The Oscar Publishing Services
American Journal of Applied Science and Technology

VOLUME Vol.06 Issue 02 2026
PAGE NO. 14-24
DOI 10.37547/ajast/Volume06Issue02-02

Processing Used Oils To Produce Reducer Lubricants And Studying Their Physicochemical Properties

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Received: 14 December 2025; **Accepted:** 06 January 2026; **Published:** 09 February 2026

Abstract: Work is underway to develop experimental samples of reducer lubricating oil compositions based on locally available raw materials and secondary (recycled) materials from the chemical industry. Reducer lubricants RSMy.s.-Y (summer) and RSMy.s.-Q (winter) are semi-fluid reducer lubricants intended for use in gear transmissions of heavy machinery reducers. RSMy.s.-Y is designed for operation in summer conditions, while RSMy.s.-Q is intended for winter conditions.

Keywords: Reducer, lubricant, used oil, deparaffinated residual oil, gossypol resin, additives, combination, viscosity, sorbents, regeneration.

INTRODUCTION:

Today, there are various methods for restoring and purifying used oils. The selection of suitable methods depends on the nature of their physical and mechanical properties, the specific characteristics of contamination, the advantages and economic efficiency of regeneration processes, and the feasibility of their application. In view of the study's objectives, special attention is given to restoring used oils with sorbents, including adsorbents.

The operation of used oils (transformer, engine, etc.) is always associated with certain changes in their physicochemical properties, which ultimately limit their service life. The products of physicochemical changes in oils, as well as harmful impurities entering from outside and rendering oils unsuitable for further use, constitute an insignificant fraction of the total mass and can be removed using various purification methods. After contaminants and wear products are separated from the oil during regeneration, the physical and mechanical properties of the oils are restored, and, as a rule, they can be reused either together with new oils or by mixing with them.

The choice of a method for regenerating used oils is determined by the nature of contaminants and wear products present in them: for some oils, simple removal of mechanical impurities is sufficient; for others, deeper processing is required; and in some cases sorbents are used. Before considering regeneration methods for used oils, it is necessary to analyze how their properties change under environmental influences during the service period.

METHODOLOGY

Today, humanity's demand for machines, equipment, electrical devices, public transport, and automobiles is increasing year by year. The above-mentioned machines and devices can hardly operate without lubricating oils. This scientific article employs traditional/classical approaches as well as physicochemical and mathematical modeling methods.

RESULTS

Reducer lubricating oil compositions were produced on the basis of used motor oil, deparaffinated residual oil, gossypol resin, and the anti-wear and anti-deposit additive RD-7 (zinc dialkyldithiophosphate). Experimental samples of the reducer lubricating oil composition were prepared by combining the following components:

- used M-20A grade motor oil (IMM);
- deparaffinated residual oil (DQM);
- gossypol resin (GQ);
- RD-7 additive.

The combined reducer lubricating oil compositions are presented in Table 1.

Table 1

Composition of substances in reducer lubricants (%)

Name of combined sample	Composition of substances,%			
	IMM (M-20A)	DQM	GQ	RD-7 additive
RSM-1	40	45	14,5	0,5
RSM-2	40	40	19,5	0,5
RSM-3	45	40	14,7	0,3
RSM-4	45	45	9,5	0,5
RSM-5	50	40	9,7	0,3
RSM-6	55	35	9,7	0,3

According to Table 1, the physicochemical indicators of the RSM-5 sample fully comply with the requirements of TSh 05767930-286:2018, and research work was carried out based on Table 3.4 to evaluate the quality of its performance indicators.

