FTD-HT-23-922-68

FOREIGN TECHNOLOGY DIVISION

COMBINING LUBRICANTS FOR INTERNAL COMBUSTION ENGINES

by

I. I. El'cvich, G. G. Khanlarov, et al.

FTD-HT-23-922-68

EDITED TRANSLATION

COMBINING LUBRICANTS FOR INTERNAL COMBUSTION ENGINES

English pages: 235

Source: Legirovaniye smazki dlya dvigateley vnutrennego sgoraniya, 1967, pp. 1-188.

Translated by: Contract No. F33657-68-D-0865/P002

PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
WP-AFB, OHIO.

DATA HANDLING PAGE

01-ACCESSION NO. / 98-DOCUMENT LOC	TM9000365
09-TITLE	COMBINING LUBRICANTS FOR INTERNAL COMBUSTION ENGINES
39-TOPIC TAGS	lubricant, lubricant property, lubricant additive, internal combustion engine, wear resistance
47-SUBJECT AREA	11, 21
42-AUTHOR/CO-AUTHORS	EL'OV'CH, I. I.;16-KHANLAROV, G. G.; 16-BASHAYEV, V. YE.;16-KHIGER, V. G.
10-DATE OF INFO	53---67
43-SOURCE	LEGIROVANIYE SMAZKI DLYA DVIGATELEY VNUTRENNEGO SGORANIYA, BAKU, IZD-VO AKADEMII NAUK AZERBAYDZHANZKOY SSR (RUSSIAN)
68-DOCUMENT NO.	FTD-HT-23-922-68
69-PROJECT NO.	72301-78
63-SECURITY AND DOWNGRADING INFORMATION	UNCL, O
64-CONTROL MARKINGS	NONE
97-HEADER CLASN	UNCL
76-REEL/FRAME NO.	1888 0979
77-SUPERSEDES	
78-CHANGES	
40-GEOGRAPHICAL AREA	UR
NO OF PAGES	235
CONTRACT NO.	F33657-68-D-0865/P002
X REF ACC. NO.	65-AM8001243
PUBLISHING DATE	94-00
TYPE PRODUCT	TRANSLATION
REVISION FREQ	NONE
STEP NO.	02-UR/0000/67/000/000/0001/0188
ACCESSION NO.	

ABSTRACT

(U) This book is intended for engineering personnel and chemists concerned with improving the quality of motor oils and lubricants used in internal combustion engines. Properties of motor oils and lubricants produced from crudes of various Soviet regions are outlines and the effect of various additives introduced to oils and lubricants is analyzed. Results of lubricant tests are presented and the service life, wear resistance, and corrosion resistance of various internal combustion engine parts are discussed.

TABLE OF CONTENTS

INTRODUCTION

The most important branches of the Soviet national economy, including the petrochemical and petroleum-refining industry, are now being developed at an accelerated rate on the basis of the latest advances in science and technology, which are being used for rapid expansion of production resources. Use of the inexhaustible potentialities of the chemical industry, which has been assigned the decisive role in development of Soviet production resources, is of special significance.

It was pointed out in the decisions of the December (1963) Plenum of the CPSU that use of chemical products and synthetic materials will permit radical reorganization of the most important areas of manufacturing. This reorganization will in turn permit a rapid rise in output, increase the quality of manufactured goods, and simultaneously reduce capital expenditures and production costs.

Petrochemistry is to play an especially important role in the development of Soviet production resources. The raw-material base for this branch of industry has continuously expanded: petroleum supplies have increased by a factor of almost 4 and gas supplies by a factor of 11 over the past decade.

The development of the petrochemical and petroleum-refining industry should substantially enlarge our opportunities for use of the latest achievements of science and technology in one of the leading branches of industry, machine building and particularly engine building. The continuous improvement in engine design has made the requirements imposed by operating conditions on fuels and, especially, on lubricating oils more stringent.

Development of a variety of lubricating oils with a broad range of properties produced by introduction of special additives is of enormous importance for effective use of existing internal combustion engines.

Different types of synthetic additives that improve the viscosity-temperature characteristics of lubricating oils, increase their lubricating properties, and permit their use under extremely varied environmental-temperature conditions have recently come into wide use. Many types of additives are known to be effective antioxidants and corrosion inhibitors.

Some additives combine a number of very important operational properties and can therefore be regarded as multipurpose [1].

Investigations begun at the AzNII NP imeni Kuybysheva [Azerbaydzhan Scientific Research Institute of Petroleum Refining imeni Kuybysheva] [2-4] in 1953 and subsequently continued by the INKhP AN AzbSSR [Institute of the Petrochemical Industry, Academy of Sciences, Azerbaydzhan SSR], VNII NP [All-Union Scientific Research Institute of Petroleum and Gas Refining and Production of Artificial Liquid Fuels], and a number of other scientific research institutes working on the development and application of oils and additives for modern engine building showed that introduction of new high-efficiency oils with multipurpose additives into the national economy provides an increase in transport productivity, a substantial decrease in operating costs, and a decrease in specific chemical expenditure per unit transport work.

In a number of cases, work on the main trends in engine design (use of fuel injection, development of short-stroke engines, increased compression, use of new high-efficiency bearing materials, etc.) has been substantially hampered by the quality of the oils and additives used in internal combustion engines. In defining the general problems confronting automobile builders and the petroleum and chemical industries with respect to development of effective oils, Prof. K.S. Ramayya [5] stated:

"General economics and available resources dictate the use of mineral oils as the main raw material for production of automobile oils far into the future. However, mineral oils must undergo extensive processing, which consists in purification and in compounding by addition of synthetic additives.

Compounded automobile lubricants should be developed on the basis of investigation of their physicomechanical, physicochemical, and chemical properties, just as alloys for the automobile and aviation industries are developed. Production of compounded lubricants requires close cooperation among the automobile, petroleum, and chemical industries."

The best direction to take in developing a variety of additive-containing motor oils that will satisfy the more stringent requirements of modern engine building must, however, be determined both by thorough investigation of the properties of additive-containing oils and by careful study of the conditions under which these oils function in engines and of the operational characteristics of different types of engines in various areas of industry and transport.

The research and tests on motor oils and oil additives whose results are given in this monograph were performed at the Test-Experimental Station of the Institute of Additive Chemistry, Academy of Sciences, Azerbaydzhan SSR; G.A. Zeynalova, K.I. Sadykov, and Sh.A. Mkhitaryan participated in the work, under the supervision of Academician A.M. Kuliev and F.G. Suleymanova. A.F. Aslanov, Kh.M. Mamedov, K.N. Gabel', M.I. Zenevich, N.G. Geydarov, V.I. Ansheles, and others participated in making the tests and the authors wish to thank them.

Chapter 1

TYPES OF MOTOR OILS AND THEIR APPLICATION CONDITIONS

Rational development of a variety of motor oils should be based on the following prerequisites.

1. The properties of the base oil and of the multipurpose additives used to improve these properties should increase the operating indices of appropriate engines as efficiently as possible.

2. The variety of available motor oils should conform as fully as possible to the different operating conditions for various types of internal combustion engines [ICE] (ДВС), as dictated by the specific features of their use under different climatic, highway, industrial, transport, and other conditions.

3. The required operational properties of oils for ICE should take into account both the needs of existing engines and the prospective characteristics of future engines. Using this as a basis, the present chapter considers certain aspects of the relationship between the properties of additive-containing oils and the conditions under which they function in engines.

§1. INFLUENCE OF OIL PROPERTIES ON OPERATION OF PISTON ICE

The development of modern ICE is proceeding both by improvement of piston engines and by development of new, economical, high-efficiency designs for pistonless engines.

New types of gas turbines, jet engines [JE] (ВРД), and rocket engines have come into wide use of powerplants in modern aviation and their use in surface transport is being planned. However, piston ICE will remain the basic type of industrial powerplant over the next 10-15 years. In considering the influence of oil properties on engine-operation indices, we will therefore limit ourselves to piston ICE.

Motor oils are used as lubricants for piston aircraft engines, automobile engines intended for different purposes (light and heavy machinery, buses, special equipment, etc.), locomotive engines, engines for tractors and other agricultural machinery, engines for ships, powerplants for construction, road-building, and other self-propelled and non-self-propelled auxiliary machines and units, and powerplants for standard and portable electric generators.

The main purpose of these engines is to provide a given unit with a powerplant that operates at the required performance level, i.e., whose torsional moment (torque) M_{kr} is a uniquely defined function of engine speed for given operational conditions.

As is well known, the torsional moment of an ICE (operating on liquid fuel) is defined by the equation

$$M_{кр} = \frac{N_e}{n} \cdot 716{,}2,$$

where N_e is the effective power ($N_e = \frac{p_e v_h i n}{450 \tau}$), n is the engine speed corresponding to this power, p_e is the mean effective pressure, v_h is the cylinder working volume in liters, i is the number of cylinders, and τ is the engine stroke coefficient.

Replacing p_e by its value,

$$p_e = \frac{0{,}0427\, H_u \gamma_v}{\alpha L_0} \eta_h \eta_i \eta_m,$$

where H_u is the lowest heat value of the fuel, L_0 is the amount of air (kg) theoretically required for combustion of 1 kg of fuel, γ_v is the specific gravity of the ambient air, kg/m^3, η_h is the filling factor, η_i is the gauge output, η_m is the mechanical output, and α is the excess-air coefficient, we obtain

$$M_{кр} = A \frac{\eta_h \eta_i \eta_m}{\alpha n},$$

where A is a factor constant for each given type of engine, while the coefficients η_h, η_i, η_m, and α vary as a function of load and speed during engine operation and change with the condition of the engine and the quality of the oil.

We will discuss below the manner in which the quality of the oil used in an ICE can affect its basic operating indices and the possible ways for improving these indices through the quality of the oil, principally by use of effective additives.

Let us assume that a change in effective output η_e occurs during prolonged operation of an engine with a given additive-containing oil. Actually, as numerous observations of ICE operation under both test and operational conditions have shown, the change in η_e as a function of crankcase-oil quality is usually associated mainly with different degrees of wear for the cylinder-piston components and with formation of different types of deposits on the pistons, rings, and combustion chambers. As is well known, use of multipurpose additives for lubricating oils permits broad control of both the wearing of the main engine components and of the extent and character of the various deposits on the cylinder-piston components.

The quality of the additive-containing oil used in an engine thus affects the initial effective output η_e and also has a material influence on its variation during prolonged engine operation.

Let us use the following symbols:

η_e^n is the effective output of the beginning of engine operation for a given type of additive-containing oil and;

η_e^k is the effective output at the end of a given operational period for a given type of additive-containing oil, determined from the operation time or the number of kilometers traveled by the automobile. The relative change in effective output over a given engine-operation period can then be characterized by the ratio

$$k_э = \frac{\eta_e^к}{\eta_e^н}.$$

Let us call this the efficiency-change coefficient.

As is well known, $\eta_e = \eta_i \eta_m$, while $\eta_i = \frac{A p_i}{H_u \eta_h}$ and $\eta_m = \frac{p_i - p_т}{p_i}$,

$$\text{where } A = \frac{1{,}985\, T_o L_o \alpha}{p_o},$$

p_t is the average pressure loss, and

T_0 and p_0 are the absolute temperature and pressure of the ambient air.

The expression for η_e can then be written in the following form:

$$\eta_e = \frac{A(p_i - p_т)}{H_u \eta_h}.$$

Hence we obtain the following expressions for the values of η_e^k and η_e^n:

$$\eta_e^к = \frac{A(p_i^к - p_т^к)}{H_u \eta_h^к} \text{ and } \eta_e^н = \frac{A(p_i^н - p_т^н)}{H_u \eta_h^н},$$

where η_h^k, p_t^k, and p_i^k are the values of the volumetric efficiency, average pressure loss, and average gauge pressure at the end of the operation period in question, while η_h^n, p_t^n, and p_i^n are the values of the same quantities at the beginning of the operation period, with a given additive-containing oil.

The magnitude of the efficiency-change coefficient k_e is then defined by the following relationship:

$$k_e = \frac{(p_i^k - p_T^k)\,\eta_{lh}^n}{(p_i^n - p_T^n)\,\eta_{lh}^k}.$$

The volumetric efficiency equation used in ICE theory has the form [6]

$$\eta_{lh} = \frac{T_0}{T_0'}\frac{1}{k(\varepsilon - 1)}\left[\frac{p_a}{p_0}(\varepsilon k - k + 1) - \frac{p_r}{p_0}\right],$$

where T_0/T_0' is the ratio of the ambient-air temperature to the charge temperature during intake into the cylinder,

p_a/p_0 is the ratio of the gas pressure in the cylinder during intake to the ambient-air pressure,

p_r is the residual-gas pressure,

$k = c_p/c_v$ is the heat-capacity ratio, and

ε is the compression.

We can transform this equation and write it in the following form:

$$\eta_{lh} = \frac{T_0}{T_0' p_0}\left[p_a - \frac{p_r - p_a}{k(\varepsilon - 1)}\right].$$

We then obviously obtain

$$\eta_{lh}^k = \frac{T_0}{T_{0_k}' p_0^k}\left[p_a^k - \frac{p_r^k - p_a^k}{k(\varepsilon - 1)}\right]$$

$$\text{and } \eta_{lh}^n = \frac{T_0}{T_{0_n}' p_0^n}\left[p_a^n - \frac{p_r^n - p_a^n}{k(\varepsilon - 1)}\right].$$

As previously, the superscript k in the resultant expressions represent the values of the indices in question at the end of the operation period, while the superscripts n represent these indices at the beginning of the operation period.

Substituting the values found for η_{lh}^k and η_{lh}^n into the formula for the efficiency-change coefficient k_e and making certain transformations, we obtain:

$$k_e = \frac{(p_i^k - p_T^k)\,[p_a^n - c_3(p_r^n - p_a^n)]\cdot T_{0k}'}{(p_i^n - p_T^n)\,[p_a^k - c_3(p_r^k - p_a^k)]\cdot T_{0n}'},$$

where

$$c_3 = \frac{1}{k(\varepsilon - 1)}.$$

Let us assume that the ratio p_r/p_a for a given engine design can be regarded as comparatively constant. We can then write the expression for $k_э$ in the following form:

$$k_э = \frac{p_a'' T'_{ок} (p_i^к - p_r^к) [1 - c_3 (\alpha_p'' - 1)]}{p_a^к T'_{он} (p_i'' - p_r'') [1 - c_3 (\alpha_b^к - 1)]},$$

where

$$\alpha_p'' = \frac{p_r''}{p_a''}, \quad \alpha_p^к = \frac{p_r^к}{p_a^к}.$$

Then, taking into account the foregoing and assuming that $\alpha_p^к \approx \alpha_p''$, we ultimately obtain:

$$k_э = \frac{p_a'' T'_{ок} (p_i^к - p_r^к)}{p_a^к T'_{он} (p_i'' - p_r'')}, \text{ or}$$

$$k_э = k_1 k_2 k_3,$$

where

$$k_1 = \frac{p_a''}{p_a^к},$$

$$k_2 = \frac{T'_{ок}}{T'_{он}},$$

$$k_3 = \frac{p_i^к - p_r^к}{p_i'' - p_r''}.$$

Since it is obvious that the change in the coefficient $k_э$ has a direct influence on the variation in specific fuel consumption, we have thus established that there is a relationship between possible changes in the values of the factors in the formula for $k_э$ (since such changes can be associated with changes in oil quality) and the economy of engine operation.

In considering certain problems in the theoretical development of requirements to be imposed on the operational properties of oil for ICE, I.I. El'ovich [7] found the following function that expresses the relationship between engine economy and operating parameters, the latter being characterized principally by the degree of cylinder working-volume compression during the intake, compression, and exhaust strokes and by the change in thermal state and in a number of factors associated with heat transfer at the working surfaces of the cylinder-piston components:

$$g_e = \frac{c_2 [p_i - c_3 (p_r - p_a)]}{c_1 p_c - p_r + p_a - p_r},$$

where $c_1 = \frac{\rho}{\varepsilon - 1} \left\{ \lambda (\rho - 1) + \frac{\lambda \rho}{n_2 - 1} \left[1 - \left(\frac{\rho}{\varepsilon} \right)^{n_2 - 1} \right] - \frac{1}{n_1 - 1} \left[1 - \frac{1}{\varepsilon^{n_1 - 1}} \right] \right\},$

$$c_2 = \frac{632 H_u}{1{,}985 L_0 \alpha T_0},$$

$$c_3 = \frac{1}{k (\varepsilon - 1)}.$$

where p_c is the pressure at the end of compression,

ρ is the degree of preliminary expansion, and

λ is the pressure-rise coefficient.

The working-volume compression changes during engine operation, as a result of wearing of the piston rings, changes in their mobility, and wearing of the pistons, piston grooves, and cylinder sleeves. Wear resistance, which depends to a large extent on oil quality, is thus directly related to possible changes in ICE economy.

M.M. Khrushchov [8] proposed the so-called "integral method" for evaluating the wearing of machine components; in this procedure, the wear is estimated from the change in certain operational functions of a component or of the group of components forming the unit under consideration.

Using the "integral method" as a basis, one criterion of the permissible wearing rate for the cylinder-piston components of an ICE and hence the corresponding antiwear efficiency of the oil used is the quality of cylinder compression, which is indirectly determined from the volume of gas blown by from the combustion chamber.

The average engine-wear rate I is related to the average gauge pressure and the average piston speed by the formula

$$I = Ap_i^M c_m^N,$$

where A is a constant that depends on the individual characteristics of the engine and the over-all antiwear efficiency of the lubricating oil.

When experimental data are available, the values of N and M can be used to determine the improvement in lubricating-oil antiwear properties necessary for supercharging of an ICE.

As an example, let us calculate the necessary relative increase in over-all lubricating-oil antiwear efficiency for engines of the Yaroslavl Automobile Plant [YaAZ] (ЯАЗ) [7].

It has been found experimentally that $N = 2$ and $M = 2/3$ for these engines. When a YaAZ-204 engine is supercharged to 150 hp at 2100 r/min or a YaAZ-206 engine is supercharged to 225 hp, the average effective pressure rises from 6.35 to 7.25 kg/cm² and the average piston speed from 8.5 to 8.9 m/s. Assuming that the engine service life must be maintained at its previous level, a new crankcase oil whose total antiwear efficiency A_2 must exceed the initial efficiency A_1 is required for lubrication.

Given the condition $I_1 = I_2$, which corresponds to maintenance of engine service life at a constant level, we obtain:

$$\frac{A_2}{A_1} = \left(\frac{p_{i_2}}{p_{i_1}}\right)^2 \left(\frac{c_{m_2}}{c_{m_1}}\right)^{2/3};$$

or $A_2 = 1.94\ A_1$.

Research conducted at the AzNII NP [Azerbaydzhan Scientific Research Institute of Petroleum Refining] has shown that such an over-all anticorrosion-efficiency ratio is characteristic of diesel oils containing the additives AzNII-4 and AzNII-7 [9].

Experiments conducted for comparative evaluation of the effectiveness of other multipurpose additives synthesized and tested at the AzNII NP imeni Kuybysheva [Azerbaydzhan Scientific Research Institute of Petroleum Refining imeni Kuybysheva] and later at the INKhP AN Azerbaydzhan SSR [Institute of the Petrochemical Industry, Academy of Sciences, Azerbaydzhan SSR], showed that there are substantial opportunities for reducing the wear of the principal engine components and thus prolonging their service lives [10].

Increasing Engine Service Life

The problem of increasing engine service life currently facing Soviet machine building is associated to a large extent with selection of motor oils that will reduce the wearing of the main engine components.

It is thus required that

$$l_2 > l_1 \text{ or } l_1 = \text{Д} l_2,$$

where D (Д) is the durability.

It is now possible to obtain a value of 1.3-1.5 for D and it is assumed that it will be raised to 2 in the near future.

Under these conditions, we will have, for example, $A_2 = 2.68\ A_1$ in the case discussed above. There consequently arises the problem of obtaining antiwear-efficiency ratios for the multipurpose additives used as compounding agents for motor oils such that the efficiency of the new additives exceeds that of existing additives by a factor of 2-3.

The results of a comparative evaluation of the antiwear efficiency of current additives, which were obtained by numerous stand and operational tests, have shown that it is practically possible to prolong service life by reducing wear.

It must be kept in mind, however, that the problem of prolonging engine service life involves factors other than the wearing of the main components. The economic indices of engine operation, particularly the specific fuel consumption g_e, have a considerable influence on maintenance of engine operability and hence on service life. The operative Soviet State Standard (USSR GOST) 491-55 for automobile and tractor engines permits a variation of no more than 5% in g_e.

The influence of the quality of the lubricating oil used in an engine on the change in its economic indices was analyzed above.

It was pointed out that engine economy is affected by the variation in the gas-pressure ratio in the cylinder during intake, the charge-temperature ratio during intake, which is governed principally by the volumetric efficiency, and the average pressure loss due to friction. As operational experience has shown, all these indices are closely related to the quality of the oil used to lubricate the engine.

According to the data of certain authors [11, 12], the decrease in effective functional indices observed during operation of automobile engines and resulting, for example, solely from formation of carbon deposits ranges from 3 to 14%.

The limits of the variation in average effective indices depend to a substantial extent on the type of engine and the operating conditions.

In analyzing the distribution of losses associated with formation of carbon deposits in an engine, it has been hypothesized that 2/3 of these losses are due to the reduction in the filling factor resulting from the decrease in air delivery caused by the reduction in combustion-chamber volume and the increase in T_0. The remaining losses are associated with the decrease in thermal efficiency. Oil quality may affect the change in the filling factor in the following manner. When the pressure of the air or fuel-air mixture is reduced during intake, the work of expansion goes to create a velocity head and to overcome the resistance in the intake channel. The latter is obviously composed of the frictional losses L_t and L_k (in the lines and valves) and of local losses.

