). At the same
time, PAO-4 oil has higher values of kinematic viscosity (4.06
vs 2.54 cSt at 100 °C). Synthetic oil PAO-2 provides the best
low-temperature characteristics of greases based on it. Thus,
for LTG based on base oils of the same nature, obvious
dependence of their effective viscosity on the kinematic
viscosity of the dispersion medium is observed, which does
not correlate with the results of similar research conducted on
the rotational viscometer.30

Figure 6 shows the dependence of the effective viscosity on
the temperature for lubricants based on oils with different
natures with a kinematic viscosity of 4.0 ± 0.6 cSt at 100 °C. It
was found that the lubricant based on synthetic oil PAO-4,
which has a high viscosity index (124) and the lowest pour
point (−68 °C), is characterized by the best low-temperature
properties. Lubrication based on oils obtained as a result of
hydrogenation processes VHVI-4 with high viscosity index
(123) and the highest pour point (−24 °C) at temperatures of
up to −50 °C has values of effective viscosity close to those of
grease based on mineral oil AU with the lowest viscosity index
(41) and much lower that those for pour point (−48 °C);
however, at temperatures of −53 °C, high-viscosity oil VHVI-4
provides better low-temperature properties for lubrication,
prepared on its basis, in comparison with mineral oil AU.

A study of the dependence of the viscosity–temperature
properties of grease samples on the composition of the
dispersion medium showed that the maximum increase in the
effective viscosity is observed in the interval corresponding to
the pour point of the base oil. When the temperature decreases
further, the effective viscosity of grease depends on the
viscosity index of base oil.

4. CONCLUSIONS

The influence of fractional composition on the high-temper-
ature properties of both base oils (kinematic viscosity, flash
point, NOACK evaporability) and greases based on them was
discovered for the first time. The following regularity was
found: the evaporation at 120 °C of LTG samples on the basis
of low-viscosity mineral and hydproprocessing oils corresponds
to the proportion of distillation at 300 ± 10 °C. When
developing multipurpose LTG and selecting a dispersion
medium, it is necessary to focus on fractional composition as
one of the factors determining the upper temperature limit of
LTG operation.

The content of the type of hydrocarbon affects the
viscosity–temperature and antwear characteristics of base
oils and LTG based on them as well as the thickening capacity
of the dispersed phase of greases and their colloidal stability.
The best viscosity–temperature characteristics have LTG with
isoaraffin hydrocarbons dominating in the dispersion
medium. Aromatic hydrocarbons have a negative impact on
the antwear characteristics of the LTG, while the increase in
napthenes content in the composition of low-viscosity
dispersion media improves the lubricity of the LTG based
on them.

Thus, the uniqueness of the present work lies in establishing
the ability to predict the viscosity–temperature and
tribological characteristics of lithium LTG based on standard
methods for analyzing base oils. This research showed the
possibility of obtaining LTG with extended operating temper-
ature range and extended antwear properties by adjusting the
fractional and group composition of the dispersion medium by
the joint application of low-viscosity mineral oil and high index
mid-viscosity hydproprocessing base oils (like VHVI-4).

![Figure 6. Viscosity–temperature properties LTG based on oils of different nature.](image-url)
REFERENCES

(1) Shvets, N. N.; Beresneva, P. V. In Oil and Gas in Arctic: Legal Status, Reserve Estimates and Economic Feasibility Study, MGIMO Review of International Relations, 2014; pp 54–59.

(2) Parenago, O. P.; Safieva, R. Z.; Antonov, S. V.; Stenina, N. D.; Lyadov, A. S. State and prospects of development of biodegradable greases production. Pet. Chem. 2017, 57, 1144–1146.

(3) Ishchuk, U. L. Tekhnologiya plastichnykh smazok; Nauk. Dumka: Kiev, 1986; p 248.

(4) Coffin, P. S. Characteristics of synthetic lubricating greases. J. Synth. Lubr. 1984, 1, 34–60.

(5) Kulleev, A. M. Himiya i tekhnologiya prisadok k maslам и toplivam; Khimiya: Leningrad, 1985; p 312.

(6) Lynch, T. R. Process Chemistry of Lubricant Base Stocks; CRC Press: Boca Raton, 2007; p 392.

(7) Lend’el, I. V.; Ishchuk, U. L. Issledovanie vlyaniya frakcionnogo sostava и vyazkosti dispersionnoj sredy na nizkotemperaturnye svojstva smazok; Nauk. Dumka: Kiev, 1978; pp 178–179.

(8) Garshin, M. V.; Porfir’yev, Y. V.; Zaychenko, V. A.; Shuvalov, S. A.; Kolybelsky, D. S.; Gushchin, P. A.; Vinokurov, V. A. Effect of base oil composition on the low-temperature properties of polyurea greases. Pet. Chem. 2017, 57, 1177–1181.

(9) Razvi, S. A Comprehensive Review of Lubricant Chemistry, Technology, Selection and Design; ASTM International: West Conshohocken, Baltimore, 2009.

(10) Beercheck, R. Global Outlook; Lubes’n’Greases, 2015; pp 25–30.

(11) Masson, R. Base Oil Report; Lubes’n’Greases, 2017; pp 6–16.

(12) The Global and Asian Base Oils Market: Overview of the Market in 2015. In presentation material at 10th ICIS Asian Base Oils & Lubricants Conference; Kline, 2016.

(13) Fathi-Najafi, M.; Malm, L.; Li, J. Replacement of group I; A way forward for the grease manufacturers. Tribol. Schmierengtech 2018, 65, 14–19.

(14) Kapustin, V. M.; Tonkonogov, B. P.; Fuchs, I. G. Oil Refining Technology. Part 1: Primary Oil Processing; KolosS: Moscow, 2012; p 456.

(15) De Laurentis, N.; Cann, P.; Lugt, P. M.; Kadirić, A. The influence of base oil properties on the friction behaviour of lithium greases in rolling/sliding concentrated contacts. Tribol. Lett. 2017, 65, No. 128.

(16) De Laurentis, N.; Kadirić, A.; Lugt, P.; Cann, P. The influence of bearing grease composition on friction in rolling/sliding concentrated contacts. Tribol. Int. 2016, 94, 624–632.

(17) Mota, V.; Ferreira, L. A. Influence of grease composition on rolling contact wear: Experimental study. Tribol. Int. 2009, 42, 569–574.

(18) Delgado, M. A.; Valencia, C.; Sanchez, M. C.; Franco, J. M.; Gallegos, C. Influence of soap concentration and oil viscosity on the rheology and microstructure of lubricating greases. Ind. Eng. Chem. Res. 2006, 45, 1902–1910.