Table 2

Regulatory requirements of TSh 05767930-286:2018 for semi-fluid reducer lubricants

Names of indicators	Requirement for the brand		Method of testing
	Summer	Summer	
Density at 20°C, kg/m³	Not standardized — to be determined.		GOST 3900 or GOST 31392
Kinematic viscosity at 100°C, mm²/s (range)	90,0-110	135-165	GOST 31391
Viscosity index, not less than	55-60	60-75	GOST 25371 or GOST 32500
Pour point (solidification temperature), °C, not higher than *(i.e., "below")*	-11	-15	GOST 20287 or GOST 32393
Flash point in an open cup, °C, not lower than *(i.e., "above")*	200		GOST 4333 or GOST 12.1.044

Mass fraction of mechanical impurities, %, not more than	0,015	GOST 6370
Mass fraction of water, %, not more than	Izlar	O'z DSt 3271
Acid number, mg KOH per 1 g of oil, not more than	1,2	GOST 5985 or GOST 11362
Copper strip corrosion test at 100°C for 3 hours, rating, not worse than *(i.e., "less than" in your text)*	1b	GOST 2917 or GOST 32329
Color by SNT colorimeter, SNT units	Not standardized; to be determined.	GOST 20284

Study on determining the density of RSMK at 20°C. The density of RSM samples was determined through tests conducted in accordance with GOST 31392-2009 "Crude oil and petroleum products. Methods for determining density, relative density, and API gravity using a hydrometer." The tests were carried out at the Central Laboratory of the Fergana Oil Refinery, and the following indicators were obtained (Table 3).

Table 3.
Density indicators of reducer lubricants

Indicator name	Gearbox lubricants					
	RSM-1	RSM-2	RSM-3	RSM-4	RSM-5	RSM-6
Density at 20°C, kg/m³	965	973	969	889	901	913
Density at 40°C, kg/m³	905	912	907	824	839	850
Density at 100°C, kg/m³	859	865	862	801	808	814

It was observed that the density of the reducer lubricant samples presented in Table 5 varies depending on the amount of gossypol resin used as a thickener, and a graph was plotted in Figure 1.

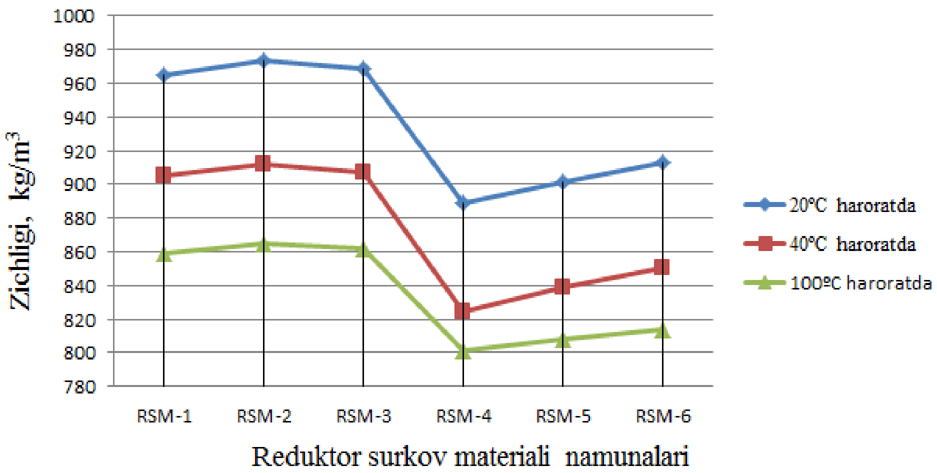

Figure 1. Temperature dependence of the density of reducer lubricant samples.

As can be seen from Figure 1, the densities of the RSM-1, RSM-2, and RSM-3 samples are very close to the regulatory requirements for plastic lubricants, while the RSM-4, RSM-5, and RSM-6 samples correspond to the regulatory requirements for semi-fluid reducer lubricants.

Study on determining the kinematic viscosity of RSM at 20, 40, and 100°C. The kinematic viscosity of RSM samples was determined through tests conducted in accordance with GOST 31391-2009 “Petroleum products. Transparent and opaque liquids. Method for determination of kinematic viscosity and calculation of dynamic viscosity.” Based on the obtained results, the kinematic viscosity was calculated using the formulas below. Before calculating kinematic viscosity, the dynamic viscosity was calculated using the Poiseuille equation. The Poiseuille equation is as follows:

$$\eta = \frac{\pi \Delta P r^4 \tau}{8LV} \qquad (1)$$

where:

η — dynamic viscosity, Pa·s;

ΔP — pressure difference in the capillary, dyn/cm²;

r — capillary radius, cm;

L — capillary length, cm;

V — volume of liquid passing through the capillary, cm³;

τ — time for the liquid to pass through the capillary, s.