As is well known, the filling factor is defined in the following manner:

$$\eta_v = \frac{T_0}{p_0}\frac{\varepsilon(p_a - p_r)}{(\varepsilon - 1)T_0'}, \text{ where } p_0 = 1{,}003\frac{\text{kgf}}{\text{cm}^2}, T_0 = 288^\circ\text{K},$$

while the ratio of the initial and final values of η_{vn} and η_{vk} is:

$$\frac{\eta_{vn}}{\eta_{vk}} = \frac{(p_{an} - p_{rn})T_{0k}'}{(p_{ak} - p_{rk})T_{0n}'};$$

where T_0 is the temperature of the charge heated by the cylinder walls, the ideal case (with the filling factor equaling the volume coefficient) obviously occurring at $T_0' = T_0$,

p_a is the pressure at the end of the intake stroke, and

p_r is the counterpressure.

Let us represent the value of p_a in the following manner:

$$p_a = p_0 - \Delta p_a \text{ kg/cm}^2.$$

The value of Δp_a can be determined from the Bernoulli equation, if we consider charge intake into the cylinder to be a steady-state process

$$\Delta p_a = k_1 \frac{n^2}{f_k^2},$$

where

$$k_1 = \frac{\gamma}{2g}\left(\sum \frac{e_i}{d_i \lambda_i} + \xi\right)\left(\frac{sF}{30}\right)^2$$

γ is the specific gravity of the charge,
ξ is the local-loss coefficient for the intake system,
s is the piston travel,
F is the piston area,
n is the engine speed, and
f_k is the through valve cross-section.

Then:

$$\Delta p_a = \frac{\gamma}{2g}\frac{n^2}{f_k}\left(\frac{sF}{30}\right)^2\xi + \frac{\gamma}{2g}\frac{n^2}{f_k^2}\left(\frac{sF}{30}\right)^2\left(\frac{l_t}{d_t}\lambda_t + \frac{l_k}{d_k}\lambda_k\right).$$

With a constant cylinder size, the losses Δp_a are proportional to the square of the engine speed and inversely proportional to the square of the through valve cross-section.

The values of $\frac{\sum f_k}{\sum F}$ are from 1/12 to 1/8 at $c_m < 6.5$ m/s, 1/9 to 1/6 at $6.5 < c_m < 10$, and 1/6 to 1/4.5 at $c_m > 10$.

With moderate airflow speeds through the inlet valves (W_k = = 30-70 m/s), the pressure at the end of the intake stroke for a four-stroke engine is roughly $p_a = (0.85 \div 0.90)\ p_0$ kg/cm^2 without injection and $p_a = (0.92 \div 0.66)\ p_k$ with injection, where p_k is the injection pressure.

In two-stroke engines, p_a is less than the receiver pressure p_k by an amount equal to the hydraulic losses in the blow-off system. These losses are directly related to oil quality in some types of engines.

The principal factor associated with oil quality that has a direct effect on the losses Δp_a is the change in the loss coefficients λ_k, λ_t, and ξ, as can be seen from the formula above.

The coefficients of the losses due to friction are known to be governed by the relative wall roughness. The greater roughness of an uneven carbon deposit will therefore cause greater losses. Finally, the change in the relative active intake-system cross-section $\frac{\sum f_{\kappa}}{\sum F}$ caused by deposits, which are usually associated with oil quality, also cause considerable losses.

Losses due to friction or local resistance and changes in active cross-section, which are governed by the number and character of the carbon deposits, are undoubtedly directly related both to the quality of the base oil used and to the type of fuel.

It can also be seen from the formula defining the relative change in volumetric efficiency that this change affects the charge temperature. The heating of the air or fuel-air mixture by the component surfaces raises this temperature during intake.

The temperature of the piston face, cylinder wall, and cylinder head has a particularly strong effect on the observed rise in T_0'. M.M. Maslennikov and M.S. Rappiport cite data indicating that the average rise in the temperature of fresh fuel-air mixture is 30-60°C [13]. The heating of the mixture therefore decreases when there are fewer deposits of tars and carbon on the cylinder-piston components.

The quality of the oil used, which has a direct influence on the decrease in pressure during intake and on the rise in mixture temperature, thus reduces the specific gravity of the mixture, the weight of the charge, and hence the admission.

Influence of Motor-Oil Quality on Losses Due to Friction

As was pointed out above, the change in engine-operating efficiency is affected by the ratio of the final and initial values of the average pressure losses due to friction. This pressure loss or the power loss equivalent to it includes both losses associated directly with the friction of the moving parts of the engine and those associated with power consumption in driving auxiliary units.

Experimental determination of the power loss due to friction involves substantial difficulties.

Determination of this power as the difference between the gauge power and the effective power results in large errors, since the gauge power is determined to within 2-3% and the effective power to within 1-2%.

Since the power loss due to friction has a substantially smaller absolute value, the relative error in its determination can reach 30%.

Vansheydt [14] gives the following data on the relationship of the losses due to friction in an internal combustion engine [ICE] (ДВС):

Type of Loss	Percent of Power
Ring friction	55-65
Bearing friction	35-45

According to the data of M.M. Maslennikov and M.S. Rappiport [13], the distribution of mechanical power losses in an engine can be characterized in the following manner:

Type of loss	Percent of power
Losses due to friction	
piston assembly	45-65
bearings	5-10
auxiliary units	10-15
Power losses in drive and pump lines	
in distribution mechanism	5-10
in auxiliary units	5-10
pump lines	10-15

As can be seen from the data given above, a substantial portion of the losses result from the friction of the piston assembly on the cylinder wall. The average pressure loss p_t is therefore directly related to the viscosity of the lubricating oil. The latter varies as a function of engine operating temperature and of the change in the chemical structure of the oil hydrocarbons during prolonged operation. Two processes occur simultaneously at moderate and high temperatures: a reversible change in viscosity with temperature and an irreversible change in viscosity caused by oxidation of the oil (or depolymerization when thickened oils are used). A reversible change in viscosity is the main process at low temperatures. The character of the change in viscosity is especially complex when thickened oils are used.

As has already been pointed out, the average pressure loss is affected by the losses in driving auxiliary units and by pump losses as well as by losses due to friction. Changes in the quality of the oil used in the engine, principally through oxidation, which leads to deposition of carbon and tars on the combustion-chamber walls, can also be largely responsible for losses of the former type. For example, carbon deposits on the combustion-chamber walls cause a change in compression ratio.

There is a relationship that defines the relative change in power loss due to friction at different compression ratios [13]:

$$\frac{N_f}{N_{f_0}} = \frac{\varepsilon + 8,5}{\varepsilon_0 + 8,5},$$

where N_f is the power loss due to friction at a compression ratio ε, and

N_{f_0} is the power loss due to friction at a compression ratio ε_0.

Data are also available [13] on the influence of the pressure and temperature of the incoming air on the power loss due to friction; as was shown above, the change in these factors is related to the quality of the lubricating oil used in the engine.

However, the viscosity of the lubricating oil, which varies with the complex engine operating conditions, and, even more important, its viscosity index undoubtedly have a special influence on the average pressure losses due to friction.

Numerous investigations conducted at the INKhP AN Azerbaydzhan SSR, a number of other Soviet scientific research institutes, and abroad have shown that introduction of additives such as antioxidants is exceptionally effective in reducing the increase in oil viscosity that usually results from the oxidation of oil hydrocarbons occurring at high temperatures. The change in oil structure caused by oxidation has an especially severe effect on viscosity during operation at low temperatures, where formation of carbon deposits and sludge produces both undesirable additional losses and even greater disruptions of the conditions under which the lubrication system and the engine as a whole operates.

The character of the additives employed also has a material influence on the change in the viscosity index of the oil.

According to Walter, the dependence of oil viscosity on temperature can be expressed in the following manner:

$$\lg[\lg(100\nu + 0{,}8)] = A + B \lg T,$$

where A and B are constants,

T is the absolute temperature, and

ν is the kinematic viscosity (in St).

In addition to the commonly employed additives of the thickening type, which make it possible to obtain favorable initial-oil viscosity indices, it must be pointed out that additives can provide stability of the constants A and B in Walter's equation for oils in prolonged service.

The stabilizing influence of various additives on the depolymerization resistance of thickened oils was described by Ye.G. Semenido et al. [14]. Thus, additives have been found to permit ... ad regulation of the variation in oil viscosity during service in engines.

The experimental data given below on the influence of lubricating-oil viscosity on the losses due to friction enable us to make a quantitative characterization of the efficiency of techniques for stabilizing oil viscosity with the aid of multipurpose additives.

I.S. Khvoshchev's empirical formula [15], which he derived from the results of experiments on diesel automobile engines, has the form:

$$p_T = 0{,}2 + 1{,}31\left(\frac{n}{100}\right)\eta^{1/4}\ \text{kg/cm}^2,$$

where p_t is the average pressure loss due to friction,

n is the engine speed, and

η is the dynamic viscosity of the oil (in poises).

This relationship has been verified experimentally for temperatures down to −5°C.

In investigating the maximum pressure loss due to friction $p_{t\ max}$ during the starting of four-stroke diesel engines as a function of lubricating-oil viscosity, M.L. Minkin [16] used the experimental data of various authors as a basis for recommending the following relationship:

$$p_{T\ max} = 1{,}9\sqrt[4]{\nu_0}\ \text{kg/cm}^2,$$

where ν_0 is the kinematic viscosity in St (cm^2/s). Using the results of experiments conducted with a two-stroke GMC engine, the same author obtained the following expression for the maximum pressure loss due to friction $p_{t\ max}$ during starting as a function of oil viscosity:

$$p_{T\ max} = 1{,}24\sqrt{\nu}\ \text{kg/cm}^2.$$

Investigations conducted by M.M. Likhachev and Yu.M. Galkin [17] yielded curves representing the average pressure loss due to friction p_t as a function of crankshaft speed with the engine in different thermal states. At temperatures of about 10–20°C, p_t rises in direct proportion to crankshaft speed. Two segments are observed in the curves below this temperature: p_t falls as engine speed is increased to 20–60 rpm and then either remains almost constant (at t = 69.5°) or increases in direct proportion to engine speed. A sharp rise in p_t (to 9–10 kg/cm^2) at low engine speed (40–80 rpm) is observed at temperatures of about 0° or below. The further increase in p_t is less abrupt and there may even be an inflection in the curve (at t = − 7.5° and −12.5°C) in some cases. M.L. Minkin [16] attributes the rise in average pressure loss due to friction with increasing engine speed to the increase in the shear resistance of individual layers of the oil film as the relative friction-surface speed rises.

Hence it can be assumed that the boundary properties of the lubricating layers adsorbed on the friction surfaces, which are known to be regulable within wide limits through the properties of the additives employed, also affect the loss due to friction.

§2. ANALYSIS OF OPERATING CONDITIONS FOR PRINCIPAL TYPES OF PISTON ICE UNDER DIFFERENT SERVICE CONDITIONS

Automobile Engines

Even under ordinary highway conditions, automobile operation is characterized by quite frequent fluctuation of varying loads as a result of the different amounts of power consumed in overcoming resistance to motion. The operating regime of an automobile engine is still further complicated by frequent starts, stops, and acceleration. On the other hand, the design of engines intended for automobile (especially light vehicles) should provide maximum power and economy with minimum size and weight, which subjects such engines to severe stresses and thus makes them particularly susceptible to abruptly varying operating regimes.

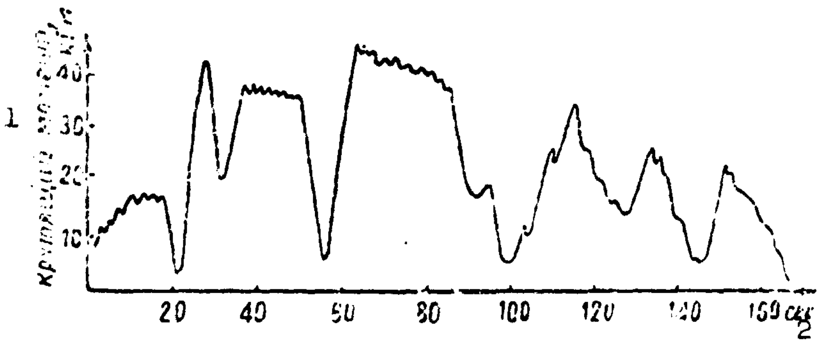


Fig. 1. Oscillogram of torque of automobile engine. 1) Tor ue, kg/m; 2) s.

Figure 1 shows a torque oscillogram characteristic of a massive automobile engine [18], demonstrating how abruptly the torque varies over short time intervals.

The different conditions under which trucks are used results in nonuniform loading of the engine over its total operating time.

Ye.S. Kuznetsov, who investigated the operating regimes of the ZIL [ЗИЛ] automobile during summer and winter service, established that the operating-time distribution was characterized by the following data:

Operating-time distribution index	Operating time, per cent
Length of loaded trip, km	
up to 20	56-45
from 20 to 25	25-32
more than	19-23
Average speed, km/h	
15-20	28-31
20-25	20-24
25-30	52-46

As experience in the operation of automobile engines with oils of different types (with and without multipurpose additives) has shown [19], especially high requirements are imposed on the operating properties of crankcase oil used for engine lubrication in winter transport. This is particularly true of the engines of light automobiles and buses, which operate with frequent starts and stops.

The results of numerous investigations have shown that piston and cylinder wear is accelerated by a factor of more than three as a result of fuel condensation and disruption of the lubrication regime when the engine temperature regime is reduced from 96 to 35°C. Water vapor, which condenses at low temperatures, promotes formation of emulsions, deposits, and sludge, thus causing increased wear.

Low-temperature automobile-engine operating conditions thus create great obstacles to normal functioning.

Under normal engine-operating conditions, the requirements imposed on lubricating-oil quality are made up of a number of characteristics associated with design factors, which are discussed below.

1. With the high compression ratios obtained in modern carburetor-equipped engines (up to 10-12), there is a great increase in engine sensitivity to the number of deposits in the combustion chamber. The amount of gas blown by into the crankcase increases, thus promoting rapid "aging" of the oil.

2. The increased pressures and temperatures in modern automobile engines are accompanied by a decrease in lubrication-system capacity. Thus, according to some data [11], the lubrication-system capacity is reduced from 5-5.5 to 4.5 quarts when the combustion temperature is raised from 2700 to 4000°F. This entails a rise in crankcase-oil temperature. According to American researchers [12], the average oil temperature in automobile-engine crankcases increased by 30°F between 1946 and 1956, while, according to George's data, an increase of 20°F in oil temperature doubles the oil-oxidation rate when aeration occurs.

3. The conditions for formation of acidic compounds characteristic of automobile-engine operation cause rapid corrosion of bearing alloys.

Automobile-engine operating conditions at moderate, high, and low ambient-air temperatures impose special requirements on the viscosity indices of automobile oils, this factor to a large extent governing the economy of engine operation.

According to data obtained at the VNIIAT [All-Union Scientific Research Institute of Automobile Transport] [19, 20], the power loss at a temperature of 2° is 45-50%, while only 20% of the gauge power is effectively used to create traction at the automobile's drive wheels at lower temperatures (-12°).

Tractor Engines

Tractor engines are used primarily during the spring and summer and their loading rate is substantially lower during the fall and winter. Other characteristic features of tractor-engine operation that serve to distinguish their loading conditions from those for, for example, automobile engines are associated with the characteristics of tractor use in different types of agricultural work and are due to the quite pronounced nonsteady loading.

V.N. Boltinskiy [21] pointed out the following principal regimes for tractor-engine operation:

idling during starts, brief stops, and changes in operating regime, where the engine is running at minimum speed;

idling at maximum speed, as governed by the regulator, before full loading with an agricultural implement;

different speed regimes involving complete or partial loading of the tractor engine, both in carrying out various agricultural operations and under minimum load with the tractor idling (in performing various types of agricultural work, the load on the tractor engine is usually 85-95% of the nominal load, while the idle load for a moving tractor is 15-45% of the nominal load);

overloading of the tractor engine, which is characterized by reduced power with full fuel delivery.

The substantial fluctuations in loading and the conjunction of frequently alternated regimes thus enable us to characterize tractor-engine operation as occurring under nonsteady loading. Thus, according to the data of V.N. Boltinskiy, the degree of nonuniformity of the moment of engine resistance during plowing can reach 0.3-0.4, while the average moment of resistance can vary by 35-40%. Fluctuations of this magnitude occur when there is nonuniform delivery during threshing, when moving over broken terrain, and in other cases.

In a special investigation devoted to tractor-engine operation under nonsteady loads, V.N. Boltinskiy [21] made a thorough analysis of the conditions leading to various fluctuations in engine-operating regimes as a function of external factors and established a number of criteria that enable us to characterize the influence of nonsteady loading on the parameters of tractor-engine operation.

The moment of resistance at a tractor-engine shaft during linear tractor movement is expressed by the following sum:

$$M_c = M_f + M_{\text{кр}} + N_a + M_0 + M_T,$$

where M_s is the total moment of resistance,

M_f is the moment of resistance to roll,

M_{pr} is the moment of drawbar resistance,

M_α is the moment of resistance during supercharged hoist operation,

M_θ is the moment of resistance due to inertial forces, and

M_t is the moment of resistance due to frictional forces.

The degree of nonuniformity is one index characterizing tractor-engine operation under nonsteady loads.

The degree of nonuniformity of each of the components of the moment of resistance δ is determined from the expression:

$$\delta = \frac{M_{max} - M_{min}}{M_{cp}},$$

where M_{max}, M_{min}, and M_{sr} are the maximum, minimum and average values of the component in question respectively.

In addition to the degree of nonuniformity, the variation in the components making up the moment of resistance is also affected by the period of the variation in a given component.

Both the magnitude and duration of deviations from the average moment of resistance have a material influence on tractor-engine operation. This effect is especially pronounced at loads close to the rated load.

The actual deviations of the components of the moment of resistance from their average long-term values are characterized by the coefficient of possible rise in a given component of the moment of engine resistance or by the coefficient of possible engine overloading during performance of a given agricultural operation:

$$\nu = \frac{M_{c\,cp.\,max}}{M_{c\,cp.}},$$

where ν is the coefficient of possible rise in a given component of the moment of engine resistance or the coefficient of overloading,

$M_{s\ sr,max}$ is the average temporarily elevated component of the engine resistance, and

$M_{s\ sr}$ is the average long-term value of the component of the moment of engine resistance in question.

A general analysis of the factors responsible for the different types of variation in the components of the moment of tractor-engine resistance enables us to give the approximate values in Table 1 for the parameters governing nonsteady tractor-engine operating regimes.

As can be seen from the data in this table, the variation in engine-operation regimes resulting from various operational and other causes are associated with many variables that generally have random values. Combinations of random values naturally do not have the character of regular phenomena. It is quite possible that the over-all nonuniformity is eliminated under certain conditions, when deviations of opposite sign occur simultaneously. However, there can also be cases where the maximum values of the components of the moment of resistance coincide. The nonuniformity can be assumed to range up to 0.4, while the coefficient of possible overloading is no more than 1.5. V.N. Boltinskiy suggested that, in first approximation, the varying moment of resistance be represented by the periodic function:

TABLE 1

Tractor-Engine Operating Regime with Different Components of Moment of Resistance

[1] Компонент момента сопротивления	[2] Степень неравномерности	[3] Период изменения	[4] Частота изменения	[5] Коэффициент перегрузки
[6] Момент сопротивления движению трактора				
[7] колесного	0,58—1,16	0,1 —0,3	10—3,3	1,33—2,0
[8] гусеничного	0,08—0,15	0,1 —0,2	10—5	1,88—2,1
[9] Момент сопротивления с.-х машины-орудия				
[10] Плуг	0,15—0,30	0,2 —2,0	5—0,5	1,33—1,1
[11] Борона	0,06—0,12	0,1 —0,3	10—3,3	1,0
[12] Сеялка	0,12—0,25	0,15—0,4	6,6—2,5	1,0
[13] Комбайн				
[14] моторный	0,06—0,36	0,2 —0,4	5—2,5	[18] 1,34—1,4
[15] безмоторный	0,03—0,22	0,06—0,5	14—2	до 1,4
[16] Молотилка	0,08—0,22	0,07—0,5	14—2	1,35—1,4
[17] Прицеп	0,06—0,40	0,04—0,2	25—5	—

1) Component of moment of resistance;
2) Degree of nonuniformity;
3) Variation period;
4) Variation frequency;
5) Overload coefficient;
6) Moment of resistance to tractor movement;
7) Wheel;
8) Track;
9) Moment of resistance of agricultural machinery;
10) Plow;
11) Harrow;
12) Seeder;
13) Combine;
14) Motor-driven;
15) Undriven;
16) Thresher;
17) Wagon;
18) Up to.

$$M_{\kappa x_1} = M_\kappa \left(1 + \frac{\delta_{\kappa_1}}{2} \sin m t_{x_1}\right)$$

and $$M_{\kappa x_2} = M_\kappa \left(1 - \frac{\delta_{\kappa_1}}{2} \sin m t_{x_2}\right),$$

where t_{x_1} and t_{x_2} are fractions of the maximum possible period of variation in the moment of resistance within which the quantities M_{kx_1} and M_{kx_2} are determined, while $m = 2\pi/T$ where T is the period of variation in the moment of resistance, which changes with the character of the work done by the tractor and the equipment it pulls.

Tractor-engine operation under winter conditions is characterized by comparatively low loads.

S.A. Chernov and Ya.I. Kuvshinov [22] give data on the results of observations of the operation of caterpillar tractors during winter (Table 2); these data show that 25-50% of engine-operation time is in idle and 15-38% under light loads.

TABLE 2

Data on Tractor Loading During Winter

1 Вид работы	2 Загрузка в смену при движении		5 Работа двигателя при неработающем тракторе
	3 с грузом	4 без груза	
6 Сельскохозяйственные работы			
ч	1,81	1,88	3,64
%	24,7	25,4	49,9
7 Строительные работы и планировка			
ч	2,68	2,77	1,84
%	36,7	38,0	25,3
8 Трелевка леса			
ч	4,49	1,39	3,19
%	49,3	15,4	35,3
9 Вывозка леса			
ч	2,38	2,06	3,84
%	29,5	25,6	45,8

1) Type of work;
2) Per-shift loading, tractor moving;
3) Loaded;
4) Unloaded;
5) Engine operation with tractor stationary;
6) Agricultural work;
7) Construction and leveling;
8) Wood skidding;
9) Wood hauling.

As has been pointed out, both rapid wear of cylinder-piston components and rapid aging of the crankcase oil, which leads to formation of more deposits and sludge, occur at low ambient temperatures.

Ship Engines

Operating conditions for ship engines differ materially from those for land-transport diesels.

Under normal conditions, operation of ship powerplants does not usually involve abrupt changes in load or speed. In most cases (except for light vessels), the diesels of both main and auxiliary powerplants operate under conditions where they are not subject to any substantial variations in ambient-air temperature, while the air contains no contamination in the form of abrasive particles that might enter the engine together with dust. From this standpoint, the operating conditions for ship diesels are substantially better than those for land-transport engines. However, there are also certain specific features that complicate these conditions, principally the danger of high air humidity, which is especially detrimental to engines operating on fuel with a high sulfur content.

Operating conditions for engines in riverboats are complicated by the more severe running conditions [23]. Engine overloads are more frequent and their duration often exceeds the permissible level. Ship operation in shallow water or in canals is associated with an increase in resistance to movement, which also promotes engine overloads and leads to an increase in thermal stresses and to a decrease in the durability of the cylinder-piston components.

The most typical temperatures for the cooling water leaving the engine are 55-65° for closed systems and 40-45° for through-flow systems [23]. Such temperatures are in themselves quite unfavorable from the standpoint of wearing of the cylinder-piston components, especially when the engine operates on heavy fuels with a high sulfur content, and are lower than the recommended operation temperatures.

According to the data of N.M. Renskii [23], the temperature of the cooling water leaving the engine for D-48, 6L 275 and other engines with closed cooling systems should be held between 70 and 75°C when the engine is operating at its rated power and under partial loads. For through-flow systems, this temperature should be 50-55°C.

Supply conditions for marine powerplants using engines with compressive ignition create the problem of developing the smallest possible number of types of oils for the great variety of diesel engines used in ships. In this connection, it can be assumed that use of highest-quality oils providing good operational reliability and life for marine powerplants, longer oil service life, and smaller expenditures for repair and dipping can compensate for any possible rise in oil cost.

A detailed technical-economic analysis of this situation should take into account the operation of a number of factors, prime among which are the type of engine used, the oil consumption in changes made at different intervals and resulting from the altered degree of oil burning caused by the improvement in cylinder-piston operating conditions, and the optimum variety of oils to be used.

Locomotive Engines

Two- and four-stroke engines with compressive ignition used as powerplants for locomotives operate in a manner similar to the marine powerplants considered above and are not subject to abrupt changes in load or speed.

The coefficients of resistance to motion are minimal when modern technical facilities are employed in railway transport. Through-train locomotives do not make frequent starts and stops and their powerplants therefore operate for longer periods under steady-state load and speed regimes. In contrast to marine diesels, their working conditions are characterized by higher cooling-water and lubricating-oil temperatures.

§3. PROMISING 'ICE' TYPES AND ALLOTMENT

The makeup of the present ICE fleet and the prospects for its development are to a substantial extent governed by the directions taken in the development of agricultural and industrial machinery and of transportation facilities in which given types of ICE's are used as powerplants.

Most current ICE's are automobile and tractor engines, which account for about 80% of the total power of powerplants using such engines. Using this as a basis, let us consider the main trends and directions in contemporary automobile and tractor design in the USSR and perspective types of ICE's for use in these vehicles.

Automobiles

Trucks. Trucks predominate in the Soviet automobile fleet. This characteristic of the makeup of the Soviet fleet essentially distinguishes it from the makeup of the world fleet. About 77.7% of Soviet motor vehicles are trucks, while they account for only 22% of the world fleet.

The developmental features of the Soviet national economy, both during the first five year plans and at present, have made the development of truck production a task of prime importance.

The truck fleet of the USSR is dominated by vehicles of moderate carrying capacity (from 2 to 5 t): these accounted for 92.2% of the fleet in 1958 and about 80% in 1965. The proportion of light trucks (less than 2 t) is about 10%. On the basis of the needs of the Soviet national economy, the number of trucks with carrying capacities of less than 2 t should be no less than 30% of the total number of trucks. The proportion of such vehicles in the world truck fleet is 60-70%.

The following table compares the truck-fleet makeups for the principal capitalist nations:

Carrying Capacity	USA	England	FRG	France	Italy
Less than 2 t	64.5	59.0	62.2	66.2	64.0
From 2 to 5 t	27.3	26.9	29.3	21.0	26.0
More than 5 t	8.2	14.0	8.5	12.8	10.0

Light trucks thus predominate in the makeup of the truck fleets of foreign countries, while medium trucks predominate in the USSR.

The advantages of the planned national economy of the USSR permit national centralization of goods transfer by trucks concentrated in large depots. These conditions permit mass transfer of large batches of goods in trucks with large carrying capacities, thus greatly reducing transportation costs.

The trends in the development of the Soviet truck fleet thus also differ radically from those in foreign countries in this respect. As can be seen from the data given above, the relative increase in the number of light trucks has been less rapid than that in the number of heavy trucks. In this connection, the extent to which diesels have been introduced into the Soviet fleet is also higher than in the USA: a total of 4% of the registered trucks in the USSR have engines with compressive ignition, while only 2.5% of the trucks in the USA are diesel-equipped.

Buses. The makeup of the bus fleets in both the USSR and foreign countries is governed by the layout of the over-all national transportation system.

The Soviet bus fleet is intended to provide both municipal and interurban transport; both types of application are undergoing dynamic development in accordance with the requirements of the populace.

Determination of bus-fleet makeup abroad is usually dominated by commercial considerations, as well as by the specific requirements of the localities in which the buses run.

The features of the economic development and geographic location of some nations causes the proportion of buses in their over-all motor vehicle fleets to be high, as in the USSR; available figures are 9.2% for India, 6.5% for Indonesia, 3.5% for Japan, and about 2.4% for England. The number of buses does not exceed 1-1.2% of the over-all fleet in other countries.

TABLE 3

New Gasoline-Engine Models in the USSR

[1] № модели	[2] Число цилиндров	[3] Рабочий объем	[4] N_e, л.с.	[5] n, об/мин	[6] M, кгм	$D \times H$	[7] Примечание
1	4	0,65—0,75	23—25	—	—	—	[8] Сверхмалолитражный
2	4	1,22	45	4500	8	—	[9] Новый малолитражный
3	6V	2,5	95	4200	19	—	[10] «Волга», ГАЗ-62, ГАЗ-56
	6V		85	3600		—	
4	6V	3,75	110	3800	25	100×80	[11] Вместо ГАЗ-51
5	8V	5,0	150	4000	34	100×80	[12] ЗИЛ
6	6V	5,2	135	3200	35	108×95	[13] Вместо ЗИЛ-120
7	8V	7,0	180	3200	47	108×95	[14] Автобусы
	8V	6,0	200	4000	41	108×95	[15] ЗИЛ-111
8	8V	10	240	2800	63,5	120×110	

1) Model No.;
2) Number of cylinders;
3) Working volume;
4) N_e, hp;
5) n, rpm;
6) M, kg-m;
7) Notes;
8) Ultralow-displacement;
9) New low-displacement;
10) "Volga," GAZ-62, GAZ-56;
11) Replaces GAZ-51;
12) ZIL;
13) Replaces ZIL-120;
14) Buses;
15) ZIL-111.

Light automobiles. Expansion of the light-automobile fleet in the USSR is directed principally at developing designs that will permit use of a minimum number of vehicles to satisfy maximum demands for passenger and special transport. Private-use automobiles are the most common type of light vehicle in the USSR, accounting for more than half of all light automobiles.

Since the light automobile is not at present regarded as a prime necessity, transportation will be principally by taxicabs and rented light automobiles in the near future. According to the data of the Academy of Municipal Economy RSFSR, the productivity of taxicabs is twice that of light rental automobiles and more than 12 times that of private-use automobiles.

The most common vehicles in the USSR are low-displacement "Moskvich" automobiles, which account for about half the light-automobile fleet. Like ultralow-displacement automobiles, they will soon enjoy preferential use as the vehicles most suited to operating requirements.

The predominance of models of the "Volga" class in the Soviet taxi fleet is not justified by their actual load (80% of taxi trips were for 1 or 2 passengers). The main type of taxi should therefore be based on low-displacement automobiles of the "Moskvich" type.

The requirement imposed on motor-oil quality by the "Moskvich" engine are therefore largely definitive for Soviet light automobiles.

The aforementioned trends in the development of the Soviet automobile fleet to a substantial extent determine the prospective types of engines that will be available, which are characterized by the data in Table 3.

This assortment provides eight basic models and two modifications with 6 piston diameters. This narrow range of automobile engines differs greatly from things abroad, where the commercial situation results in a mad race for greater power and there may be several dozen engine-model changes in a single year.

As is well known, the high engine power in current American light automobiles is largely due to competitive conditions. On the other hand, the increased power is also undoubtedly dictated by the need to raise both the dynamic and economic indices of the vehicles. However, these improvements are to a large extent attributable to the specific conditions of light-automobile operation in the USA. High engine power ensures rapid acceleration to high speed, which is of great importance for abrupt starts at intersections in heavy city traffic and makes it possible to reach high speeds on interurban highways. The high traffic speeds on American highways require minimum passing time, which is also provided by high engine power.

In addition, various automatic and auxiliary devices (servomechanisms, air-conditioners, and drive mechanisms for power windows and automatic convertible tops) consume up to 15-20% of the engine power in some cases.

Finally, the low cost of gasoline, which is cheaper in the USA by a factor of 2-3 than in most Western European nations, makes it possible to use high-power engines in American light automobiles.

Road conditions. Truck transport of goods is carried out over vast reaches of the Soviet Union, a factor that has a special effect on highway conditions for domestic automobile transport and to a considerable extent governs the trends in motor vehicle design.

The rate of automobile-transport development is known to outstrip the rate of roadbuilding in the USSR. For example, automobile freight traffic increased by a factor of 7.5 between 1940 and 1958, while the total length of hard-surface roads increased by a factor of only 1.65. According to the data of G.V. Zimelev and L.A. Bronshteyn [25], the USSR had 251.0 thousand kilometers of hard-surfaced roads in 1960, accounting for 18.3% of total highway mileage. Improved-surface roads (concrete, asphalt, and blacktop) accounted for 66.6 thousand kilometers or 5% of the highways in the USSR. Total truck freight traffic is distributed about equally between rural and urban roads. A substantial amount of freight traffic associated with supplying agriculture, industry, and rural construction, interurban transfer, centralized transport of commercial products, and supplying other specialized industries thus moves under severe road conditions, where the above-cited authors' data indicate that annual truck capacity does not exceed 20-25 thousand ton-kilometers.

Such operating conditions greatly reduce average speed (by a factor of 3-5), increase fuel consumption, reduce the service lives of basic automobile assemblies, and ultimately increase transport costs by a factor of 2-3 over dirt roads and by a factor of 5-6 over roadless terrain.

In addition to the direct losses that occur under the aforementioned conditions, capital expenditures must be increased when the service lives of the main vehicle assemblies are reduced, in order to assure that a given amount of freight can be moved with the requisite number of registered vehicles.

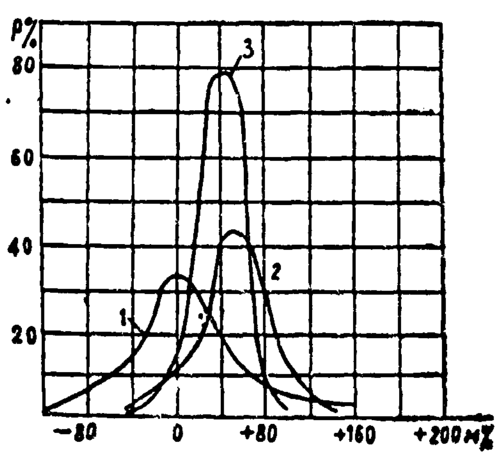


Fig. 2. Statistical torque distribution *f(M)* on relative coordinates under different running conditions. 1) Roadless terrain; 2) dirt road; 3) improved dirt road.

As can be seen from the results obtained by B.V. Gol'd and Ye.M. Obolenskiy in processing data obtained at the Moscow Automotive Mechanics Institute, the NAMI (НАМИ) [Central Order of the Red Banner of Labor Scientific Research Automotive and Automotive-

Engine Institute], and the LISI (ЛИСИ) [Leningrad Order of the Red Banner of Labor Structural Engineering Institute] [24], automobile-engine operation under severe running conditions is characterized by great scattering of torque values.

Gol'd and Obolenskiy present the results of an investigation of the torque-distribution curves for severe operating conditions. The authors considered three sets of running conditions:

1) travel over very poor hard-surfaced roads (improved gravel roads),where the torque varies considerably both in magnitude and direction;

2) travel over poor dirt roads and roadless terrain;

3) travel over unrolled dirt roads, which are usually encountered in rural areas.

Figure 2 shows the differential torque-distribution curves (% of M_e), taking into account the test regimes, which involve starting and shifting [the curves for $f(M)$ were constructed with the interval ΔM = 16%].

Automobile operation under severe road conditions thus creates abruptly varying loads on the engine, making its operating regime approximate the nonsteady tractor-engine regime described above.

Tractor fleet

The makeup of the Soviet agricultural-tractor fleet differs greatly in different areas of the country. Thus, tractors of low and medium power predominate in the northern and northwestern regions, while general-purpose tractors of high power and extremely powerful row-crop tractors predominate in the steppes, with their vast cultivated areas.

The data in Tables 4 and 5 give a general idea of the distribution of the main types of agricultural tractors in the USSR.

In 1958, Soviet industry produced six basic tractor models (С-80, ДТ-54А, КДП-35, МТЗ-5, ДТ-24М, and ДТ-14Б) and six modifications (С80Б, ДТ-55, ДТ-24, М-3, ТДТ-40, ТДТ-60, and ДСШ-14). In addition, the tractor fleets of tractor stations [TS] (МПС) and sovkhozes included various out-of-production machines: АСХТЗ-НАТИ, "Universal," СХТЗ, etc.

The prospective tractor fleet is based on ten classes differing in drawbar indices.

In accordance with GOST 7057-54, the main classification index in this system is the drawbar pull on stubble of normal dampness at the lowest operating speed.

The types of tractor engines available are based on this classification.

TABLE 4

Tractor Distribution in the Soviet National Economy [26, 27]

1 Республики и зоны	2 Число тракторов, тыс. ед.		5 Уд. вес гусеничных тракторов, %
	3 всего	в т. ч. гусеничных 4	
6 СССР	1051,8	636,3	60,4
7 В том числе			
8 РСФСР	612,2	391,4	63,5
7 В том числе			
9 Север	20,0	14,6	73,0
10 Северо-запад	24,6	13,2	56,0
11 Центр	197,8	112,3	67,0
12 Поволжье	38,5	43,7	64,0
13 Северный Кавказ	76,1	40,6	53,4
14 Урал	81,8	55,1	67,4
15 Западная Сибирь	87,4	64,2	73,5
16 Восточная Сибирь	38,9	29,4	73,5
17 Дальний восток	21,0	15,4	73,5
18 УССР	164,6	83,7	51,0
19 БССР	19,5	15,4	52,3
20 Узбекская ССР	41,8	13,2	27,1
21 Казахская ССР	111,5	85,4	76,7
22 Грузинская ССР	6,0	3,7	62,6
23 Азербайджанская ССР	12,4	6,6	53,3
24 Литовская ССР	13,6	8,5	63,0
25 Молдавская ССР	11,6	6,1	52,6
26 Латвийская ССР	10,7	6,0	55,7
27 Киргизская ССР	9,5	4,6	48,6
28 Таджикская ССР	7,0	2,9	41,5
29 Армянская ССР	3,4	2,2	64,3
30 Туркменская ССР	7,2	3,0	42,4
31 Эстонская ССР	7,0	3,5	49,8

1) Republics and areas;
2) Number of tractors, thousands;
3) Total;
4) Caterpillar tractors;
5) Proportion of caterpillar tractors, %;
6) USSR;
7) Including;
8) RSFSR;
9) North;
10) Northwest;
11) Center;
12) Povolzh'ye;
13) Northern Caucasus;
14) Urals;
15) Western Siberia;
16) Eastern Siberia;
17) Far East;
18) UkSSR;
19) BSSR;
20) Uzbek SSR;
21) Kazakh SSR;
22) Georgian SSR;
23) Azerbaydzhan SSR;
24) Lithuanian SSR;
25) Moldavian SSR;
26) Latvian SSR;
27) Kirgiz SSR;
28) Tadzhik SSR;
29) Armenian SSR;
30) Turkmen SSR;
31) Estonian SSR.

TABLE 5

Makeup of Soviet Tractor Fleet, by Types [26, 27]

1 Типы тракторов по назначению и мощности	2 Физические единицы, %	3 Условные единицы, %
4 **Тракторы общего назначения**		
5 Гусеничные ДТ-140 класс[6] 8,5 *т*[7]	0,3	1,5
ДТ-100 " 5,5 *т*	1,2	3,7
ДТ-70 " 4,0 *т*	8,4	15,2
ДТ-54 " 3,0 *т*	18,8	28.8
ДТ-40 " 2,0 *т*	3,6	4,1
8 Колесные ДТ-40 " 1,4 *т*	1,1	1,3
9 Итого	33,4	55,1
10 **Тракторы пропашные (универсальные)**		
5 Гусеничные ДТ-40 класс[6] 2,0 *т*[7]	3,4	3,8
8 Колесные ДТ-40 " 1,4 *т*	25,9	23.3
ДТ-24 " 0,9 *т*	26,5	14,7
ДТ-14 " 0,6 *т*	10,8	3,1
Итого	66,6	44,9
11 Всего	64,3	42,4

1) Tractor types by purpose and power;
2) Physical units, %;
3) Arbitrary units, %;
4) General-purpose tractors;
5) Caterpillar;
6) Class;
7) t;
8) Wheel;
9) Sum;
10) Row-crop tractors (general-purpose);
11) Total.

There is a trend in tractor building to increase the operating speed of wheel tractors to 9 km/h and that of caterpillar tractors to 7 km/h. This is associated with the fact that agricultural machinery is more productive at high speeds and with the wider use of agricultural tractors for transport in construction and materials handling.

The increase in engine power required to realize these goals will be achieved by raising the average effective rated-regime pressure from the present 5.0-6.1 kg/cm^2 to 6-7 kg/cm^2.

Wide use has been proposed for air-cooled engines, which have a power of up to 40-60 hp, as well as for two-stroke and fuel-injection engines.

The main type of tractor engine in the USSR at present is the four-stroke engine with compressive ignition. Table 6 shows the prospective types of four-stroke tractor diesels. The basic models in this list are the four-cylinder engines in each power range. These basic models are the foundation for one-, two-, and six-cylinder modifications intended for various restricted agricultural needs.

Six-cylinder engine designs with powers of more than 100 hp are provided for reasons of dynamics and balance.

TABLE 6

Perspective Types of Four-Stroke Diesels

1 Класс двигателя	2 Предназначается для тракторов с тяговым усилием, *т*	3 Число цилиндров	4 Рабочий объем, *л*	5 Основные технические показатели при различных регулировках: 6 Непрерывная работа с перегрузкой до 10%* — 10 N_e, л. с.	7 Длительная работа с временной перегрузкой** — 10 N_e, л. с.	8 Работа без перегрузки*** — 10 N_e, л. с.	9 Работа с переменной кратковременной нагрузкой — 10 N_e, л.с.	9 — 11 *n*, об/мин	12 Отлаждение
Д-0,8	0,2	1	0,85	7,5	8	10	12,5		13 Воздушное
	0,6	2	1,7	15	16	20	25	2250	
	0,9	4	3,4	30	32	40	50		
Д-1,0	1.4.2	4	4,2	42	45	55	68	2100	14 Воздушное и водяное
Д-1,4	3	4	5,8	58	62	75	95	2100	15 Водяное
	4	6	8,7	87	93	113	142		
Д-2,0	5,5—8,5	6	12,0	120	128	155			
				160 (с наддувом) [16]	180 (с наддувом) [16]	200 (с наддувом) [16]			

*n = 1500 rpm
**n = 1600 rpm
***n = 1800 rpm

1) Engine class;
2) Intended for tractors with drawbar pull of, t;
3) Number of cylinders;
4) Working volume, liters;
5) Basic technical indices with different engine adjustments;
6) Continuous operation with 10% overload*;
7) Long-term operation with temporary overload**;
8) Operation without overload***;
9) Operation with brief varying load;
10) N_e, hp;
11) *n*, rpm;
12) Cooling;
13) Air;
14) Air and water;
15) Water;
16) With injection.

As is well known, tractors are used in various branches of industry outside agriculture. They are employed in construction, particularly in setting up powerplants and hydroelectric projects and in laying railroad track, blacktops, and other types of highways.

The data in Table 7 show that, of the total of 3,250,000 units required by the national economy in 1966, most should go to satisfy

TABLE 7

Tractors Required for the National Economy on 1 January 1966 (Thousands of Physical Units)

Класс и тип тракторов (1)	Сельское хозяйство (2)	Строительство (3)	Лесная промышленность (4)	Прочие (5)	Итого (6)
14 *т* гусеничный (7)	—	0,8	1,45	0,75	3,0
8,5*т* »	8,5	4,5	8,65	2,35	24,0
5,5*т* »	30,4	75,3	17,2	37,1	160,0
4 *т* »	211,0	—	—	9,0	220,0
3 *т* »	473,7	58,6	—	97,7	630,0
2 *т* » общего назначения (8)	91,4	1,5	—	7,1	100,0
1,4*т* колесный » (9)	27,0	41,0	—	2,0	70,0
2*т* гусеничный прокатный (10)	85,3	—	—	4,7	90,0
1,4*т* прокатный колесный (11)	650,2	—	—	49,8	700,0
0,9*т* » »	664,7	2,0	—	109,3	770,0
0,6*т* » »	272,5	5,1	—	72,4	350,0
Специальные с.-х. (12)	40,0	—	—	6,0	46,0
Гусеничные трелевочные (13)	—	—	83,0	2,0	85,0
Мощные колесные вездеходные тягачи (14)	—	—	1,8	0,2	2,0

1) Tractor class and type;
2) Agriculture;
3) Construction;
4) Timber industry;
5) Others;
6) Total;
7) t caterpillar;
8) General-purpose;
9) Wheel;
10) Caterpillar roller;
11) Wheel roller;
12) Special agricultural;
13) Caterpillar skidding;
14) High-power all-terrain wheel tow.

the needs of agriculture (2574.7 thousand units) and only 188.8 thousand to construction and 112.1 thousand to the timber industry.