The pressure difference is determined as follows:

$$\Delta P = gH\rho \qquad (2)$$

where:

g — acceleration due to gravity, m/s²

H — difference between liquid levels in the viscometer, cm;

ρ — relative density of the liquid, g/cm³.

Then the dynamic viscosity is:

$$\eta = \frac{\pi g H \rho r^4 \tau}{8LV} \qquad (3)$$

The viscometer constant **C** (mm²/s²), taken from the viscometer passport, is calculated as:

$$\frac{\pi g H r^4}{8LV} = const = C \qquad (4)$$

Therefore, dynamic viscosity can be written as:

$$\eta = C\tau\rho \qquad (5)$$

To determine the **kinematic viscosity** of the reducer lubricant, the following formula is used: (text continues).

$$\nu = C\tau \qquad (6)$$

Here:

$\boldsymbol{\nu}$ — kinematic viscosity, mm²/s;

C — viscometer constant, mm²/s²;

$\boldsymbol{\tau}$ — time for the liquid to pass through the capillary, s.

The kinematic viscosity of the six reducer lubricant samples was calculated as follows.

:

For the RSM-1 sample, kinematic viscosity at 20, 40, and 100°C:

$$\nu_{20} = C\tau = 30 \cdot 445 = 13350\ {mm^2}/{s};$$

$$\nu_{40} = C\tau = 30 \cdot 105 = 3150\ {mm^2}/{s};$$

$$\nu_{100} = C\tau = 30 \cdot 6 = 180\ {mm^2}/{s}.$$

For the RSM-2 sample, kinematic viscosity at 20, 40, and 100°C:

$$\nu_{20} = C\tau = 30 \cdot 478 = 14340\ {mm^2}/{s};$$

$$\nu_{40} = C\tau = 30 \cdot 114 = 3420\ {mm^2}/{s};$$

$$\nu_{100} = C\tau = 30 \cdot 7 = 210\ {mm^2}/{s}.$$

For the RSM-3 sample, kinematic viscosity at 20, 40, and 100°C:

$$\nu_{20} = C\tau = 30 \cdot 457 = 13710\ {mm^2}/{s};$$

$$\nu_{40} = C\tau = 30 \cdot 109 = 3270\ {mm^2}/{s};$$

$$\nu_{100} = C\tau = 30 \cdot 6{,}5 = 195\ {mm^2}/{s}.$$

For the RSM-4 sample, kinematic viscosity at 20, 40, and 100°C:

$$\nu_{20} = C\tau = 30 \cdot 291 = 8730\ {mm^2}/{s};$$

$$\nu_{40} = C\tau = 30 \cdot 59 = 1770\ {mm^2}/{s};$$

$$\nu_{100} = C\tau = 30 \cdot 3{,}3 = 99\ {mm^2}/{s}.$$

For the RSM-5 sample, kinematic viscosity at 20, 40, and 100°C:

$$\nu_{20} = C\tau = 30 \cdot 297 = 8910\ {mm^2}/{s};$$

$$\nu_{40} = C\tau = 30 \cdot 64 = 1920\ {mm^2}/{s};$$

$$\nu_{100} = C\tau = 30 \cdot 3{,}6 = 108\ {mm^2}/{s}.$$

6. For the RSM-6 sample, kinematic viscosity at 20, 40, and 100°C:

$$\nu_{20} = C\tau = 30 \cdot 306 = 9180\ {mm^2}/{s};$$

$$\nu_{40} = C\tau = 30 \cdot 69 = 2070\ {mm^2}/{s};$$

$$\nu_{100} = C\tau = 30 \cdot 4{,}2 = 126\ {mm^2}/{s}.$$

To compare the kinematic viscosity values of these six reducer lubricant samples, **Table 4** and **Figure 2** are provided.