The Soviet tractor industry is continually improving the quality of its output. The ДТ-75 caterpillar tractor produced by the Volgograd Tractor Plant has a power 25% greater than its predecessor, the ДТ-54 tractor, which is now the most widely used in agriculture. The Lipets Tractor Plant is producing a new general-purpose wheel tractor, the T-40, which has an engine power of 40 hp, as well as the MT3-50 tractor. Tractor engines with turbine injection promise to become the most widely used.

The following data characterize the increase in average tractor-engine power:

Year of Production	Average Power, hp
1963	48
1964	53.8
1965	58.0

Maximum tractor-engine power will be realized in a tractor with a planned power of 220 hp. However, tractors of this class will account for less than 1% of the total number in operation.

Most of the tractor fleet will consist of units of low and medium power, which can be most efficiently used in the continually expanding range of mechanized agricultural operations.

§4. BRIEF SURVEY OF THE DEVELOPMENT OF MOTOR-OIL SPECIFICATIONS

The development of motor-oil specifications abroad was closely related both to the quality of the oils used, which continuously changed as the requirements imposed by progress in engine building increased, and to oil-test methods, principally for motor oils. The latter played an especially important role in the formulation and development of specifications and, in many cases, it is now difficult to establish which came first, specifications or motor tests.

This was reflected in the unarguable fact that testing of the physical, chemical, mechanical, and other properties of oils in various types of equipment is meaningful only for identification, quality control, and, to some extent, research. Such tests do not establish actual operating properties, since the test conditions do not mirror actual conditions.

Before mineral oils were used in engines, such procedures could serve as a basis for oil selection, since they could be employed to select a set of basic oil-quality indices that would largely include the most important operating properties. This was due in great measure to the fact that, with the load and speed regimes then operative, the viscosity index was the principal factor governing the suitability of a given oil or a given engine.

The more rigid engine-operation conditions in the nineteen-thirties caused corrosion, increased carbon deposits, ring seizure, and other detrimental processes.

From the outset, foreign specifications, which were worked out principally in the USA, aimed at development of engine-test methods for oil-quality evaluation that would make it possible to determine the extent to which a given oil satisfied definite qualitative requirements.

Work in this area in the USA was handled by the Coordinated Research Council (CRC), which was organized by the American Petroleum Institute (API) and the Society of Automotive Engineers (SAE). The first specifications, which were based on a series of engine tests, were adopted by the Artillery Command of the US Army in 1941 (2-104, 3 September 1941) and were intended for evaluation of oils operating under heavy-duty conditions (HD). This set of specifications later underwent a number of modifications (2-104a, 9 April 1942 and 2-104b, 6 May 1943). For example, specifications 2-104B for HD oils included 5 types of engine tests:

1) CRC-L-1-545 (AXS-1551) – 480-hour tests in a single-cylinder Caterpillar engine, which evaluated wear, ring seizure. and carbon deposits on the main cylinder-piston components;

2) CRC-L-2-545 (AXS-1552) – a 3 hour, 20 minute test in a Caterpillar engine, which evaluates tar deposits on the piston rings;

3) CRC-L-3-545 (AXS-1553) – a 120-hour test in a four-cylinder engine, which evaluates oil stability at high temperatures and the corrosion resistance of lead-bronze bearings;

4) CRC-L-4-545 (AXS-1554) – 36-hour tests in a six-cylinder gasoline engine, which evaluate the oxidation characteristics of HD oils;

5) CRC-L-5-545 (AXS-1555) – 500-hour tests in a 3- or 4-cylinder General Motors diesel engine, which evaluate oxidation resistance, tendency toward ring seizure, carbon deposition, and corrosion.

Experience in the use of this set of specifications showed that a sufficiently complete characterization of oil quality could be obtained by using only the L-1 and L-4 tests, rather than all five. On the basis of this experience, the previously effective 2-104 B specifications were succeeded by the new military specifications USA MIL-O-2104 (4 August 1950).

Another difference in the new specifications was the fact that the quality of the oil required for the L-1 engine test (no more than 0.4% sulfur) was changed(to no less than 0.35% sulfur).

The specifications used by the British army and navy were also based on the 2-104B specifications and stipulated the properties of the following types of oil: OE-10-HD, OE-30-HD, and OE-50-HD.

Later changes in the American specifications (MIL-O-2104A, February 1954) were similar to the changes in the British specifications (DEF-2101A, July 1953). The DEF-2101B specifications (30 September 1957) excluded viscosity-index improvers and limited the depressant content to 1.5%. Use of depressants that simultaneously serve as viscosity-index improvers was permitted.

Supplement I oils are intended for engines running on fuel with a sulfur content of more than 1%. The properties of these oils should be higher than those specified by MIL-O-2104. Experience in the use of these oils and a broad special correlative program that preceded establishment of specifications showed that the required properties were provided by oils that passed the L-1 test when fuels containing 1% sulfur were employed.

The subsequent development of the American specifications was associated with the fact that some supercharged engines with compressive ignition operating on fuels with high sulfur contents were not satisfactorily lubricated by oils that passed the MIL-O-2104A and Supplement I tests when operating conditions were severe.

It was established that an oil met the specifications for Series 2 if it passed a 480-hour test in a supercharged single-cylinder diesel by the "I-D Test" method (operating on a fuel containing 1% sulfur).

In 1955, the Caterpillar Corp. raised the specifications for Series 2 oil quality.

TABLE 8

Test Procedures for Series 3 Oils

1 Показатели	2 Метод испытания и двигатель			
	3 „Катерпиллер 1-А" СКС L-1 AXS-1551, одноцилиндровый дизель „Катерпиллер"	4 „Катерпиллер 1-D", одноцилиндровый дизель, „Катерпиллер" с наддувом	5 „Катерпиллер 1-G", одноцилиндровый дизель „Катерпиллер" с наддувом	6 AXS-1554 СКС L-4, бензиновый 6-цилиндровый двигатель „Шевроле"
7 Диаметр×ход поршня, дюймы	$5^{1}/_{4}\times8$	$5^{3}/_{4}\times8$	$5^{1}/_{8}\times6^{1}/_{2}$	$3^{1}/_{8}\times3^{3}/_{4}$
8 Скорость, *об/мин*	1000	1200	1800	3150
9 Длительность опыта, *ч*	480	480	480	36
10 Т-ра масла, °F	150	175	205	280
11 Т-ра воды (или охлаждающей жидкости), °F				
12 на выходе	180	200	190	200
13 на входе	19 Менее 100	200	225	80(мин) 20
14 Давление на входе, *мм рт. ст.*	21 Атмосферное	22 1140(абс.)	22 1350(абс.)	21 Атмосферное
15 Мощность, *л. с.*	20	42—45	42—45	30
16 Топливо	23 S=0,3% S не менее 1% для „Suppl. I"	S=0,95—1,05 %	S=0,35 % min	S=0,1 % min
17 Оценочные показатели	Прихват колец, износ, отложения 24	Прихват колец, износ отложения 24	Прихват колец, износ, отложения 24	Окисление и коррозия подшипников 25
18 Оценочное испытание для спецификаций	MIL-L-2104A 26 (США) DEF-2101B 27 (Англия) IS:496—1955 BC·1905:1952 Suppl	Superior lubricants Series-2 Series-3	Superior lubricants Series-3	MIL-L-2104A DEF 2101B IS:496—1955 BS 1905:1952

1) Index; 2) Test procedure and engine; 3) Caterpillar 1-A, CRC L-1 AXS-1551, single-cylinder Caterpillar diesel; 4)Caterpillar 1-D, single-cylinder Caterpillar diesel with fuel injection; 5) Caterpillar 1-G, single-cylinder Caterpillar diesel with fuel injection; 6) AXS-1554 CRC L-4, six-cylinder Chevrolet gasoline engine; 7) Bore and stroke, inches; 8) speed, rpm; 9) experiment duration, h; 10) oil temperature, °F; 11) water or coolant), temperature, °F; 12) at discharge; 13) at intake; 14) intake pressure, mm Hg; 15) power, hp; 16) fuel; 17) indices evaluated; 18) test for specifications; 19) less than; 20) min; 21) atmospheric; 22) abs; 23) S = 0.3%, S no less than 1% for Supplement I; 24) ring seizure, wear, and carbon deposition; 25) oxidation and bearing corrosion; 26) USA; 27) England.

On the basis of a broad correlative program that included laboratory investigations and field tests of high-supercharged short-stroke six-cylinder engines, the Caterpillar Corp. set up requirements for Improved Series 2 oils. These requirements included 480-hour tests in the new Caterpillar engine, using a fuel with a high sulfur content. The amount of additives in these oils was almost double that in oils satisfying the requirements of the Series 2 specifications, ranging from 15 to 25%.

TABLE 9

Summary of Military Specifications and Engine-Test Procedures

1 Страна	2 Спецификация	3 Разновидности спецификаций	4 Комплекс специализированных испытаний	5 Краткое содержание спецификационного испытания	6 Соответствующие спецификации или двигатели
1	2	3	4	5	6
[7] США	[8] Артиллерии	MIL-L-2101A	[10] Катерпиллер 1-А	[12] Оценка детергентных свойств на дизельном двигателе	IP 124/60 CRC L-1-545
			CRC L-38 [11] (взамен Шевроле К-4)	Оценка окисления и коррозии вкладышей из свинцовой бронзы	[14] Шевроле L-4
	[9] Общевойсковая	MIL-L-2104 B	[10] Катерпиллер Е. Т. 17	[15] Оценка детергентных свойств на двигателе с наддувом	[10] Катерпиллер 1-G
			CRC L-38	[16] Оценка окисления и коррозии вкладышей	Шевроле L-4 [14]
			CRC L-43	[17] Оценка детергентных и диспергирующих свойств масел в условиях низких температур	Labeco
			[18] Низкотемпературное испытание	[19] Испытание в процессе отработки	Labeco
	[8] Артиллерии	MIL-L-45199	[20] Федеральный метод 340-Т-Катерпиллер 1-D		[21] Видоизмененная Series-3
			[22] Федеральный метод 341-Т-Катерпиллер		
			[23] Испытания Шевроле L-4		

TABLE 9 CONTINUED

1	2	3	4	5	6
	[24] Военно-морского флота	ML-L-9000A, [25] Класс А[6]	[26] Катерпиллер L-1, спецификация MIL-P-17271		
			[27] G -75, спецификация MIL-P-17269		
			[28] GM-71, спецификация MIL-P-17270 только для масел 9005		
		ML-L-9000A, [25] Класс В[6]	[29] GM-71, спецификация MIL-P-17273		
			[30] Катерпиллер L-1 Спецификация MIL-P-17271, модифицированная		
		MIL-L-9000 E	[31] То же, что и для MIL-L-9000A, Класс А[6], но опыт Катерпиллер L-1 проводится без смены масла		
[32] Великобритания	[33] Армии	DEF 2101B	[10] Катерпиллер L-1		
			[34] Петтер W-1		IP 176 60T

TABLE 9 CONTINUED

1	2	3	4	5	6
	3 5 Адмиралтейства	EInC 0—5 EInC 0—8	1 0 Катерпиллер L-1		
			3 4 Петтер V-1		IP 176,COT
3 6 Бельгия	3 3 Армии	QOCG-10A	1 0 Катерпиллер L-1		
			CRC L-38		
			3 4 Петтер AVI CEC AT-4 5-04		IP 175,COT.
	3 7 Флота	ZQM 1100-C	3 4 Петтер AVI		
			GM-71		
			1 0 Катерпиллер L-1		
3 8 ФРГ	3 3 Армии	VTL 9150-006	1 0 Катерпиллер L-1		
			1 4 Шевроле L-1		

Key to Table 9

1) Country;
2) Specifications;
3) Specification designation;
4) Specialized tests;
5) Summary of specificaton tests;
6) Corresponding specifications for engines;
7) USA;
8) Artillery;
9) All services;
10) Caterpillar;
11) Replaced by Chevrolet K-4;
12) Evaluation of detergent properties in diesel engine;
13) Evaluation of oxidation and corrosion of lead-bronze bearings;
14) Chevrolet;
15) Evaluation of detergent properties in fuel-injected engine;
16) Evaluation of oxidation and bearing corrosion;
17) Evaluation of detergent and dispersion properties of oil under low-temperature conditions;
18) Low-temperature test;
19) Test in development;
20) Federal method 340-T-Caterpillar 1-D;
21) Modified;
22) Federal method 341-T-Caterpillar;
23) Chevrolet L-4 test;
24) Navy;
25) Class;
26) Caterpillar L-1, MIL-P-17271 specifications;
27) GM-75, MIL-P-17269 specifications;
28) GM-71, MIL-P-17270 specifications, for oil 9005 only;
29) GM-71, MIL-P-17273 specifications;
30) Caterpillar L-1, MIL-P-17271 specifications, modified;
31) The same as for MIL-L-9000A, Class A[6], but Caterpillar L-1 test conducted without oil change;
32) Great Britain;
33) Army;
34) Petter;
35) Admiralty;
36) Belgium;
37) Navy;
38) FRG.

Still more stringent requirements on oil quality were imposed by the Caterpillar Corp. in 1956, when it was found that oils that satisfied the Improved Series 2 specifications did not perform satisfactorily under certain operating conditions.

The new requirements, which were designated as Superior Lubricant - Series 3, provided for tests by the 1-D and 1-G methods, as can be seen from Table 8.

Current international specifications for evaluating motor-oil quality

Most ICE oils currently being produced abroad satisfy the following basic specifications for quality:

Military, including the Army and Navy specifications in the USA, the War Ministry and Admiralty in Great Britain, and the armies and navies of most European countries (France, Belgium, etc.);

the Caterpillar Corp., which stipulate oil quality for tractor engines operating under severe conditions (fuel injection, use of fuels with high sulfur contents, etc.);

the API, IP, UK, and European Council classifications.

Table 9 gives a brief summary of these specifications.

Since the operations of the Caterpillar Corp. had a considerable influence on the development of specifications in the USA, we will briefly consider the special requirements imposed by this company, which are widely employed in the USA.

The high-speed tractor diesels produced by the Caterpillar Corp., which have fuel injection and operate on fuels with high sulfur contents, use oils whose properties satisfy the Series 2 and Series 3 specifications.

Evaluation of Series 2 oils is carried out by the Caterpillar 1-D engine-test method, using a fuel containing 1% sulfur. Series 3 oils are evaluated by the 1-D and 1-G methods, using a fuel containing 0.35% sulfur.

TABLE 10

Test Regimes for Caterpillar 1-D and 1-G Methods

1 Показатели	2 Метод „Катерпиллер 1-D"	3 Метод „Катерпиллер 1-G"
4 Диаметр цилиндра, дюймы	$5^3/_4$	$5^1/_8$
5 Номенклатурный номер испытательного комплекта	IV 7620	IV 7999
6 Длительность опыта, ч	480	480
7 Скорость, об/мин	1200 ± 10	1800 ± 10
8 Нагрузка, эффективные л. с.	42—45	42—45
9 Содержание серы в топливе, %	0,95—1,05	0,35 мин. 0,45 макс.
10 Т-ра охлаждающей жидкости, °С		
11 на выходе	93,33	87,78
12 на входе	18 На 5—10 меньше, чем на выходе	18 На 5—10 меньше, чем на выходе
13 Т-ра масла, подаваемого на смазку подшипников, °С	79,44	96,11
14 Т-ра воздуха, подаваемого в двигатель, °С	93,33	123,89
15 Количество масла, кг	4,99	4,99
16 Давление масла, кг/см²	2,1	2,1
17 Давление наддува, дюймы рт. ст.	44—45	52,7—53,3

1) Indices; 2) Caterpillar 1-D method; 3) Caterpillar 1-G method; 4) Cylinder diameter, inches; 5) model number of unit tested; 6) experiment duration, h; 7) speed, rpm; 8) load, effective hp; 9) sulfur content of fuel, %; 10) coolant temperature, °C; 11) at discharge; 12) at intake; 13) temperature of oil supplied for bearing lubrication, °C; 14) temperature of air supplied to engine, °C; 15) amount of oil, kg; 16) oil pressure, kg/cm²; 17) injection pressure, inches of mercury; 18) 5-10°C lower than at discharge.

Table 10 briefly summarizes the engine-test regimes.

API Classification of Lubricating-Oil Application Conditions

This classification makes it possible to establish a number of general features characterizing the conditions under which lubricating oils function in engines and to determine the requirements that must be imposed on oil quality for it to satisfy these conditions. The classification does not stipulate the methods that should be used to test oils for given operating conditions.

Three categories of lubricating-oil operating conditions for gasoline engines and three corresponding categories for diesel engines have been defined: ML, MM, MS, DG, DM, and DS.

ML. Operating conditions typical of gasoline and other internal-combustion engines operating under mild and favorable conditions. The engine has no special lubrication requirements or design features affected by carbon-deposit formation.

MM. Operating conditions typical of gasoline and other engines with spark ignition used under operating conditions ranging from moderate to severe but presentin problems in controlling carbon deposition or bearing corrosion when crankcase-oil temperature is high.

MS. Operating conditions typical for gasoline and other engines with spark ignition used under unfavorable or severe operating conditions. Special requirements are also imposed on lubricant quality in order to prevent carbon deposition, wear, and bearing corrosion. These special requirements may result from operational conditions or from the design features of the engine or may arise when unfavorable types of fuel are used.

HG. Operating conditions typical of compressive-ignition engines under any operating conditions where there are no stringent requirements for wear and carbon deposition associated with fuel and lubricating-oil quality or resulting from design features in the engine.

DM. Conditions typical for compressive-ignition engines operating under severe conditions or on fuels that increase wear or carbon deposition under normal conditions, but with design features or operating conditions such that the engine may be either less severely affected by the fuel or more severely affected by deposits produced by the lubricating oil.

DS. Conditions typical for compressive-ignition engines operating under very severe conditions and having design features for using fuels that cause extreme wear and carbon deposition.

MS operating conditions in the API classification correspond to high-supercharged regimes for V-block automobile engines.

Engine tests to determine whether oil properties satisfy the special requirements dictated by the operating conditions for these engines are handled in accordance with the so-called ASTM GIV MS test grades, using full-size V-block automobile engines.

TABLE 11

Summary of Methods for Evaluating Motor-Oil Properties by API Grades

1 Градации	2 Методика	3 Двигатель	4 Длительность, ч	5 Оценочные детали
I	6 Низкотемпературная, на средних скоростях для оценки задиров и износа	11 Олдсмобиль, модель 1958 г.	30	12 Кулачки и толкатели клапанного механизма
II	7 Низкотемпературные отложения	13 То же	96	14 Толкатели клапанного механизма
III	8 Окисление при высоких температурах	13 То же	36	15 Поршни и кольца, клапанный механизм, прокачка масла
IV	9 Высокотемпературная, на высоких скоростях для оценки задиров и износа	16 Де Сото, модель 1958г.	24	17 Распределительный вал, толкатели
V	10 Оценка осадкообразования, накопления нерастворимых примесей, забивка маслоприемников	18 Линкольн, 1957г. или одноцилиндровый двигатель CLR (градация Va)	288	19 Поршень и кольца, клапанный механизм, маслоприемник

1) Grade;
2) Method;
3) Engine;
4) Experiment duration, h;
5) Components evaluated;
6) Low-temperature, at moderate speeds, for evaluating seizing and wear;
7) Low-temperature carbon deposits;
8) High-temperature oxidation;
9) High-temperature, at high speeds, for evaluation of seizing and wear;
10) Evaluation of carbon deposition, accumulation of insoluble impurities, and clogging of oil passages;
11) Oldsmobile, 1958 model;
12) Cams and valve pushrods;
13) The same;
14) Valve pushrods;
15) Pistons and rings, valves, oil pump;
16) DeSoto, 1958 model;
17) Camshaft, pushrods;
18) Lincoln, 1957 model, or single-cylinder CLR engine (grade Va);
19) Pistons and rings, valves, oil passages.

Tables 11 and 12 give indices fully characterizing the test procedures used to evaluate oil properties whose specifications must conform to given operating conditions.

The test cycles for grades I, II, and III follow one another without an oil change. The condition of the engine is determined after the tests for grade III.

The tests for the following two grades are each conducted with fresh oil and evaluations are made at the end of the appropriate experiments (Table 13).

TABLE 12

Test Regimes for Grades I, II, and III (Oldsmobile Engine, 1958 Model)

1 Показатели	I	II	III
2 Скорость, *об/мин*	2500±20	1500±20	3400±20
3 Нагрузка, *л. с.*	—	25± 2	85± 2
4 Температура охл. жидкости, °C			
5 на выходе	35,00	35,00	93,33
6 на входе	29,44	29,44	87,78
7 Т-ра масла в картере, °C	48,89	48,89	129,44
8 Состав топливовоздушной смеси	—	16:1	16:1
9 Влажность воздуха, *г/кг* сухого воздуха	1,1	1,1	1,1
10 Нагрузка на клапанные пружины	18 17 Нормальная		
11 Время работы двигателя	10 *мин*	3 *ч*	36 *ч*
12 " простоя "	50 *мин**	3 *ч*	—
13 Число циклов в испытании	30	16	1
14 Топливо	19 Серы 0,16+0,02 % (вес)		
15 Вентиляция картера	20 Заглушена		Нормальная
16 Масляные фильтры	21 Отключены		

*The water temperature is held at 35°C.

1) Index;
2) Speed, r/min;
3) Load, hp;
4) Coolant temperature, °C;
5) At discharge;
6) At intake;
7) Crankcase-oil temperature, ;
8) Composition of fuel-air mixture;
9) Atmospheric moisture content, g/kg dry air;
10) Valve-spring load;
11) Engine operating time;
12) Engine idle time;
13) Number of test cycles;
14) Fuel;
15) Crankcase ventilation;
16) Oil filters;
17) Normal;
18) Min;
19) Sulfur — 0.16 + 0.02% by weight;
20) Choked;
21) Disconnected.

The test conditions for grade IV (De Soto engine, 1958 model; fuel for test not stipulated) are:

speed — 3680 r/min,
load — idle,
Water temperature at discharge — 82.22°C,
Crankcase-oil temperature — 104.44°C,
Valve-spring load — 36% overload,
Engine operating time — 2 h,
Engine idle time — 2 h with cold-water circulation,
Number of test cycles — 6,
Total test time — 24 h.

TABLE 13

Test Conditions for Grade V (Lincoln-Mercury Engine, 1957 Model)

[1] Показатели	[2] Этапы испытаний		
	1-й	2-й	3-й
[3] Скорость, об/мин	[14] 500	2500	2500
[4] Нагрузка, эффективные л. с.	Холостой ход	105	105
[5] Т-ра воды на выходе	37,38—51,67	51,67	76,67
[6] Т-ра масла в картере	51,67	82,2?	98,79
[7] Состава топливовоздушной смеси	9:1—10:1	15:1—16:1	15:1—16,1
[8] Нагрузка клапанных пружин	[16]	[15] Нормальная	
[9] Время работы двигателя	45 мин	2 ч	75 мин
[10] » простоя	[17] 8 ч в течение каждого 24-часового периода		
[11] Число циклов в опыте		48	
[12] Общее время испытаний		288 ч	
[13] Тип топлива	[18] Летняя марка сорт „Regular"		

1) Index;
2) Test stages;
3) Speed, r/min;
4) Load, effective hp;
5) Water temperature at discharge;
6) Oil temperature in crankcase;
7) Composition of fuel-air mixture;
8) Valve-spring load;
9) Engine operating time;
10) Engine idle time;
11) Number of test cycles;
12) Total test time;
13) Type of fuel;
14) Idling;
15) Normal;
16) Min;
17) 8 h in each 24-h period;
18) Summer-type, regular grade.

The British standards (IP) specify five types of tests:

1) Caterpillar 1-A – IP 124/60 method, used for DEF-2101B specifications;

2) Caterpillar 1-D – IP 173/60 method, used for Caterpillar Series II specifications;

3) Gardner IL-2 – method 174 60/T for evaluating ring seizure and wear in diesel engines using fuels containing 1.0% sulfur;

4) Petter A.V. I – method 175/60T for compressive-ignition engines using fuels with a sulfur content of 0.35-0.45% (method A) or 0.95-1.05% (method B);

5) Petter W.I. – IP 176/50T method for spark-ignition engines, used for the DEF-210IB specifications.

British Admiralty Specifications for Diesel Engines used in Marine Powerplants

During the period preceding the Second World War, Ships of the British Admiralty used oils without additives, whose properties were specified by the results of physicochemical analyses.

During the war, the navy used American oils intended for heavy-duty conditions HD) in accordance with the USA 14-0-13 specifications, based on the SAE-10, 20, 40 and 50 weights and compounds, the SAE-30 being the most satisfactory.

During the postwar period, the British OMD-111 series, which was used until 1953, corresponded to the 14-0-13 and 14-0-13A specifications.

After 1954, the DEF-2101 specifications (corresponding to the American military standard MIL-L-2108) for land-transport use provided occasion for development of the improved OMD-110(NS) specifications, which supplemented the OMD-110 specifications with a better oil test under L-1 experimental conditions, using a fuel containing 1% sulfur. This intermediate specification was later replaced by two new sets of specifications, which established two different oil-quality levels: for normal conditions and for supercharged engines (Deltic type).

Both specifications were based on evaluations by the Caterpillar L-1 method.

The new types of oil came to be known as OMD-109 and OMD-112 and met the requirements specified in E-in-C08 (1957) and E-in-C05 (1956). These specifications were in force until recently, when the Admiralty decided to standardize the OMD-114 specifications.

Brief description of the E-in-C 05 and E-in-C 08 specifications

The engine-test methods used for these two sets of specifications are the same as those for the DEF 2101 B specifications employed for series CMD-110. They include testing of antioxidation properties, corrosion of lead-bronze bearings, and detergent properties. The first two factors are investigated in a carbureted engine (IP 176/60 method) and the third in a diesel engine (IP 124/60 method).

The principal difference between the OMD-109 and OMD-112 specifications on one hand and the OMD-110 specifications on the other lies in the fact that a fuel with a sulfur content of 1% is used in testing detergent properties in the diesel engine; in addition, a definite limiting piston ring wear is stipulated. The tests to evaluate oxidation resistance and lead-bronze corrosion are the same as for OMD-110.

The existing Admiralty specifications had to be reviewed when the MIL-L-900 specifications were introduced for the US Navy, these specifying tests in a GM-71 diesel with 2.0% sea water added to the oil at the beginning of the experiment, and when the MIL-L-9000D specifications and the still more rigid MIL-L-9000E specifications came into force (March, 1959).

TABLE 14

Oil Properties from USA 2-104B Specifications

1 Показатели качеств	SAE-10	SAE-30	SAE-50
2 Вязкость условная (*сст*) при			
54,4° C	2,75—3,64	5,59—7,69	11,0—20,00
98,9° C	—	2,00—2,31	2,31—3,19
3 Индекс вязкости по Дину и Дэвису, не ниже	85	55	75
4 Т-ра застывания, не выше (°C)	—23	—18	— 9
5 То же после разбавления 20% лигроина	—40	—40	—
6 Температура вспышки, не ниже (°C)	182	200	204*

*The minimum flash point of SAE-50 oil before introduction of additives should be 232°C.

1) Property;
2) Viscosity (cSt) at;
3) Viscosity index, according to Din [sic] and Davis, no less than;
4) Solidifcation temperature, not above (°C);
5) The same, after dilution with 20% ligroin;
6) Flash point, not below (°C).

TABLE 15

Oil Properties from VV-0-196 Specifications

1 Показатели качеств	SAE-20	SAE-30	SAE-40	SAE-50	SAE-60	SAE-70
2 Вязкость условная при						
54,4° C, от 3	3,64	5,59	7,69	11,10	20,00	26,00
до 4	5,59	7,69	11,10	20,00	26,00	33,10
98,9° C, от 3	1,46	1,65	2,00	2,31	3,19	3,79
до 4	1,65	2,00	2,31	3,19	3,79	4,54
5 Т-ра вспышки в закрытом тигле, не менее (°C)	171	177	188	202	218	238
6 Т-ра застывания, не более (°C)	—18	—18	—15	—12	—9	—9
7 Содержание кокса, не выше (%)	0,6	0,8	1,0	1,4	1,7	2,0
8 Коэффициент окисления, не выше	50	50	50	50	50	50
9 Кислотность не выше (*мг* KOH)	0,3	0,3	0,3	0,3	0,3	—
10 Испытания на коррозию	12 Выдерживает					
11 Цвет в баллах шкалы NPA, не более	5	6	7	7	8	8

1) Properties;
2) Viscosity at;
3) From;
4) To;
5) Flash point in closed crucible, no less than (°C);
6) Solidification point, not above (°C);
7) Coke content, not above (%);
8) Oxidation coefficient, not above;
9) Acidity, not above (mg KOH);
10) Corrosion test;
11) Color, points on NPA scale, no more than;
12) Pass.

A distinctive feature of foreign motor-oil specifications is their integral relationship to test procedures. The actual oil properties, determined directly by physicochemical methods or indirectly through certain indices characterizing operating properties, are usually stipulated in the American specifications only within the SAE grades. For example, the well-known Army Ordinance specifications USA 2-104B for lubricating oils used in ICE's define the oil properties shown in Table 14.

The properties of automobile oils are stipulated in similar fashion by the Federal VV-O-166 specifications. Six SAE grades of automotive lubricating oils are produced in accordance with these specifications (Table 15).

The standard specifications of the American Maritime Administration, Federal Aviation Agency, and other governmental organizations use an arbitrary system of designations (symbols) consisting of four figures: the first figure indicates the oil class and the last three show the oil viscosity in Saybolt Universal Seconds.

The oil classes are as follows: 1) high-grade mineral lubricating oils with high viscosity indices; 2) oils with low viscosity indices; 3) automotive oils with medium viscosity indices; 4) mixed marine oils; 5) mineral marine oils; 6-8) mixed oils for steam engines and air compressors.

The rated viscosities of oils in classes 2 and 8 are for a temperature of 54.4°C, while those of the other oils are for a temperature of 98.9°C.

The specifications described above stipulate the following basic indices, which are determined either by ASTM methods or by nonstandard procedures: 1) color (Д 155-35T); 2) content of mineral acids and alkalies; 3) acidity (Д 138-27T); 4) residual asphalt (Д 91-41); 5) content of elemental sulfur or other corrosive compounds; 6) water content; 7) coke content by Conradson's method (Д 189-39); 8) ash content; 9) sulfur content (Д 129-39); 10) density (Д 287-39); 11) flash point (Д 92-33); 12) turbidity and solidification points (Д 97-39); 13) viscosity; 14) viscosity index by Din and Davis's method; 15) test for emulsion formation by agitation in distilled water and in 1% salt solution at 54.4°C; 16) determination of "working factor," which characterizes oil stability at working temperatures, in accordance with the Federal USA VV-L-791 specifications.

Individual companies specify the properties of their oils in similar fashion.

Classification of motor oils in the USSR

The variety of oils available in the USSR was to a large extent built up without any unified system. A classification system for ICE oils was proposed in 1963 [28, 29]. The authors of this classification base it on the prospective development of engine building in the USSR and took into account foreign experience and the variety of motor oils being produced. They concluded that

"A rational motor-oil classification must be based on oil functional properties satisfying the requirements of different groups of engines classified by severity of operating conditions" [28].

It was suggested that existing and prospective engines be divided into six groups on the basis of thermal and mechanical stresses:

1. Old-model carbureted engines.

2. Current and prospective carbureted engines.

3. Old-model tractor diesels.

4. Current and prospective tractor, automobile, and certain marine diesels operating on fuels with sulfur contents of less than 1%.

5. Current and prospective locomotive and special marine diesels operating on fuels with sulfur contents below 1%.

6. Lubricator-equipped marine engines operating on heavy fuels with sulfur contents below 3%.

Despite certain shortcomings, this classification creates a preliminary basis for developing groups of oils corresponding to engine operating conditions.

It is recommended that the viscosity grades in the new range of oils be based on engine design features (clearances, specific loads, and speed), climatic conditions, and equipment-storage conditions.

A second prerequisite for development of a motor-oil classification system is grouping of oils by viscosity. It is assumed that oil applications permit establishment of the following series of oil types (with viscosities in cSt at 100°C) for different engine classifications: automobile engines – 6, 8, and 10, tractor engines – 8, 10, 12, marine and stationary engines – 10, 12, 14, and 20, tank engines – 8 and 16, aircraft engines – 20, and locomotive engines – 12, 14, and 20.

The proposed motor-oil classification [28] thus divides ICE lubricating oils into seven grades in accordance with their viscosity at 100°C (Table 16). These grades cover the viscosity range from 6.0 to 20.0 cSt at 2-cSt intervals.

The oils within each grade are subdivided into groups characterized by the fact that they may contain oils with different viscosities.

The oil groups are distinguished by the severity of engine-operating conditions for which the oils are intended. The ascending sequence of the six proposed oil groups corresponds to greater severity of engine-operating conditions.

In roughly assigning an engine to a given group of oils, its

TABLE 16

New Motor-Oil Classification

1	2	3	4	5	6	7
Вязкость при 100° C, *ccm*	Группа А (типа Premium)	Группа Б (типа HD)	Группа В (типа Supplement)	Группа Г (типа Series-2)	Группа Д (типа Series 3)	Группа Е (типа Mobilgard)
6,0±0,5	М-6А	М-6Б	М-6В	—	—	—
8,0±0,5	М-8А	М-8Б	М-8В	М-8Г	М-8Д	—
10,0±0,5	М-10А	М-10Б	М-10В	М-10Г	М-10Д	—
12,0±0,5	М-12А	М-12Б	М-12В	М-12Г	М-12Д	—
14,0±0,5	М-14А	М-14Б	М-14В	М-14Г	М-14Д	—
16,0±0,5	М-16А	М-16Б	М-16В	М-16Г	М-16Д	М-16Е
20,0±0,5	М-20А	М-20Б	М-20В	М-20Г	М-20Д	М-20Е

1) Viscosity at 100°C, cSt;
2) Group A (Premium type);
3) Group Б (HD type);
4) Group В (Supplement type);
5) Group Г (Series 2 type);
6) Group Д (Series 3 type);
7) Group E (Mobilgard type);

normal operation under different climatic conditions naturally requires no more than two grades of oil.

In drawing an analogy between the proposed classification and that use abroad, the authors cited the SAE grades and API classification, which they related in the following manner: ML – Regular, MM – Premium, MS and DG – Heavy Duty, MS and DM – Supplement 1, DS – Series 2, and DS – Series 3. They also noted that there is an oil grade outside these groups, which is used for cylinder (lubricator) lubrication of marine diesels.

Certain economic problems in building up an optimum motor-oil variety

In principle, the following directions can be taken in building up a commercial variety of motor oils:

development of special oil types for given engines and definite operating conditions or for very restricted groups of similar engine designs with operating conditions that impose similar requirements on oil quality;

development of a variety of oils known to be of high quality and having a large safety margin for satisfcation of the requirements of different designs operating under different conditions.

Naturally, the principles used to build up a given variety of commercial ICE oils, taking into account the numerous factors governing production and consumption economics in each specific case, may be far from either "extreme" trend and comprise an "intermediate" system having the advantages of both trends.

In working out an over-all solution to the problem, however, it is necessary to take into account both the economic factors associated with the cost of production and the effect produced in operating engines for transport or commercial purposes and those relating to the costs borne by the national economy in transporting, storing, and marketing petroleum products.

The formulation of this problem differs radically for the two different aspects involved in building up a commercial oil variety, i.e., that pertaining to viscosity index and that pertaining to quality, which is governed by such indices as oxidation and corrosion resistance, and high wear and detergent properties, etc.

In the former case, if we develop an oil known to be of high quality (e.g., wide-application oils for operation over broad temperature ranges), they may be employed under operating conditions where these properties are not utilized.

In the latter case, use of high-quality oils under less stringent conditions obviously introduces an additional effect, which, as research has shown, substantially exceeds the rise in oil cost. The economic effect produced in this case naturally includes savings in transportation, storage, and marketing.

REFERENCES

1. Kuliyev, A.M., Prisadki k smazochnym maslam [Additives to Lubricating Oils]. Moscow-Leningrad, "Khimiya," 1964.

2. Kuliyev, A.M. et al., Collection of the Transactions of the Azerbaydzhan Scientific Research Institute of Petroleum Refining imeni Kuybysheva, No. II. Azerneftneshr, 1958.

3. Kuliyev, A.M. et al., Collection of the Transactions of the Azerbaydzhan Scientific Research Institute of Petroleum Refining imeni Kuybysheva, No. III. Azerneftneshr, 1958.

4. Kuliyev, A.M. et al., Collection of the Transactions of the Azerbaydzhan Scientific Research Institute of Petroleum Refining imeni Kuybysheva, No. IV. Azerneftneshr, 1959.

5. Ramayya, K.S., "Avtomobil'naya i traktornaya promyshlennost'," 1950, No. 5.

6. Maslennikov, M.M., Trudy TsIAM [Transactions of the Baranov Central Scientific Aircraft-Engine Research Institute], No. 75, 1944.

7. El'ovich, I.I., Trudy Tret'yey Vsesoyuzn. konf. po treniyu i iznosu v mashinakh [Transactions of the Third

All-Union Conference on Friction and Wear in Machinery], Vol. III. Moscow, Izd-vo AN SSSR, 1960.

8. Khrushchov, M.M., Povysheniye iznosostoykosti i sroka sluzhby mashin [Increasing Machinery Wear Resistance and Service Life]. Kiev, Mashgiz, 1953.

9. Ivanova, L.V., Puti povysheniya kachestv smazochnykh masel na bakinskikh neftezavodakh [Means of Increasing Lubricating-Oil Properties at the Baku Petroleum Refineries]. ANKh, 1955, No. 10.

10. Suleymanova, F.G., El'ovich, I.I., Ekspluatatsionnyye svoystva topliv i masel dlya dvigateley vnutrennego sgoraniya [Operational Characteristics of Fuels and Oils for Internal Combustion Engines]. Izd-vo AN Azerb. SSR, 1961.

11. Ravolio, U.G., SAE Journal, 1951, 59, No. 2.

12. Drinkard, W.E., Carpenter, M.L., SAE Quarterly Transactions, Vol., 1951.

13. Maslennikov, M.M., Rappiport, M.S., Aviatsionnyye porshnevyye dvigateli [Aviation Piston Engines]. Voyenizdat, 1954.

14. Motornyye i reaktivnyye masla i zhidkosti [Motor and Jet Oils and Liquids], edited by K.K. Papok and Ye.G. Semenido. "Khimiya," 1964.

15. Khvoshchev, I.S., Issledovaniye puskovykh svoystv bystrokhodnykh dizeley [Study of Start-Up Properties of High-Speed Diesels]. ONTI, 1938.

16. Minkin, M.L., Pusk avtotraktornykh dizeley [The Starting of Tractor Diesel Engines]. Mashgiz, 1948.

17. Likhachev, M.M. and Galkin, Yu.M., "Izv. NATI," 1932, No. 1-2.

18. Kugel', "Vestn. mashinostroyeniya," 1955, No. 8; collection entitled "Prochnost' pri neustanovivshikhsya rezhimakh" [Strength in Nonsteady Regimes]. Mashgiz, 1954.

19. Velikanov, D., "Avtomobil'nyy transport," 1955, No. 1.

20. Velikanov, D., "Avtomobil'nyy transport," 1954, No. 1.

21. Boltinskiy, V.N., Rabota traktornogo dvigatelya pri neustanovivsheysya nagruzke [Tractor Engine Operation under Nonsteady Load]. OGIZ, Sel'khozgiz, 1949.

22. [illegible], S.A., Kuvshinov, Ya.I., Ekspluatatsiya traktorov i avtomobiley v zimnikh usloviyakh [Automobile and Tractor Operation under Winter Conditions]. Moscow, Izd. [illegible] RSFSR, 1963.

23. Renskiy, N.M., Ekspluatatsiya glavnykh dvigateley seriynykh teplokhodov [Operation of Main Engines in Steam-Engine Series]. Moscow, Izd-vo "Rechnoy transport," 1963.

24. Gol'd, B.V., Obolenskiy, Ye.P., "Avtomobil'naya promyshlennost'," 1962, No. 2.

25. Zimelev, G.V. and Bronshteyn, L.A., Collection entitled "Razvitiye avtomobil'nykh transportnykh sredstv v 1959-1965 gg." [Development of Automotive Transport Facilities in 1959-1965]. Moscow, Avtotransizdat, 1960.

26. Opyt opredeleniya sel'skokhozyaystvennogo proizvodstva SSSR na perspektivu [Experience in Determining Future USSR Agricultural Production]. Izd. SOPS AN SSSR, 1957.

27. Statistical Bulletin of 28 November 1957.

28. Blagovidov, I.F. et al., "Khimiya i tekhnologiya topliv i masel," 1963, No. 2.

29. Blagovidov, I.F. et al., "Khimiya i tekhnologiya topliv i masel," 1963, No. 3.

Manuscript Page No.	Transliterated Symbols
4	кр = kr = krutyashchiy moment = torsional moment (torque)
4	в = v = vozdukh = air
5	н = n = nachalo = beginning
5	к = k = konets = end
6	э = e = effektivnost' = efficiency
10	т = t = truboprovod = line
10	к = k = klapan = valve
18	с = s = soprotivleniye = resistance
18	пр = pr = pritsep = drawbar
19	ср = sr = sredny = average

Chapter 2

FUNCTIONAL PROPERTIES OF ADDITIVE-CONTAINING MOTOR OILS

Numerous investigations conducted in recent years by Soviet and foreign researchers have made it possible to establish that the functional properties of oils (especially those containing additives, can be most reliably evaluated when they are performing in an engine.

Nevertheless, it is often necessary to make a comparative study of the influence of individual functional properties of a motor oil on its operating efficiency in order to get a preliminary idea of the feasibility of producing a lubricating compound for engines requiring definite properties.

A number of researchers [1, 2] have recently summarized their experience in evaluating the functional properties of additive-containing motor oils with the aid of methods for determination of individual properties. These works present experimental data characterizing the reproducibility of tests of individual motor-oil functional properties under engine conditions.

The aforementioned authors give an affirmative answer to a question that has long been a central concern of specialists working on investigation and testing of motor oils for modern engines, that of whether individual "laboratory" procedures can be used to evaluate the functional properties of oils.

Without going into a detailed analysis of data on the feasibility of such evaluation, we need point out only that, in addition to the large mass of experimental results that tend to confirm the feasibility of such an approach, there are cases in practice where contradictory results are obtained in evaluating motor-oil functional properties by laboratory methods and under actual application conditions.

This forces us to exercise great care in dealing with evaluation of individual motor-oil functional properties by various laboratory procedures and to take into account the conditions under which these properties are determined; when extrapolating laboratory results to operating conditions, one must make as full as possible a determination of the additional factors that might seriously alter the appraisal previously made.