Table 4. Kinematic viscosity indicators of reducer lubricants

Name of indicator	Gearbox lubricants					
	RSM-1	RSM-2	RSM-3	RSM-4	RSM-5	RSM-6
Kinematic viscosity at **20°C**, mm²/s	13350	14340	13710	8730	8910	9180
Kinematic viscosity at **40°C**, mm²/s	3150	3420	3270	1770	1920	2070
Kinematik	180	210	195	99	108	126

qovushqoqligi 100 ºC da, mm^2/s						

The variation of the kinematic viscosity of reducer lubricants depending on the amount of gossypol resin used as a thickener was observed in Table 4. As the temperature decreased, the kinematic viscosity values of the reducer lubricant samples increased, because resin–asphaltene substances in the gossypol resin and used oil play a significant role. To clearly see the effect of temperature on kinematic viscosity, see Figure 2.

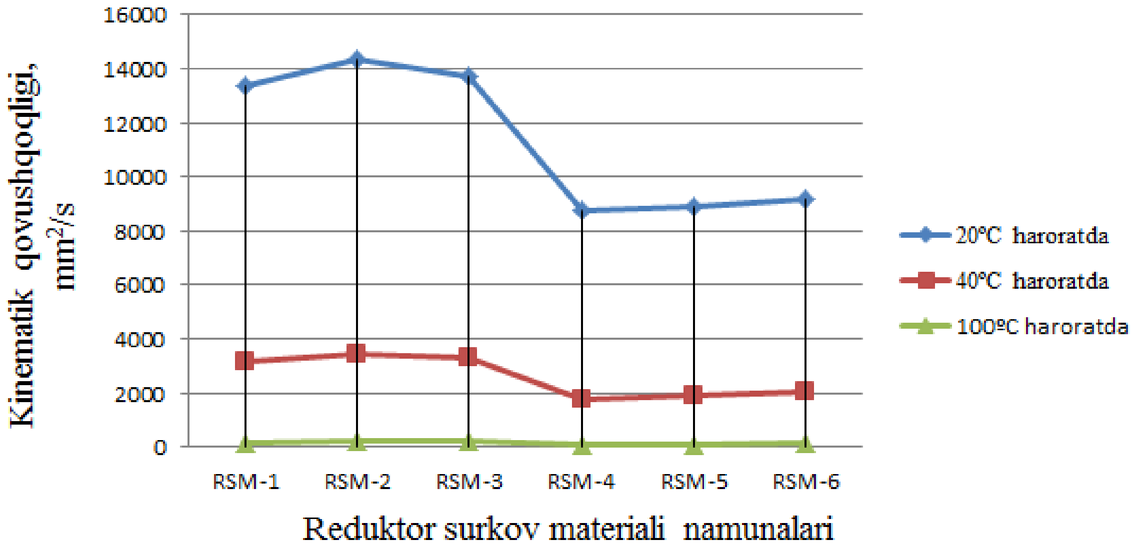

Figure 2. Graph of changes in the kinematic viscosity of reducer lubricant samples at 20, 40, and 100°C.

The kinematic viscosity indicators of the RSM-1, RSM-2, and RSM-3 samples meet the requirements for plastic lubricants. However, since the main objective was to create a low-viscosity liquid reducer lubricant, the RSM-5 and RSM-6 samples meet the requirements of TSh 05767930-286:2018 (Figure 2).

Study to determine the viscosity index of RSM. Tests to determine the viscosity index of RSM samples were conducted in accordance with GOST 25371-2018 "Petroleum products. Kinematic viscosity and viscosity index", and the following results were obtained (Table 5).

Table 5. Viscosity index indicators of reducer lubricants

Name of indicator	Gearbox lubricants					
	RSM-1	RSM-2	RSM-3	RSM-4	RSM-5	RSM-6
Qovushqoqlik indeksi	89	98	92	51	59	65

Study to determine the pour point of RSM. Tests were carried out to determine the pour point of RSM samples in accordance with the requirements of GOST 32393-2013 "Petroleum products. Determination of pour point by the rotational method", and the following results were obtained (Table 6).