With this in mind, experimental data characterizing the most important motor-oil functional properties are presented below.

§1. DETERGENT PROPERTIES

Large qualitative differences in the lubricating properties of oils (a term that, in general, refers to their ability to keep the most important engine components clean) are obtained principally by introducing various types of additives.

TABLE 17

Chemical Composition of Oils Tested

1 Месторождение нефти	2 Условия очистки			6 Групповой состав масел, %			10 Кольцевой состав масел, %		
	3 Соотношение селективный растворитель: сырье	4 Глина, %	5 Кислота, %	7 Нафтено-парафиновые углеводороды	8 Ароматические углеводороды	9 Смолы	11 Нафтеновые кольца	12 Ароматические кольца	13 Парафиновые цепи
14 Бинагадинское	1:1,5	15	—	72,0	19,0	9,0	39,56	5,1	55,34
	1:1,5	5	1,0	73,5	20,87	5,63	39,60	4,97	55,43
15 Нефтяные Камни	1:1,5	15	—	75,6	14,8	9,5	37,0	4,9	58,1
	1:1,5	5	1,0	76,0	15,6	8,4	37,54	4,76	57,7

1) Oil deposit;
2) Refining conditions;
3) Ratio of selective solvent to crude oil;
4) Clay, %;
5) Acid, %;
6) Group composition of oils, %;
7) Naphthene-paraffin hydrocarbons;
8) Aromatic hydrocarbons;
9) Tars;
10) Ring composition of oils, %;
11) Naphthene rings;
12) Aromatic rings;
13) Paraffin chains;
14) Binagadinskoye;
15) Neftyanyye Kamni.

However, in characterizing the chemism of additive detergent action as the main active factor in improving oil detergent properties, S.S. Nametkin [3] noted that oils without additive can differ in detergent power in some cases.

We can speak of oils with a greater or lesser ability to hold oil-aging products, particularly tars and asphalts, in solution or suspension. It should be noted that this ability is particularly pronounced in oils containing aromatic hydrocarbons and present to a lesser extent in paraffin oils.

Table 17 shows the detergent properties of additive-free automotive oils from crude Apsheron oil. We have carried out a comparison of the detergent properties of type-10 base oils obtained from different crude oils and subjected to different degrees of refining The evaluation was made in PZV (ПЗВ) points, testing the detergent-free oils under a mild regime (1 h) in order to permit differentiation of their detergent properties. (The PZV method is intended for evaluation of the detergent properties of additive-containing oils). The oils were produced from a petroleum mixture and from crude oil from the Binagadinskoye, Neftyanyye Kamni and Balakhanskoye deposits.

Distillates of the corresponding oils were refined in two ways: with 150% furfurol and 150% clay and with 150% furfurol, 1% acid, and 5% clay.

We obtained 9 oil specimens, comprising the three distillates, which we will arbitrarily designate as A (from Binagadinskoye crude oil), Б (from Neftyanyye Kamni crude oil), and B (from Balakhanskoye crude oil), as well as six specimens produced from the three distillates subjected to the two different types of refining. We will arbitrarily designate these specimens as A-1, A-2, Б-1, Б-2, B-1, and B-2.

The detergent properties of the additive-free oils and, for comparison, those of a standard specimen of type-10 oil produced from a petroleum mixture are given below:

Oil Specimen	Detergent Properties, PZV points
Standard	4-4.5
A	4
A-1	2.5
A-2	2-2.5
Б	4
Б-1	3
Б-2	2.5-3
B	4-4.5
B-1	3.5
B-2	3

TABLE 18

Detergent Properties (MT-16 Base Oil), PZV Points

Присадка [1]	3 %	4 %	5 %
АзНИИ-5	4—4,5	3	2
АзНИИ-7 [2]	2,5—3	2	1—1,5
АзНИИ-7 (высокозольная)	3	2	1
АзНИИ-8	3,5—4	2,5—3	2
ЦИАТИМ-339	2.5	2—1,5	1

1) Additive; 2) High-ash.

As can be seen, the oil produced from Binagadinskoye crude oil have the best "detergent" properties.

We have thus confirmed that the chemical composition of oils affects their detergent properties.

Actually, if we consider the data on the chemical composition of the oils produced from the Binagadinskoye and Neftyanyye Kamni crude-oil distillates, the best "detergent" properties correspond to the highest aromatic-compound content.

As has already been noted, various additives have a substantial influence on oil detergent properties. The concept of the "detergent action" of additives is usually related to their ability to hold extremely fine insoluble hydrocarbon particles, which are formed principally as a result of contact between the oil and the engine components at high temperatures, in solution in a highly dispersed state. However, S.S. Nametkin [3] attributed the mechanism of the cleansing action of additives both to their ability to disperse the thickening and carbonization products formed during oil functioning (dispergant action), which keeps them from being precipitated from the oil, and to their ability to form adsorbed layers on the metal surfaces (detergent action), which prevent deposition of oil-aging products.

In some cases, the detergent action of crankcase-oil additives is manifested in a simple "cleansing" effect, i.e., an oil containing an active "cleansing" additive reduces the number of deposits formed on the component surfaces.

Table 18 shows the "cleansing" properties of different concentrations of АзНИИ additives, which are of the sulfonate and alkylphenol types. For purposes of comparison, similar data are given for the alkylphenol additive ЦИАТИМ-339.

In order to obtain clearer differentiation of the additive solutions in the oils, we determined their detergent properties in a PZV apparatus under a stringent regime, which differed from the standard regime in the fact that the exhaust-valve clearance was reduced to 1.2 mm (instead of 3.2 mm) and the gap between the wall of the ring groove and the compression ring was increased to 0.18 ± 0.01 mm (instead of 0.13 ± 0.01 mm).

TABLE 19

Detergent Properties of Д-11 oil with Sulfonate Additives, PZV Points

Присадка [1]	[illegible] %	6 %	1 %	10 %
СБ-3 (сульфонат бария) [2]	2,5	1,5	1	0
СК-3 (сульфонат кальция) [3]	2,5 – 3	1,5–2	1	0 – 0,5

1) Additive; 2) barium sulfonate; 3) calcium sulfonate.

TABLE 20

Oxidation Resistance of Oils Containing СБ-3 and БФК Additives

Масло Д-11 с [1]	Осадок, % [2]	T_{250}, мин [3]
3% СБ-3	7,9	25
8% СБ-3	10,0	26
3% БФК	5,2	33
8% БФК	4	38

1) Д-11 oil with; 2) sediment, %; 3) min.

As can be seen from the data in the table, the effectiveness of detergent action increases sharply as the additive content is raised.

The most effective oil additives are sulfonates of various metals. Table 19 presents data obtained in evaluating the "cleansing" properties of oils containing certain sulfonate additives in a PZV apparatus.

There is a rapid increase in oil detergent properties when the sulfonate-additive concentration is raised, the PZV readings dropping to 0 points.

The mechanism of the detergent action of sulfonates is known [2] to be governed by their adsorptive properties, which stabilize solid carbon particles suspended in the oil solution, by their alkali properties, which neutralize oxidation products that tend to form carbon deposits in the engine, by the liquefying action of the additive micelles, and by the ability of sulfonates to inhibit formation of carbenes and carboids.

It has recently been hypothesized [2] that the dispergant action of sulfonates results principally from their ability to solubilize crankcase-oil aging products.

Metal sulfonates form micelles containing a large number of molecules in mineral solvents. These micelles are comparatively small; their formation also accounts for the fact that the low-solubility polar compounds that accumulate in worked-out oil are held in the form of a stable colloidal dispersion.

However, this mechanism also makes chemical reactions readily possible, which can explain the activity of sulfonate solutions in oil with respect to elements such as oxygen and thus account for the low oxidation resistance of sulfonate-containing oils.

Table 20 presents comparative data obtained in evaluating the bulk oxidation resistance (by the NAMI [НАМИ], or sediment, method) and thin-layer thermostability (in accordance with GOST 9352-60) of the sulfonate additive СБ-3 and the alkylphenol additive БФК.

TABLE 21

Detergent Potential of Oils Containing СБ-3 Sulfonate Additive and Mixtures of this Additive with Various Antioxidants

1 Образцы масла	2 Моющий потенциал
Д-11 с 3% СБ-3	25
Д-11 с 5% СБ-3	34
Д-11 с 8% СБ-3	46
Д-11 с 5% СБ-3 и 1,2% ДФ-11	41
Д-11 с 5% СБ-3 и 1,2% Лани-317 [4]	43
Д-11 с 5% СБ-3 и 1,2% ИНХП-21	56
Д-11 с 8% СБ-3 и 1% ИНХП-36	52
Д-11 с 8% СБ-3 и 3% ИНХП-36	68
Д-11 с 8% СБ-3 и 3% ИНХП-21	60

1) Oil specimens; 2) detergent potential; 3) and; 4) Lani-317.

At equal additive concentrations, the stability of Д-11 oil is less by a factor of 1.5-2.5 when it contains СБ-3 sulfonate additive.

As is well known [4], the efficiency of the detergent action of additives, particularly sulfonate additives, is evaluated by determining the so-called detergent potential of a thick oil layer under oxidation conditions at high temperatures. The detergent potential characterizes one of the most important functional properties of detergent additives, their ability to maintain high dispersion of the particles that appear in the oil as a result of oxidation or of contamination with soot particles and other incomplete-combustion products that enter the oil from the combustion chamber.

Using a standard compound that forms a disperse phase on oxidation, the detergent potential is numerically equal to the maximum content of this compound (in % by weight) at which the oil is still capable of maintaining a high congealing resistance.

In interpreting the results of comparative studies of the detergent potentials of sulfonate additives, it must be kept in mind that their detergent action can be appraised only to the extent that it can be attributed to maintenance of the dispersed phase formed as a result of oil oxidation or entry of combustion products into the oil.

The degree of dispersion of the particles formed by oxidation of the standard compound in the detergent-potential determination obviously depends on the detergent efficiency of the additive. (The degree of dispersion is determined by filtration of a solution of the oxidized oil in a solvent).

As can be seen from the data in Tables 21 and 22, the detergent potential of oils increases with the concentration of СБ-3 and

БФК additives. Introduction of antioxidants also promotes an increase in this index.

A similar evaluation can be made, for example, for БФК additive during detergent-property tests by the PZV method (see Table 23). Detergent efficiency amounts to 0-0.5 point at additive concentrations of 8-10%.

A comparative study of the efficiency of sulfonate additives with high detergent properties and of mixtures of these additives with alkylphenol additives established that a synergistic effect, i.e., a mutual reinforcement of properties, occurs. The synergism of sulfonate and alkylphenol additives is manifested particularly clearly in their detergent efficiency.

TABLE 22

Detergent Potential of Oils Containing **БФК** Alkylphenol Additive and mixtures of this Additive with Antioxidants

Образцы масла (1)	Моющий потенциал (2)
Д-11 с 3% БФК	45
Д-11 с 5% БФК	58
Д-11 с 8% БФК	65
Д-11 с 8% БФК и (4) 1% ИНХП-21	6
Д-11 с 8% БФК и 3% ИНХП-21	72
Д-11 с 8% БФК и 3% ИНХП-35	66
Д-11 с 8% БФК и 1,2% ДФ-11	70
Д-11 с 8% БФК и 1,2% Лани-317 (5)	69

1) Oil specimens; 2) detergent potential; 3) with; 4) and; 5) Lani-317.

TABLE 23

Detergent Properties of Oils Containing Antiphenol Additives, Evaluated by PZV method

Образцы масла (1)	Моющие свойства по ПЗВ, баллы (2)
Д-11 без присадки (3)	5—5,5
Д-11 с 2% БФК	2,5—3
Д-11 с 4% БФК	2
Д-11 с 6% БФК	0,5—1
Д-11 с 8% БФК	0,5
Д-11 с 10% БФК	0—0,5

1) Oil specimens; 2) detergent properties by PZV method, points; 3) without additive; 4) with.

Table 24 presents data on the influence of various additive combinations.

TABLE 24

Detergent Potentials of Oils with Compound Additives

1 Образцы масла	2 Моющий потенциал
Д-11+2,5% СБ-3+2,5% АзНИИ-7+1% ИНХП-21+0,005% ПМС-200А	59
Д-11+2,5% СБ-3+2,5% АзНИИ-7+1% Лани-317+0,005% ПМС-200А	48
Д-11+5% БФК+2,5% СБ-3+0,005% ПМС-200А	74
Д-11+11% БФК+4% СБ-3+0,005% ПМС-200А	88
Д-11+15% БФК+6% СБ-3+0,005% ПМС-200А	94
Д-11+5,2% БФК+2,8% СБ-3+1,2% ИНХП-21+0,005% ПМС-200А	85
Д-11+4 % БФК+2% СБ-3+1,2% ИНХП-21+0,005% ПМС-200А	83
Д-11+2,7% БФК+1,3% СБ-3+1,2% ИНХП-21+0,005% ПМС-200А	79

1) Oil specimens; 2) detergent potential.

The ability of sulfonate and alkylphenol additives to reinforce one another's detergent efficiency can be explained [5] by assuming that solutions of these additives in oils are nonaqueous electrolytes, since the decisive role in the mechanism of additive detergent action in this case should be played by dissociation and hydrolysis. Assuming that the mechanism of additive detergent action is based on adsorption of ions or ionic micelles of additives on the surfaces of soot particles and metallic components, a process that leads to development of electrostatic charges of the same sign and hence to repulsion between the particles and between the particles and metallic surfaces, it is to be expected that the efficiency of additive detergent action would increase with the degree of dissociation of the additive solution in oil. On the other hand, a higher degree of additive hydrolysis should result in more effective neutralization of oil-oxidation products and thus a smaller number of tar deposits to present a potential hazard from the standpoint of contamination of the metallic surfaces.

TABLE 25

Electrical Conductivity of Solutions of СК-3 and БФК Additives in ДС-11 Oil

1 Образцы масла	2 Электропроводность, $\frac{1}{ом} 10^{-9}$
ДС-11+10% СК-3	81,9
ДС-11+20% СК-3	125
ДС-11+10% БФК	100
ДС-11+15% БФК	250
ДС-11+6,6% СК-3+3,4 БФК	525
ДС-11+13,2% СК-3%+6,8% БФК	1660

1) Oil specimens; 2) electrical conductivity, $ohm^{-1} \cdot 10^{-9}$.

Additive solutions in oils are actually nonaqueous electrolytes. The mechanisms established for aqueous electrolytes can therefore be extended to such solutions. Specifically, the electrical conductivity of an additive solution in oil should characterize the degree of additive dissociation.

On this basis, it can be assumed that introduction of surface-active sulfonate additives will, as a result of the increased solvation effect, lead to an increase in the dissociation of an alkylphenolate additive when the latter is highly soluble in the oil. Experiments have shown that a mixture of, for example, БФК-1 and СБ-3 additives (each of which has low conductivity in pure form) causes a sharp rise in solution conductivity, which indicates an increase in degree of dissociation. This is confirmed by the data given in Table 25.

It is known [6] that the degree of dissociation

$$\alpha_{\text{д}} = \frac{\lambda_{\text{с}}}{\lambda_{\text{н}}},$$

where λ_s is the equivalent conductivity at a given concentration and λ_n is the equivalent conductivity at infinite dilution.

It can therefore be assumed that the cations or cationic micelles of the additive (a solution with a definite degree of dissociation in oil) play a large role in the mechanism of detergent action. Adsorption of these cationic particles on the metal surfaces sets up a "protective" layer that prevents tar formation.

Having thus established that there is a relationship between the detergent action of additives and their degree of dissociation in oil, it seems expedient to study the electrical conductivity of additive solutions in oils: by characterizing the degree of additive dissociation, we can indicate possible changes in the efficiency of detergent action. The electrical conductivity of oils was studied by the method described by Yu.S. Zaslavskiy et al. [7].

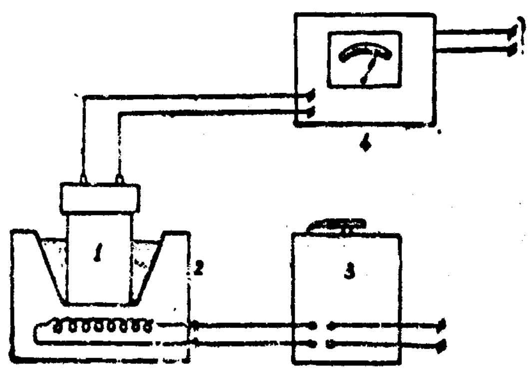


Fig. 3. Diagram of apparatus for determining electrical conductivity of additive-containing oils. 1) Beaker; 2) electric heater; 3) transformer; 4) MOM-4 teraohmmeter.

TABLE 26

Electrical Conductivity of Oils Containing Single-Component Additive Solutions

1 Масла с присадками	2 Электропроводность раствора при 100°C, $\frac{1}{ом} \cdot 10^{-9}$
АС-9,5 (НКЗ)+5,85 ЦИАТИМ-399	25,2 29,4
АС-9,5 (НКЗ)+23,4% ЦИАТИМ-339	130 170
АС-9,5+10% СБ-3	143 164
ДС-11 (НКЗ)+20% СК-3	125 125
ДС-11 (НКЗ)+8% БФК	138 133
ДС-11 (НКЗ)+10% СК-3	81,9 69,9
ДС-11+15% БФК	250 250
ДС-11+10% АзНИИ-7	175 188
ДС-11 (НКЗ)+20% БФК	295 278

1) Oils and additives; 2) conductivity of solution at 100°C, $ohm^{-1} \cdot 10^{-9}$.

A total of 25 cm^3 of the oil to be tested is poured into an aluminum beaker (Fig. 3), which serves as an oil bath. The beaker is covered with an ebonite lid, whose inner side bears cylindrical aluminum electrodes connected by leads to a teraohmmeter, which measures the resistance of the oil.

The beaker and oil are placed in a sand bath, where the oil is heated by an electric furnace. The temperature is adjusted with a laboratory transformer and measured with a mercury thermometer mounted in the beaker lid.

The determination procedure runs as follows: the oil temperature in the beaker is varied from 50 to 150°C at 25°C intervals. The oil resistance at a given temperature is determined for each point from the teraohmmeter scale. The index determined is the resistance (or conductivity) at 100°C.

Tables 26 and 27 show the results of our determinations.

Table 26 presents data obtained in evaluating oils corresponding in properties to standard lubricants.

In evaluating detergent properties, it is important to determine both the absolute "contamination" of the main engine components with tar deposits under the action of a given additive and the extent to which the action of the additive retards formation

TABLE 27

Conductivity of Oils Containing Compound Additives

1 Масла с присадками	2 Электропроводность раствора при 100°С, $\frac{1}{ом}\cdot 10^{-9}$
ДС-11 (НКЗ)+10% (66,6% СК—3+33,4% БФК)	526 583
ДС-11 (НКЗ) + 10% (33,4% СК-3 + 66,6% БФК)	370 307
ДС-11 + 15% (66,6% СК-3 + 33,4% БФК)	1430 1600
ДС-11 + 15 (33,4% СК-3 + 66,6% БФК)	435 476
ДС-11 + 20% (66,6% СК 3 + 33,4% БФК)	1660 1540
ДС-11 + 10% (50% СК-3 + 50% БФК)	500 4[illegible]4
ДС-11 + 15 (50% СК-3 + 50% БФК)	333 400
ДС-11 + 11% БФК + 4% СБ 3 + 2% АзНИИ-10	799 666
ДС-11 + 11% БФК + 4% СБ-3 + 3% Амин-38	909 500
ДС-11 + 3,1% Маск + 1% ПМСЯ	588 666
ДС-11 + 10% Маск + 10% ПМСЯ	2500 29.0
ДС-14 + 15% В-370 + 6% ПМСЯ + 0,5% ЛЗ-23К + 0,005% ПМС-200А	2500 1720
ДС-11 + 11% БФК + 4% СБ-3 + 2% БФК-S	1660 1640
ДС-11 + 11% БФК + 4% СБ-3 + 1% БФК-S	1300 1430
ДС-11 + 15% БФК + 6% СБ-3 + 0,5% ЛЗ-23К + 0,005 ПМС-200А	1250 1250
ДС-11 + 11% БФК + 4% СБ-3 + 0,5% ЛЗ-23К + 0,005% ПМС-200А	769
ДС-11 + 11% БФК + 4% СБ-3 + 1% АзНИИ-10	909
ДС-11 + 5% БФК + 1,5% СБ-3	476
ДС-11 + 11% БФК + 4% СБ-3 + 1% Амин-38	714

1) Oils and additives; 2) conductivity of solution at 100°C, $ohm^{-1}\cdot 10^{-9}$.

of products potentially dangerous in the sense of tending to produce tar deposits is retarded in the working oil.

In this connection, it is of interest to study the compositions of tar deposits and worked-out oils.

The tar-deposit composition was determined in the following manner. The scale was removed from a piston after testing. The cleaned piston was then placed in a Soxhlet apparatus, where it was successively treated with petroleum ether, alcohol, and benzene.

After treatment with each of these solvents, we determined the amount of oxidative-polymerization products (oxy acids, asphalts,

TABLE 23

Electrical Conductivity of Different Groups and Group Standards

1 Образцы	2 Электропроводность при 100°C, $\frac{1}{ом} \cdot 10^{-9}$
3 Группа А (Премиум)	
4 Эталон: ДС-11 + 0,7% Монто-613 + 0,7% Сантолюб-493	44
ДС-11 (бак) + 3% СБ-3 + [illegible] ДФ-11	46
8 Группа Б (Хеви Дьюти)	
4 Эталон: ДС-11 + 1,5% Монто-613 + 0,7% Сантолюб-493	62
ДС-11 (бак) + 4% СБ-3 + 2% ДФ-11	87
9 Группа В (серия I)	
4 Эталон: ДС-11 + 4% Монто 613 + 0,25% Сантолюб-493	200
Д-11 (бак) + 7,5% БФК + 2% СБ-3 + 0,5 ЛЗ-23к	263
10 Группа Г (серия II)	
4 Эталон: ДС-11 + 9% Монто-613 + 0,7% Сантолюб-493	714
Д-11 (бак) + 11% БФК + 4% СБ-3 + 0,5% ЛЗ-23к + 0,005% ПМСЗ-200А	702
11 Группа Д (серия III)	
4 Эталон: ДС-11 + 18% Монто-702	238
Д-11 + 15% БФК + 6% СБ-3 + 0,5% ЛЗ-23к + 0,005% ПМС-200А	614

1) Specimens; 2) electrical conductivity at 100°C, $ohm^{-1} \cdot 10^{-9}$; 3) Group A (Premium); 4) standard; 5) Monto; 6) Santolyub; 7) tank; 8) Group Б (Heavy Duty); 9) Group В (Series I); 10) Group Г (Series II); 11) Group Д (Series III).

carbenes, and carboids).