Table 6. Pour point indicators of reducer lubricants

Name of indicator	GOST 32393-2013	Examples					
		RSM-1	RSM-2	RSM-3	RSM-4	RSM-5	RSM-6

Pour point, °C	-11	-7	-4	-6	-19	-15	-13

The pour point of the reducer lubricant was determined by a decrease in its fluidity, a change in the movement of the pendulum in the test, and the transition to a crystalline state (Table 6).

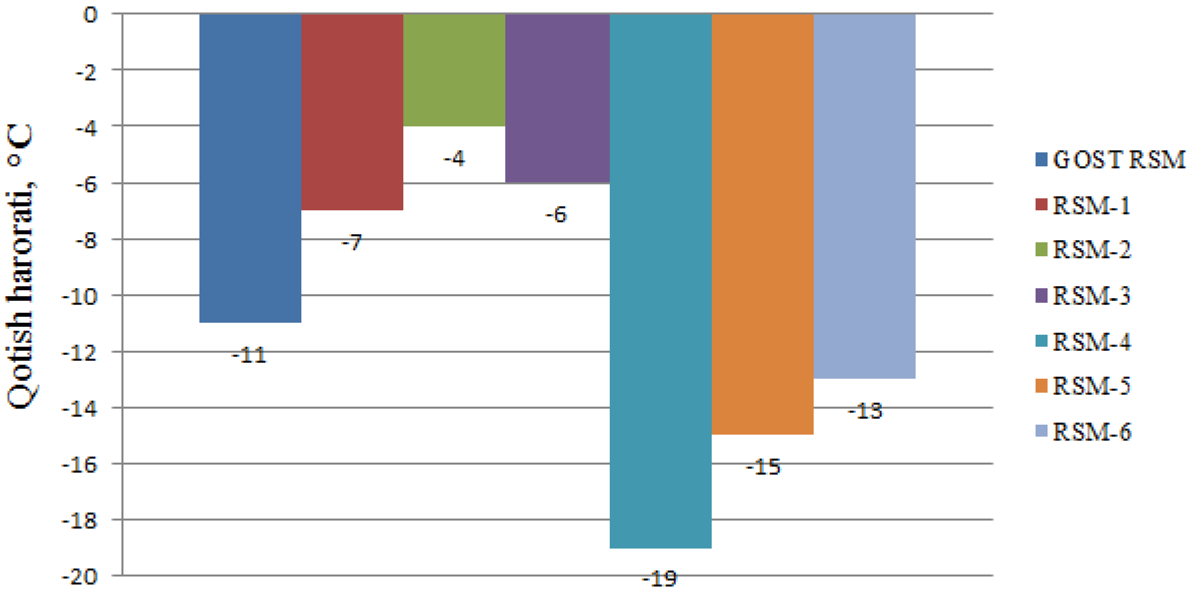

Figure 3. Pour point of reducer lubricants.

As can be seen in Figure 3.6, the RSM-4, RSM-5, and RSM-6 samples show better results than the standardized values required by GOST. Specifically, the pour point values are –19°C for RSM-4, –15°C for RSM-5, and –13°C for RSM-6.

Study on determining the flash point of RSM in an open cup.
Tests to determine the flash point of RSM samples were carried out in accordance with the requirements of GOST 4333-2021 "Petroleum products. Methods for determination of flash point and fire point in an open cup."

The test cup is filled with the sample to the specified level. First, the sample is heated at a rate of 5–17°C/min; as it approaches the flash point, slow heating is continued at a constant rate of 5–6°C/min. An ignition source is passed over the test cup at predetermined temperature intervals.

The flash point at ambient barometric pressure is taken as the lowest temperature at which the vapors ignite above the liquid surface when an ignition source is applied. To determine the fire point, the test is continued until the vapors above the sample burn for at least 5 seconds. The flash point and fire point determined at ambient barometric pressure are corrected to standard atmospheric pressure using the appropriate formula.

The flash point indicators of the reducer lubricants are presented in Table 7.

Table 7

Flash point indicators of reducer lubricants.

Name of indicator	GOST 4333-2021 RSM	Examples					
		RSM-1	RSM-2	RSM-3	RSM-4	RSM-5	RSM-6
Flash temperature,	200	230	245	239	185	205	215

°C							

The flash point of the reducer lubricant showed better results than the RSM-4 sample, because lubricants were produced using the thick mass separated after thermal distillation of gossypol resin at 360°C. For this reason, the flash points of the RSM-1, RSM-2, RSM-3, RSM-5, and RSM-6 samples increased (Table 7 and Figure 3).

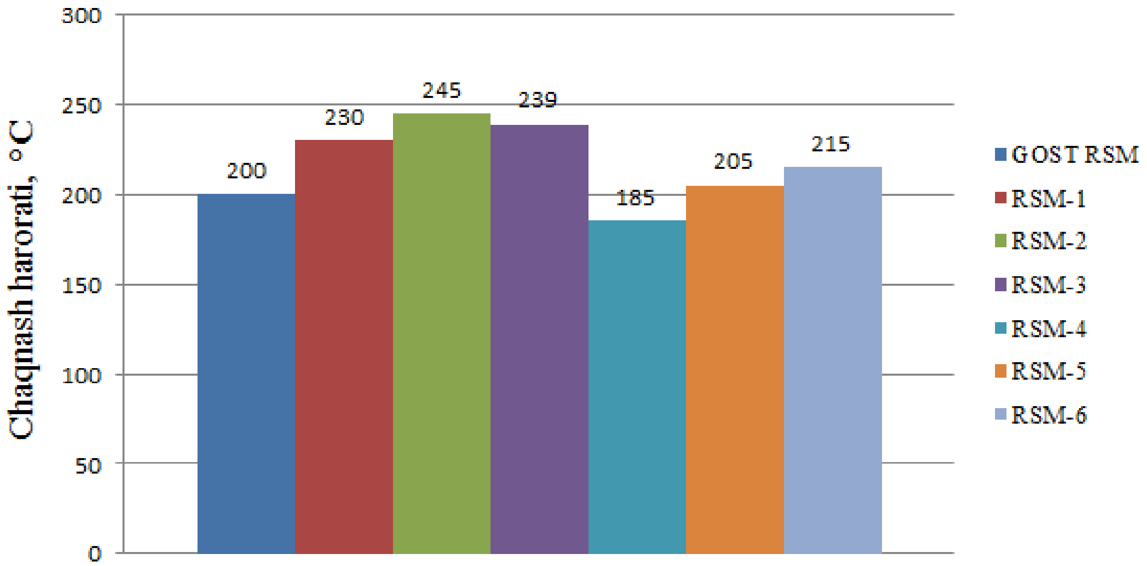

Figure 4. Difference in the flash points of reducer lubricants.

A study was conducted to determine the mass fraction of mechanical impurities in the composition of RSM. Tests and experiments to determine the mass fraction of mechanical impurities in RSM samples were carried out in accordance with the requirements of GOST 6370-2018 "Crude oil, petroleum products and additives. Method for determination of mechanical impurities."

The essence of the method consists of dissolving the test product in gasoline or toluene before filtration, filtering it through a slow filter, washing the residue on the filter with a solvent, then drying and weighing it.

The amount of mechanical impurities in the reducer lubricant samples is presented in Table 8.

Table 8

Mass fraction of mechanical impurities in the composition of reducer lubricants.

Name of indicator	GOST 6370-2018 RSM	Examples					
		RSM-1	RSM-2	RSM-3	RSM-4	RSM-5	RSM-6
Amount of additives, %	0,005	0,045	0,051	0,047	0,015	0,004	0,008

It was determined that the lowest mass fraction of mechanical impurities in the composition of the reducer lubricant samples was found in the RSM-5 sample (Table 8).

A study was conducted to determine the anti-wear and anti-deposit (clogging) formation properties of RSM when applied in heavy machinery gearbox gear transmissions. The RSM samples were poured into and tested in conventional rotating geared reducer transmissions.

Before calculating the deposit-formation index of the reducer lubricant samples, it is necessary to determine the Hertzian scar diameter under a static load.