A similar procedure was used to determine the composition of the oxidative-polymerization products in the worked-out oil.

In evaluating the "cleansing" actionof additives from their ability to retard formation of the oxidative-polymerization products most dangerous from the standpoint of tar formation (oxy acids and asphalts) and to prevent deposition of these compounds on the pistons, the following data, which were obtained by the method described above, were used to determine the "protective" power of АзНИИ-8 additive:

Test Results	MT-16+3% АзНИИ-8
Tar formation on piston, points;	3.5
Weight of tar deposits on piston, g	0.1256
Composition of tar deposits	
Oxy acids, g	0.0152
%	12.1
Asphalts, g	0.0090
%	7.1
Carbenes and carboids, g	0.1014
%	80.8
Total oxidation-product content of worked-out oil, g	4.0986
Total sediment content of oil	
Oxy acids and asphalts, g	0.3266
Carbenes and carboids, g	3.772

TABLE 29

Piston-Ring Mobility

Присадка [1]	1	2	3	4	5
АзНИИ-8	Плотное [2]	Плотное [2]	Свободное [3]	Свободное [3]	Свободное [3]
ЦИАТИМ-339	Свободное [3]	Пригорело на 90° [4]	Плотное [2]	Плотное [2]	Свободное [3]

1) Additive; 2) tight; 3) loose; 4) tar formation at 90°.

The protective power of an additive can be arbitrarily evaluated from the relative amount of oxy acids and asphalts found in the tar deposit.

If we use the symbols R for the protective power, c_1 for the amount of oxy acids and asphalts found in the tar deposits, and c_m for the amount of these compounds in the worked-out oil, then

$$R = 100 - \frac{c_л}{c_л + c_м}$$

Let us make a comparative evaluation of the "protective" power of АзНИИ-8 and ЦИАТИМ-339 additives:

Additive	$c_л + c_м$	$c_л$	R
МТ-16 + 3% АзНИИ-8	0,35	0,02	92
МС-20 + 3% ЦИАТИМ-339	0,24	0,04	83

As can be seen, АзНИИ-8 additive has a greater protective power than ЦИАТИМ-339 additive.

The piston-ring mobilities determined after engine testing of these additives (see Table 29) confirm tnat АзНИИ-8 additive is more effective.

§2. CORROSION PROPERTIES

The problem of corrosion in automobile engines initially arose in connection with the wide use of high-strength alloys in place of low-efficiency babbits; however, such alloys have a low resistance to the acidic compounds formed in the oil during engine operation [8].

Later investigations established that the corrosive aggressiveness of crankcase oils may also be due to wearing of cast iron and even steel engine components [9]. It was also found that use of oils with an effective "cleansing" action under high-temperature conditions is accompanied by removal of the protective surface films and intensification of oil oxidation. The concentration of corrosive compounds in the oil and the rate at which they are formed can thus serve as criteria for evaluating the corrosive properties of oils.

In practice, there are two common methods for evaluating the corrosive properties of crankcase oils: determination of potential and actual corrosion.

TABLE 30

Actual Corrosion for Additive-Containing Oils

1 Образцы масла	2 Действительная коррозия, г/м²
3 Автол-10 кислотно-контактной очистки	2,0
4 То же с 3% АзНИИ-8	0
5 Индустриальное 50	1,4
6 То же с 3% ЦИАТИМ-339	0,3
4 То же с 3% АзНИИ-7	0
7 Дизельное масло селективной очистки (Д-11) с 3% ЦИАТИМ-339	1,1
4 То же с 3% АзНИИ-7	0,8

1) Oil specimen; 2) actual corrosion, g/m²; 3) type-10 automotive oil, acidic contact refining; 4) the same, with 3% АзНИИ-8; 5) industrial 50; 6) the same, with 3% ЦИАТИМ-339; 7) diesel oil, selective refining (Д-11) with 3% ЦИАТИМ-339.

The principal difference between the method used to determine the actual corrosive aggressiveness of oils and the commonly employed procedure for evaluating potential corrosion consists in the following.

The active principle in determining potential corrosion is the acidic compounds formed in the oxidized oil. In determining actual corrosion, one deals with the active compounds found in the oil before oxidation.

In setting up the experiments, measures are taken to prevent oil oxidation. The experimental time is reduced to a minimum and no atmospheric oxygen is permitted to reach the contact area between the oil and the lead plate undergoing corrosion.

The NAMI method is most widely used for evaluating the actual corrosion caused by crankcase oils. This method determines the corrosion produced by mineral oil from the weight loss of a lead plate during a 30-min test at 140°C with no air permitted to reach the contact area.

A comparitive study of the actual corrosion caused by solutions of АзНИИ-7, АзНИИ-8, and ЦИАТИМ-339 additives in oil has shown (see Table 30) that these compounds differ little. The situation is different for the corrosion produced after long-term engine service. Thus, the actual corrosion caused by oil containing АзНИИ-7 additive increases to 2.7 g/m^2, while that caused by oil containing ЦИАТИМ-339 additive rises to 4.4 g/m^2.

It can be assumed that the corrosive aggressiveness of the compounds formed in worked-out oil is less for oils containing АзНИИ-7 additive than for those containing ЦИАТИМ-339 additive.

It is thus possible to evaluate the actual corrosion produced by worked-out oils and the conditions under which a crankcase oil acts on the metal components corroded during engine operation can be reproduced with sufficient accuracy.

Determination of crankcase-oil potential corrosion involves two simultaneous processes: formation of acidic compounds during oil oxidation and the corrosive action of these compounds. The over-all effect of the two factors is manifested in the experimentally determined weight loss of a lead plate.

We can observe the kinetics of these two parallel processes in determining potential corrosion for crankcase oils.

Figures 4, 5, and 6 show characteristic weight-change curves for lead plates during oil oxidation in a ДК-2 apparatus.

The procedure described above for determining the corrosive aggressiveness of motor oils and additive-containing oils provides for evaluation of the weight loss of lead plates in oil undergoing oxygen oxidation. Investigations conducted by K.S. Ramayya and R.Kh. Sil's [10] have shown that, as a result of their catalytic action on oil oxidation, organic metal salts accelerate lead corrosion. Current methods for evaluating the corrosive aggressiveness of oils (Pinkevich's method, the NAMI ДК-2 procedure) do not use oxidation catalysts, while various metals are present in or in contact with the oil in ICE's under actual operating conditions, exerting a catalytic influence on oxidation. Introduction of organic metal salts, particularly those of copper (copper naphthenate or stearate), into the oxidizing medium greatly increases the rate of oil oxidation and thus leads to a rise in lead-plate weight loss during corrosion determinations. The authors of the procedure recommend a test time of 25 h. The experiments are conducted in an NAMI ДК-2 apparatus at 140° with standard lead plate. The plates can be weighed at different intervals during the test, e.g., every 5 h, in order to get an idea of the trend of corrosion with time.

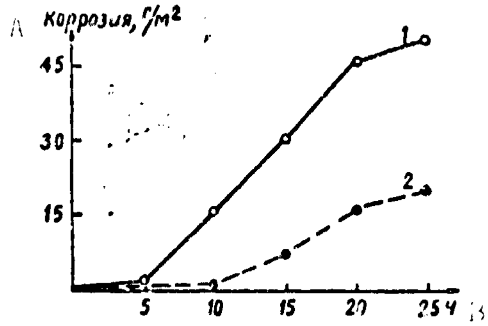


Fig. 4. Comparative evaluation of potential corrosion for following oils: 1) Industrial 50 (machine СУ); 2) industrial 50 + type МК-22 aviation oil (3:2 mixture) with 3% АзНИИ-4. A) Corrosion, g/m^2; B) h.

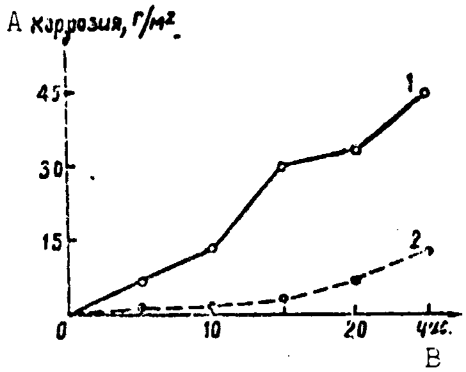


Fig. 5. Comparative evaluation of potential corrosion for following crankcase oils: 1) Type 10 without additive; 2) type 10 with 3% АзНИИ-8 additive. A) Corrosion, g/m^2; B) h.

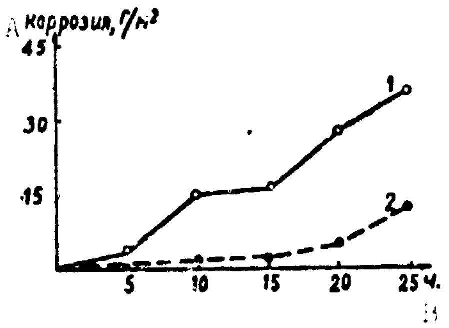


Fig. 6. Comparative evaluation of potential corrosion for following crankcase oils: 1) Diesel oil, selective refining (based on type 18 automotive oil), without additives; 2) the same oil, with АзНИИ-7 additive (3%). A) Corrosion, g/m^2; B) h.

In order to make a comparative evaluation of the corrosive aggressiveness of additive-containing oils, we compared the weight loss per unit lead-plate surface area after oil oxidation in the presence of a catalyst (copper naphthenate), which was added in an amount of 0.02% by weight, for 25 h (Tables 31 and 32).

The method described above can also be used to determine the comparative effectiveness of antioxidants. Tables 33 and 34 present the results of a comparative study of the effectiveness of the following antioxidants: tertiary butylphenol amine sulfide (АСФ), the Ba salt of a phosphorus additive derived from a cracking-paraffin polymer, БФК with sulfur and phosphorus, and АзНИИ-10.

As can be seen from the data given, effective antioxidants greatly reduce lead-plate corrosion in the presence of an oxidation catalyst.

TABLE 31

Comparison of Corrosive Aggressiveness of Oils and Additive-Containing Oils by Usual Procedure and 25-hour Method with Catalyst

1 Образцы масла	2 Без присадки	3 С присадками	
		СБ-3 (10%)	БФК-1 (8%)
Д-11 бакинское [4]	123 / 426,6	71,0 / 357,5	60,9 / 160,15
ДС-11 НК НПЗ	7,4 / 452,6	74,5 / 408,45	47,5 / 244,1
АС-9,5 НК НПЗ	17,5 / 443	90,2 / 360,[illegible]5	49,3 / 184,1
СУ-бакинское [4]	106 / 359,7	62,4 / 133,4	52,1 / 133,4
АС-6 НК НПЗ	5,4 / 442,5	177,0 / 399,9	72,5 / 268,4
АС-6 бакинское [4]	163 / 446,8	168,0 / 433,6	70,3 / 214,85

Note. The upper figure represents the corrosion (g/m^2) determined by the usual method, while the lower figure represents that determined by the more stringent method (with catalyst).

1) Oil specimen; 3) With additive;
2) Without additive; 4) Bakinskoye.

More rapid oxygen supply is important when evaluating the corrosive aggressiveness of oils in the presence of catalysts. From this standpoint, the conditions used for evaluating crankcase-oil corrosive aggressiveness by the PZZ (П33) method [4] must be regarded as approximating real conditions.

Figure 7 is a diagram of the PZZ apparatus, which consists

TABLE 32

Corrosive Aggressiveness of Additive-Containing Oils by NAMI Method (25 h, with Catalyst)

1 Образцы масла	2 Коррозия по НАМИ, г/м²
Д-11 (бак.)[3] с[4] 1,5% БФК	194
с[4] 4% БФК	122
с[4] 8% БФК	41,3
с[4] 18% БФК	1,15
ДС-11 НКЗ с[4] 8% БФК	146,4
Д-11 (бак.)[3] с 1,4% СБ-3	319,6
с[4] 4% СБ-3	290,0
с[4] 8% СБ-3	2,4,0
с[4] 18% СБ-3	240,0
Д-11 (бак.)[3] + 3% СБ 3 + 2% ДФ-11	2,7
Д-11 (бак.)[3] + 4% СБ 3 + 2% ДФ-11	1,8
Д-11 (бак.) + 7,5% БФК + 4% СБ-3 + + 0,5% ЛЗ-23к	6,4
Д-11 (бак.)[3] + 11% БФК + 4% СБ-3 + + 0,5% ЛЗ-23к + 0,005% ПМЗ-200А	7,3
Д-11 (бак.)[3] + 15% БФК + 6% СБ 3 + + 0,5% ЛЗ-23к + 0,005% ПМЗ-200А	5,9

1) Oil specimens; 2) corrosion by NAMI method, g/m²; 3) Bakinskoye; 4) with.

TABLE 33

Results of Evaluation of Corrosive Aggressiveness of Additive-Containing Oils

1 Образцы масла	2 Коррозия по ужесточенному методу, г/м²
3 **Без антиокислителей**	
ДС-11 + 6,6% БФК + 3,4% СК-3	151,0
ДС-11 + 9,9% БФК + 5,1% СК-3	53,5
ДС-11 + 5% БФК + 1,5% СБ-3	27
4 **С антиокислителями**	
ДС-11 + 11% БФК + 4% СБ-3 + 1% БФКS	10,8
" " 2% " "	23,2
" " 1% АзНИИ-10	54,0
" " 2% "	138,8
" " 1% АСФ	8,8
" " 2% "	7,2

1) Oil specimens; 2) corrosion by stringent method, g/m²; 3) without antioxidants; 4) with antioxidants.

of an aluminum delivery tank filled with the oil to be tested, a rotary pump (БНК-12 АК) driven by an electric motor, and cassettes for six lead and two copper plates. An electric heater with a power of 1 kW is used for heating and maintenance of constant oil temperature during the test.

TABLE 34

Influence of Antioxidants on Corrosive Aggressiveness of Д-11 Oil and of Д-11 Oil with СБ-3 Sulfonate Additive

1 Образцы масла	2 Коррозия по НАМИ, $г/м^2$ (ужесточенный метод)
3 Масло Д-11 без присадок	360
4 То же с 1% АФА	3,5
» с 1% ИНХП-21	0,9
» с 1% ИНХП-36	1,5
» с 1% $Р_2$	0,75
» с 1% АзНИИ-10	19
» с 1% ДФ-11	0,75
» с 0,7% Сантолюб-493 5	2,2
» с 0,5% ОЛОА-267	3,9
Д-11 с 5% СБ-3	203,0
4 То же с 1% АФА	17,0
» с 1% ИНХП-21	108,0
» с 1% ИНХП-36	144,0
» с 1% $Р_2$	135,0
» с 1% АзНИИ-10	344,0
» с 1% ДФ-11	3,0
» с 0,7% Сантолюб-493 5	0,8
» с 0,5% ОЛОА-267	1,5

1) Oil specimens; 2) corrosion by stringent NAMI method, g/m^2; 3) Д-11 oil without additives; 4) the same with; 5) Santolyub.

The circulation system consists of aluminum tubing, which connects the delivery tank and cassettes to the pump and the cassettes to the tank.

The constancy of the test regime is monitored with a thermometer, which measures the temperature of the oil before it is admitted to the cassette, a U-shaped mercury manometer, which measures the oil pressure in front of the cassette, and a rheometer, which is used to determine the amount of air entering the intake system. The apparatus operates in the following manner.

The oil to be tested, heated to a predetermined temperature, is forced by the pump from the delivery tank into the cassette, whence it is sprayed through apertures in the central tube onto the heated walls of the delivery tank and flows downward. The contact with the heated delivery-tank walls, mixing with air, and contact with different metals cause rapid oxidation of the oil, which rapidly washes the plate surfaces under pressure during the test, causing them to corrode.

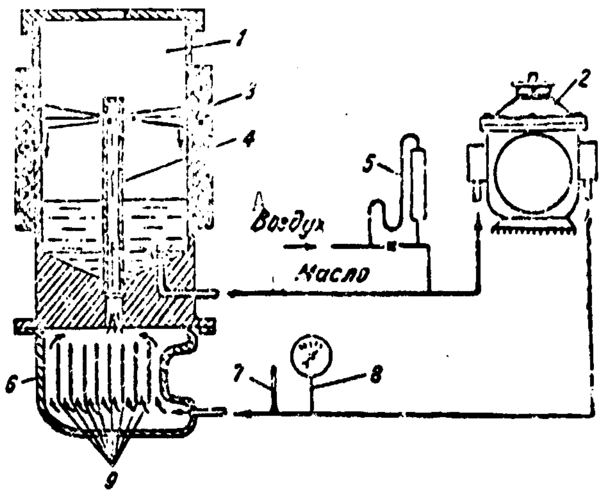


Fig. 7. Diagram of PZZ apparatus. 1) Delivery unit; 2) pump; 3) heating element; 4) tubing; 5) rheometer; 6) plate cassette; 7) thermometer; 8) manometer; 9) plates. A) Air; B) oil.

The following standard test conditions are maintained in evaluating the crankcase properties of oils in the PZZ apparatus:

1) test-specimen volume — 250 ml;

2) test duration — 2 h;

3) oil temperature at entrance to cassette — 125 ± 1°C;

4) oil-circulation rate — 125 ± 5 liters/h;

5) amount of air entering intake pipe — 50 ± 3 liters/h (measured with rheometer).

The tests are conducted in the following manner. Six lead plates (type C-1 or C-2) 40 × 20 × 2 mm in size are cleaned with fine emery paper and polished with felt until lustrous. The polished plates are rinsed with benzene, dried, and weighed together on an analytic balance to within 0.0002 g. The two copper plates are also cleaned with emery paper and rinsed in benzene.

The prepared lead and copper plates are placed in the apparatus, thoroughly rinsed after the previous test, and the latter is assembled. A total of 250 ml of the oil to be tested is poured into the delivery tank and the heater is switched on. When the oil temperature in the delivery tank reaches 160°C, the apparatus is started. As soon as the oil temperature at the entrance to the cassette reaches 150 ± 1°C, a standard air-flow rate through the intake pipe is set up with a clamp on the rubber hose connecting the rheometer to this pipe; the oil-circulation speed in the system is then adjusted, using the reduction valve on the pump to set up an oil pressure at the cassette entrance corresponding to an oil-circulation rate of 125 ± 5 liters/h.

TABLE 35

Comparative Results of Evaluation of Corrosive Aggressiveness of Oils by PZZ and NAMI Methods (GOST 8255-56)

Масло [1]	Метод ПЗЗ, г/м² [2]	Метод НАМИ, г/м² [3]
Д-11 бакинское [4]	118,38	32,8
ДС-11 НКЗ	21	5,7
АС-6 НКЗ	9,21	4,3
МС-20 грузненское [5]	13,37	—
[6] Машинное СУ	13,[illegible]	51
АС-9,5 НКЗ	2[illegible],22	12,35
АС-6 бакинское [4]	12[illegible],8	11,2
АК-10 бакинское [4]	64,05	60,5
Д-11 бакинское [4] + 10% СБ-3 + 1% АН-22	1,8	0,2
Д-11 бакинское [4] + 10% СБ-3 + 2% АН-22	0,32	0,25
Д-11 бакинское [4] + 10% СБ-3 + 3% АН-22	0,33	0,25
Д-11 бакинское [4] + 5% АзНИИ-7	1,36	0,6
Д-11 бакинское [4] + [illegible]% АзНИИ-7	1,7	0,6
Д-11 бакинское [4] + 8% БФК-S	2,0	0,2
Д-11 бакинское [4] + 8% БФКS	1,96	0,2
Д-11 бакинское [4] + 8% БФК + 4% СБ-3	0,36	−0,55
Д-11 бакинское [4] + 8% БФК + 8% СБ-3	0,16	−0,39
АС-6 НКЗ + 8% БФК	1,08	0,6

1) Oil;
2) PZZ method, g/m²;
3) NAMI method, g/m²;
4) Bakinskoye;
5) Gruznenskoye;
6) Machine.

The oil pressure corresponding to the standard circulation rate is determined by preliminary calibration of the apparatus.

The standard oil temperature at the cassette entrance is maintained during the test by varying the current supplied to the heating element with a rheostat. Testing of one oil specimen requires 2 h. The time for which the apparatus is heated in order to reach standard conditions is not included in the test time and should not exceed 10 min.

After the apparatus has operated under the proper regime for 2 h, the oil heater is switched off, the air supply through the intake system is discontinued, and the hot oil is poured into a graduate. (In order to obtain more of the oil, the electric motor is briefly run three or four times.) After the oil has been poured off, the apparatus is disassembled and the lead and copper plates are removed from the cassettes with forceps and transferred to a bath containing an alcohol-benzene mixture (1:3), where the corrosion products and alcohol-benzene-soluble oil-oxidation products are removed from their surface with cotton. After rinsing, the lead plates are transferred with forceps to filter paper, dried, and weighed on an analytic balance to within 0.0002 g.

When the delivery tank has cooled to room temperature, the apparatus is reassembled and rinsed with B-70 gasoline.

The results are evaluated after the test has been completed.

The corrosion properties are evaluated from the change in lead-plate weight per unit surface area over the test period. The weight loss is determined from the formula

$$X = \frac{\Delta p}{0.01} \text{ g/m}^2,$$

where Δp is the difference in lead-plate weight before and after the test, in g, and
0.01 is the lead-plate surface area.