At least 10 different loads (6, 8, 10, 13, 16, 20, 24, 32, 40, and 50 kgk) are selected, and the calculation for the RSM-1 sample is as follows:

$$D_1 = 8{,}73 \cdot 10^{-2}(P)^{1/3} = 8{,}73 \cdot 10^{-2} \cdot 6^{1/3} = 0{,}15\, mm;$$
$$D_2 = 8{,}73 \cdot 10^{-2}(P)^{1/3} = 8{,}73 \cdot 10^{-2} \cdot 8^{1/3} = 0{,}17\, mm;$$
$$D_3 = 8{,}73 \cdot 10^{-2}(P)^{1/3} = 8{,}73 \cdot 10^{-2} \cdot 10^{1/3} = 0{,}19\, mm;$$
$$D_4 = 8{,}73 \cdot 10^{-2}(P)^{1/3} = 8{,}73 \cdot 10^{-2} \cdot 13^{1/3} = 0{,}21\, mm;$$
$$D_5 = 8{,}73 \cdot 10^{-2}(P)^{1/3} = 8{,}73 \cdot 10^{-2} \cdot 16^{1/3} = 0{,}22\, mm;$$
$$D_6 = 8{,}73 \cdot 10^{-2}(P)^{1/3} = 8{,}73 \cdot 10^{-2} \cdot 20^{1/3} = 0{,}24\, mm;$$
$$D_7 = 8{,}73 \cdot 10^{-2}(P)^{1/3} = 8{,}73 \cdot 10^{-2} \cdot 24^{1/3} = 0{,}25\, mm;$$
$$D_8 = 8{,}73 \cdot 10^{-2}(P)^{1/3} = 8{,}73 \cdot 10^{-2} \cdot 32^{1/3} = 0{,}28\, mm;$$
$$D_9 = 8{,}73 \cdot 10^{-2}(P)^{1/3} = 8{,}73 \cdot 10^{-2} \cdot 40^{1/3} = 0{,}30\, mm;$$
$$D_{10} = 8{,}73 \cdot 10^{-2}(P)^{1/3} = 8{,}73 \cdot 10^{-2} \cdot 50^{1/3} = 0{,}32\, mm.$$

Then, the determined load weight **(A)** is calculated using the following formula:

$$A = \frac{LD}{X};\ X = \frac{X_1 - X_2 - X_3}{3};$$

Here:

A — determined load weight, kgk;

X — arithmetic mean of the wear-scar diameters of the three balls, mm;

L — applied load, kgk;

D — Hertzian scar diameter, mm.

$$A_6 = \frac{LD_1}{X} = \frac{6 \cdot 0{,}15}{0{,}13} = 6{,}92\, kgk;$$
$$A_8 = \frac{LD_2}{X} = \frac{8 \cdot 0{,}17}{0{,}165} = 8{,}24\, kgk;$$
$$A_{10} = \frac{LD_3}{X} = \frac{10 \cdot 0{,}19}{0{,}175} = 10{,}86\, kgk;$$
$$A_{13} = \frac{LD_4}{X} = \frac{13 \cdot 0{,}21}{0{,}195} = 14{,}1\, kgk;$$
$$A_{16} = \frac{LD_5}{X} = \frac{16 \cdot 0{,}22}{0{,}205} = 17{,}17\, kgk;$$
$$A_{20} = \frac{LD_6}{X} = \frac{20 \cdot 0{,}24}{0{,}225} = 21{,}33\, kgk;$$
$$A_{24} = \frac{LD_7}{X} = \frac{24 \cdot 0{,}25}{0{,}241} = 24{,}90\, kgk;$$
$$A_{32} = \frac{LD_8}{X} = \frac{32 \cdot 0{,}28}{0{,}269} = 33{,}31\, kgk;$$
$$A_{40} = \frac{LD_9}{X} = \frac{40 \cdot 0{,}30}{0{,}291} = 41{,}24\, kgk;$$
$$A_{50} = \frac{LD_{10}}{X} = \frac{50 \cdot 0{,}32}{0{,}312} = 51{,}28\, kgk.$$

After calculating the determined weight load, the deposit (clogging) formation index **(I)** is calculated using the following formula:

$$I = \frac{U}{10};$$

where:

I — deposit (clogging) formation index, **kgk**;

U — sum of the determined weight loads, **kgk**.

Thus, for the reducer lubricating oil sample **RSM-1**, the deposit (clogging) formation index is as follows:

$$I_{RSM-1} = \frac{A_6+A_8+A_{10}+A_{13}+A_{16}+A_{20}+A_{24}+A_{32}+A_{40}+A_{50}}{10} = \frac{6,92+8,24+10,86+14,1+17,17+21,33+24,90+33,31+41,24+51,28}{10} = 23\ kgk.$$

The remaining samples were calculated in the same way, and the deposit (clogging) formation indices were found to be as follows:

$$I_{RSM-2} = \frac{A_6+A_8+A_{10}+A_{13}+A_{16}+A_{20}+A_{24}+A_{32}+A_{40}+A_{50}}{10} = 21\ kgk;$$

$$I_{RSM-3} = \frac{A_6+A_8+A_{10}+A_{13}+A_{16}+A_{20}+A_{24}+A_{32}+A_{40}+A_{50}}{10} = 22\ kgk;$$

$$I_{RSM-4} = \frac{A_6+A_8+A_{10}+A_{13}+A_{16}+A_{20}+A_{24}+A_{32}+A_{40}+A_{50}}{10} = 38\ kgk;$$

$$I_{RSM-5} = \frac{A_6+A_8+A_{10}+A_{13}+A_{16}+A_{20}+A_{24}+A_{32}+A_{40}+A_{50}}{10} = 49\ kgk;$$

$$I_{RSM-6} = \frac{A_6+A_8+A_{10}+A_{13}+A_{16}+A_{20}+A_{24}+A_{32}+A_{40}+A_{50}}{10} = 44\ kgk.$$

The deposit-formation indices of the reducer lubricant samples were determined, and based on the results it can be stated with confidence that using the RSM-5 sample in the geared transmissions of heavy machinery leads to an increase in the service life of metal parts.

Based on the normative indicators specified in TSh 05767930-286:2018 and GOST requirements, the research results were used to compare and evaluate the physicochemical properties of the RSM-5 sample (Table 9).

Table 9

Comparison with the regulatory requirements of Tsh 05767930-286:2018 for RSM-5 and semi-liquid reducer lubricants.

Names of indicators	Requirement for the brand		RSM-5	Method of testing
	Summer	Winter		
Density at 20°C, kg/m³	Not standardized — to be determined.		901	GOST 3900 or GOST 31392
Kinematic viscosity at 100°C, mm²/s (range)	90,0-110	135-165	108	GOST 31391
Viscosity index, not less than	55-60	60-75	59	GOST 25371 or GOST 32500
Pour point (solidification temperature), °C, not higher than *(i.e., "below")*	-11	-15	-15	GOST 20287 or GOST 32393
Flash point in an open cup, °C, not lower than *(i.e., "above")*	200		205	GOST 4333 or GOST 12.1.044
Mechanical impurities, mass fraction, %, not more than	0,015		0,004	GOST 6370
Water content, mass fraction, %, not more than	Notes		Notes	O'z DSt 3271

Acid number, mg KOH per 1 g of oil, not more than	1,2	1,1	GOST 5985 or GOST 11362
Color by SNT colorimeter, SNT units	**Not standardized; to be determined — dark brown.**	**dark brown.**	GOST 20284

CONCLUSIONS

key method for evaluating the quality of reducer (gearbox) lubricants: it is necessary to determine their ability to prevent wear, abrasion, and deposit/sludge formation on the metal parts of geared transmissions in heavy machinery. In general, the greater the production of local products, the lower the cost price of manufactured goods becomes. Today, most used oils are utilized as fuel for pyrolysis. If used oil is simply burned, its toxicity level increases, which in turn raises the degree of negative impact on living organisms and humans. Worldwide, only about 17% of used oils are recycled. As a recommendation, if used oils are reprocessed and returned to use, environmental degradation can be prevented, while achieving economic efficiency at the same time.

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