Table 35 presents the results of a comparative evaluation of the corrosive aggressiveness of different oils by the method described above.

Analysis of the data in the table enables us to establish that, as a result of the more rapid circulation of the oil, its greater contact with the air and heated surfaces, and the catalytic effect of the copper plate, two-hour corrosion in the PZZ apparatus was greater than 10-hour corrosion by the NAMI method.

In order to make a comparison of the results from the relative data, we will group the specimens tested into definite NAMI-corrosion ranges (g/m^2):

NAMI Method	PZZ Method
0.2-0.25	0.32-2.0
0.4-0.8	0.16-1.7
4.3-12.35	9.21-128.8
up to 51	130

These data indicate that both greater absolute corrosion and clearer differentiation of corrosion levels occur in the PZZ method than in the NAMI method.

§3. LUBRICATING AND ANTIWEAR PROPERTIES

As is well known, the main function of a lubricating oil is to reduce wear, friction, and accompanying grabbing, seizure, etc. Oils and additive-containing oils having given antiwear and lubricating properties exhibit these functions under two very different sets of crankcase-lubrication conditions: boundary and hydrodynamic.

Boundary lubrication is naturally the more dangerous from the standpoint of engine durability. In this case, the properties of the oil are determined by a whole series of characteristics incorporated into the concept of the "lubricating power" of oils. The lubricating power of an oil can be defined as the property that creates differences in friction and wear when the oil viscosity, surface character, and other factors are identical and constant.

Without dwelling on the theory of lubricant action, which has been rather thoroughly discussed in works by Soviet [11-15] and foreign [16-20] researchers, we can note that the problem of procedures for evaluating the lubricating power of motor oils, particularly additive-containing oils, still contains large blank areas, despite numerous investigations [21-23]. A substantial proportion of the work that has been done was intended to study the mechanism of the lubricant action of oils and additives at high and moderately high pressures. These investigations have often been limited either to determination of the maximum loads for oil-film rupture or to evaluation of the coefficients of friction under different conditions.

In setting out to make a comparative evaluation of the lubricating and antiwear properties of additive-containing motor oils, we proceeded from the fact that the friction-surface wear can serve as one of the basic criteria for such an evaluation.

The INKhP (ИНХП) [Institute of the Petrochemical Industry] has developed a procedure for testing the lubricating power of additive-containing oils in an МИ-8 metal-wear testing machine. Figure 8 is a general view of this apparatus.

A total of 200 ml of the oil to be tested is poured into the oil beaker, where it is heated to 90°C by an electric furnace, and then goes to the oil chest, which has a rotating ring at the bottom.

The oil is returned from the chest to the beaker by a pinion pump driven from the shaft of the friction machine. The oil line has cocks, which are used to maintain a constant oil level in the oil chest. The temperature of the oil reaching the friction couples is always held constant and is measured with a thermocouple connected to a potentiometer.

Fig. 8. Friction machine for determination of oil lubricating power.

The tests were conducted with friction couples consisting of the outer races of 7204 radial-thrust bearings, which have an outside diameter of 47 mm. With the upper ring stationary and the lower ring rotating at 200 rpm, the sliding speed is:

$$v = \frac{\pi d n}{60} = 0{,}00246\, n = 0{,}00246 \cdot 200 = 0{,}492 \text{ m/s}.$$

The volumetric or gravimetric wear per unit time is taken as the basic index of oil antiwear properties.

With friction between the moving lower ring and the stationary upper ring, a hole is formed in the surface of the latter and, all other conditions being equal, its size depends on the quality of the lubricating oil, the load on the ring during friction, and the sliding speed, which in turn depends on the speed of the lower ring and the quality of the ring friction surfaces. Evaluation of the volumetric or gravimetric wear from the width of the friction track does not reflect the actual wear pattern, since the amount of metal removed during friction is a nonlinear function of the friction-track width.

Actually, the weight of the metal removed from the friction surface is determined by the volume enclosed between the two cylinder surfaces and equals the height of the cylinder genetrix multiplied by twice the area of the circle segment cut off by the chord s.

For the circle segment, we have:

$$F' = \frac{1}{2}\left[r(l - s) + sh\right],$$

where F' is the segment area,

r is the radius of curvature,

φ is the central angle,

h is the altitude, $h = 2r\,(\sin\varphi/2)^2$,

s is the length of the chord cutting the arc l at the central angle φ, $s = \sqrt{h(2r - h)}$; and

l is the arc length, $l = 0{,}0174532\,\varphi^\circ = \sqrt{s^2 + \frac{16}{3}h^2}$.

Since the factor in which we are interested, the volume of metal v removed from the ring surface, is determined by the product of twice the area of the circle segment by the length of the cylinder genetrix, we have:

$$v = F \cdot a = 2F'a = \left[r(l - s) + sh\right] a,$$

whence the weight G of the metal removed is

$$G = v \cdot \gamma,$$

where γ is the specific gravity of the ring material.

Assuming $\gamma = 7.85$ g/cm^3 and knowing that $2r = 47$ mm, and $a = 10$ mm, we can calculate the weight of the metal removed from the ring surface during friction as a function of the friction-track width s.

Thus, having obtained the weight of the metal removed from the friction surface as a function of time under constant load (P = 150 kg) from a series of experiments, we find the basic parameters determining the character of this function. When the test specimens have been sufficiently worn in, the dependence of the gravimetric wear on time is expressed by a linear equation: $y = ax + b_0$. In this case, the slope angle a of the line represents the wear rate, while the magnitude of the constant b_0 characterizes a certain degree of initial wear.

Processing of Experimental Data

If we designate the ring wear (mg) as g, the test time (h) as t, the wear rate (mg/h) as k, and the initial wear (mg) as g_0, the change in g as a function of t can be represented as:

$$g = kt + g_0,$$

where t takes the following values, in accordance with the experimental conditions: t_1 = 1 min, t_2 = 10, t_3 = 20, t_4 = 30, t_5 = 40, t_6 = 50, and t_7 = 60 min. In this case we obtain the values of g_1, g_2, g_3, g_4, g_5, g_6, and g_7.

Using the method of least squares, we obtain:

$$\Sigma gt + k\Sigma |t|^2 - g\Sigma t = 0,$$
$$\Sigma g - k\Sigma t - g_0 s = 0,$$

where s is the number of experiments.

Hence:

$$k = \frac{s\Sigma tg - \Sigma t\Sigma tg}{s\Sigma |t|^2 - |\Sigma t|^2},$$
$$g_0 = \frac{\Sigma g\Sigma |t|^2 - \Sigma t\Sigma tg}{s\Sigma |t|^2 - |\Sigma t|^2}.$$

Having substituted the known values s = 7, Σt = 211, Σt^2 = 9101 for the experimental conditions in question into the equations obtained, appropriate transformations yield:

$$k = \frac{\Sigma gt - 30\Sigma g}{2741}. \quad (1)$$

$$g_0 = \frac{\Sigma g}{7} - 30k = 1{,}31\,\Sigma g - \frac{\Sigma gt}{90}. \quad (2)$$

The ring wear d_0 corresponding to the initial gravimetric wear g_0 is obviously some arbitrary friction-track width at the beginning of application of the load P. The ratio of this load to the area $F = d_0 l$, where l is the ring width, gives an index characterizing the initial bearing capacity of the oil film σ_0 at the load in question:

$$\sigma = \frac{P}{d_0 l}. \tag{3}$$

TABLE 36

Results of Motor-Oil Tests in МИ-8 Friction Machine

1 Образцы масел	2 Интенсивность износа, мг/ч	3 Начальный след трения, мм	4 Начальная прочность масляной пленки, кг/см²
5 Машинное СУ без присадки	2,24	0,66	2350
6 То же с 3% ЦИАТИМ-339	0,225	0,29	5170
АК 10 без присадки 7	2,71	0,58	2580
6 То же с 3% ЦИАТИМ-339	0,132	0,42	3560
АС-9,5 без присадки 7	1,61	0,70	2120
6 То же с 3% ЦИАТИМ-339	0,12	0,40	3750
ДС-11 без присадки 7	1,64	0,57	2630
То же с 3% ЦИАТИМ-339	0,413	0,46	3280
8 Д-11 с 10% смеси СБ-3 и БФК (2:1)	0,132	0,40	3750
9 То же (1:1)	0,226	0,44	3400
9 То же (1:2)	0,122	0,38	3950

1) Oil specimens;
2) Wear rate, mg/h;
3) Initial friction track, mm;
4) Initial strength of oil film, kg/cm²;
5) Machine СУ without additives;
6) The same, with;
7) Without additives;
8) Д-11 with 10% of mixture of СБ-3 and БФК (2:1);
9) The same.

The basic lubricating-power indices are thus determined by the method described above in the following manner.

Seven experiments, lasting 1, 10, 20, 30, 40, 50 and 60 min are conducted with the oil to be tested. The load on the friction rings is 150 kg and the lower race turns at a speed of 200 rpm.

The value of g is calculated over the friction-track width after each experiment and Σg and Σgt are determined for the seven experiments. Equations (1) and (2) are then used to determine the values of k and g_0.

The "initial" wear d_0 corresponding to the last quantity is substituted into Formula (3), as a result of which σ_0 is found.

Table 36 shows the results of an evaluation of a number of motor oils by the method described above.

As can be seen from a comparative study of the initial stresses in a boundary lubricating layer during tests in the machine described above (see Fig. 9), they occupy a position intermediate between those obtained in the ЛТТО-2 friction machine of the Leningrad Polytechnic Institute (contact between a thrust bearing and the surface of a cylindrical rod) and in a friction machine of the "Falex" type (INKhP).

The results obtained can thus be used for a comparative evaluation of the antiwear properties of additive-containing oils only to the extent to which these properties are manifested during contact of microrononuniformities in the contacting surfaces, where high contact pressures can occur. Use of modern research techniques, particularly radioactive tracers, somewhat broadens opportunities for evaluation of the antiwear properties of additive-containing motor oils.

An INKhP friction machine, whose friction unit is similar to that used in friction machines of the "Falex" type, was employed to investigate the antiwear properties of steel – cast iron couples under different lubrication conditions.

The wear rate was determined from the increase in the radioactivity of the oil, which proved to be proportional to the wearing of radioactive Co^{60} bushings installed in cast iron thrust bearings (Fig. 10). The oil to be tested was forced through pipes and coils by a pump. CTC-8 Geiger-Mueller counter tubes and devices of the "Tiss" type were used with an ЭПП-09 recording potentiometer to measure the oil activity, which was proportional to the amount of radioactive Co^{60} that entered the oil during wearing of the bearings.

TABLE 37

Antiwear Efficiency of INKhP Compound Additives

Образцы масла [1]	ОПИ [2]
ДС-11 + 10% СК-3	40,7
То же[3] + 15% .	48,5
20% .	53,6
. 8% БФК-1	32,4
. 15% .	31,2
. 20% .	35,0
. 5% АзНИИ-7	35,6
. 10% .	32,5
. 6,6% СК-3 + 3,4% БФК-1	29,9
. 6,6% БФК-1 + 3,4% СБ-3	29,6

1) Oil specimens; 2) OPI; 3) the same.

Some authors use a wear-index determination [WID](ОПИ) in accordance with GOST 9490-60 to evaluate the antiseizing and antiwear efficiency of motor oils [24].

It is natural that, as a result of the higher contact pres-

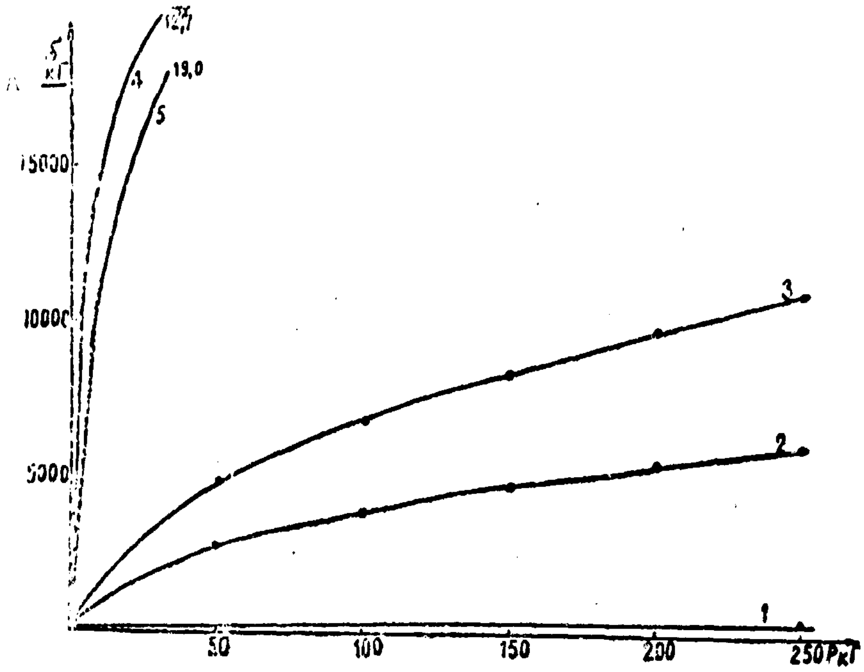


Fig. 9. Lubricating-film stress as a function of load for different friction machines. 1) ЛТТО-2; 2) МИ-8 (by INKhP method); 3) "Falex" (by INKhP method); 4, 5) four-ball friction machine with ball diameters of 12.7 mm (4) and 19.0 mm (5). A) kgf.

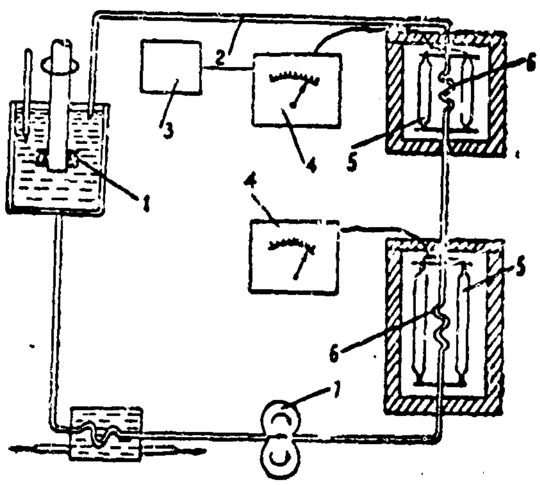


Fig. 10. Diagram of apparatus for evaluating antiwear properties of oils with radioactive cobalt. 1) Thrust bearings with radioactive inserts; 2) pipes; 3) ЭПП-09 potentiometer; 4) "Tiss" devices; 5) Geiger-Mueller tubes; 6) coils; 7) pump.

sures (the determination is made with balls 12.7 mm in diameter at 1410 r/min in a four-ball friction machine), the evaluation of motor-oil properties is limited to a narrower range of specific conditions than may actually obtain.

The poorly differentiated results obtained in evaluating the antiwear efficiency of different compound additives, which are given in Table 37, can also be explained from this standpoint.

§4. OXIDATION RESISTANCE

The high temperatures of the surfaces of many engine components, principally those of the cylinder-piston assembly, with which the lubricating oil is continuosly in contact and its exposure to fuel-combustion products and atmospheric oxygen under the catalytic action of various metals promote rapid oil oxidation. The temperatures at which a lubricating oil operates in an engine reach high levels, particularly in the vicinity of the top piston ring.

Data on the temperatures in the vicinity of the top ring groove are given below for certain types of compressive-ignition internal combustion engines [ICE](ДВС) [2]

Type of Engine	Temperature, °C
Ч 8.5/11	150-160
Ч 10.5/13	212
Ч 23/30	212
8 ДР 30/50	-
30 Д	200-210
ЧН 18/20	240-250
2Д-100	250

As is now recognized by many researchers [9, 25, 26], the mechanism of oil-hydrocarbon oxidation under these conditions involves intermediate formation of peroxides and free radicals.

It is generally acknowledged that indicated oxidation of most organic compounds at temperatures below 300°C proceeds by an automatic chain mechanism, in which the stage governing the overall reaction rate is decomposition of hydrogen peroxide [27-30].

The rate of the chain reaction can be reduced by two methods [25]: by reducing the number of initiable chains or the length of the reactive chain. Hence, turning to possible explanations of the action mechanism of antioxidants in hydrocarbon-oxidation reactions, we must point out:

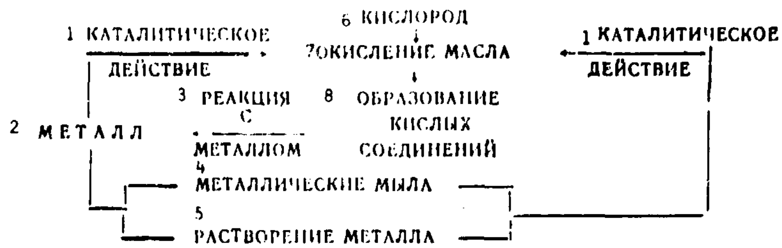
suppression of the development of new chains, i.e., inhibition of hydrogen peroxide formation by deactivation of the excited or activated atoms, ions, or radicals;

suppression of chain transfer or branching, i.e., reaction of the antioxidant with the interchangeable radical;

a decrease in chain length, i.e., interaction of the antioxidant with the intermediate product.

However, the oxidation rate is not always a reliable criterion for evaluating oxidation resistance. The character and properties of the oxidation products are no less important. Moreover, the catalytic effect of metals exerts an influence on oxidation reactions.

The interaction of the various factors involved in oil oxidation can be represented diagrammatically in the following manner:



1) Catalytic effect; 2) metal; 3) reaction with metal; 4) metallic soaps; 5) metal dissolution; 6) oxygen; 7) oil oxidation; 8) formation of acidic compounds.

It can thus be assumed that antioxidants are divided into two major groups, in accordance with their role in the aforementioned oil-oxidation processes: true antioxidants, whose action is based on interruption of the oxidation chain reaction, and metal deactivators, whose action is based on formation of a protective film that reduces the catalytic activity of a given metal surface. Often, however, the catalytic effect is exerted not by the metals themselves but by the products of their reaction with the active compounds present in the lubricating oil or formed during its operation.

In classifying antioxidant additives on the basis of their action mechanism, some authors [26] distinguish deactivators from passivators, reserving the former term for the ability to reduce the catalytic activity of metallic compounds dissolved in oils and the latter term for the ability to form films. Moreover, it has been pointed out that potential antioxidants, whose activity is manifested as a result of their interaction with oxidation products and ultimately leads to formation of compounds having inhibitory or deactivating functions, may have some effect. We thus return to the two basic functional properties of antioxidants: inhibitory and deactivating (passivating).

Functional properties and hence their evaluation for antioxidants used in motor oils differ in a number of other characteristics, which we will briefly consider.

First of all, in contrast to the well known antioxidants used, for example, to stabilize fuel oils, their functional properties should be strictly correlated with those of other types of additives present in compounds for modern motor oils. Thus, if some antioxidants react with metal surfaces to form films more or less impermeable to oxidation products on the one hand and permit diffusion of dissolved metal into the oil on the other, the simultaneous presence of a detergent additive in the compound can promote dispersion of the films.

Furthermore, the action of detergent additives is known to

TABLE 38

Influence of Л323К Additive on the Oxidation Resistance of Д-11 Oil

1 Образцы масла	Коррозия по НАМИ, $г/м^2$ (ужесточенный метод) 2	$T_{250°}$, мин 3
Д-11 без присадки 4	260	23
Д-11 + 0,2% ЛЗ-23к	131	25
Д-11 + 1% ЛЗ-23к	13,4	34

1) Oil specimens; 2) NAMI corrosion, g/m^2 (stringent method); 3) min; 4) without additives.

take the form of holding solid particles insoluble in oil in a suspended state. This functional characteristic of the "cleansing" action of additives can have a direct influence on the efficiency of an antioxidant included in the same composition with a detergent additive. Essentially, the reaction rate and induction period are materially affected by the solid phase whose activity is manifested in catalytic action. The catalytic activity of a solid phase dispersed in oil naturally depends on its total surface, while the latter depends on the degree of dispersion.

Thus, the detergent efficiency of an additive, which is manifested in a greater or lesser dispersing capacity, indirectly affects oil-oxidation processes.

Interpretation of the action mechanism of other lubricating-compound components from the standpoint of their influence on the direction and rate of contact-oxidation processes is also of interest. For example, it can be assumed that the antiseizing action of various additives, which promotes a decrease in contact temperatures, can also affect the degree of oxidation. Experiments conducted to evaluate the influence of Л3-23k antiseizing additive on the oxidation resistance of motor oils (Table 38) have shown that a rise in its concentration in Д-11 oil increases oxidation resistance.

The oxidation resistance of motor oils can be most simply characterized by evaluating their inhibition capacity, their oxidation rate, and the activity of the acidic compounds formed.

The first index can be established from the induction period determined by the АзНИИ method [25]. The average oxidation rate can be found from the amount of oxygen absorbed per unit time, as well as from data obtained in tests of oil oxidizability by the АзНИИ method. Finally, the activity of the acidic compounds formed is evaluated from the corrosion of metal in the oxidized oil, as was pointed out above.

TABLE 39

Evaluation of Oxidation Resistance of Oils from Apsheron Crude Oil

	1 Образцы масла	2 Уд. вес d_4^{20}	3 Кислотное число, мг KOH	4 Кокс, %	5 Стабильность по АзНИИ, мин		8 Коррозия по Пинкевичу, г/м²	9 Средняя скорость окисления по количеству поглощенного кислорода, мг/мин
					6 Индукционный период	7 Общее время окисления		
10	Автол-10 (эталонный образец)	—	—	—	—	—	—	
11	Дистиллят автола-10 из бинагадинской нефти	0,9460	2,56	0,44	4	50	235	0,434
12	Автол-10 из бинагадинской нефти, очищенный 150% фурфурола, 15% глины	0,9109	0,36	0,25	8	96	97	0,227
13	То же, очищен 150% фурфурола, 1% кислоты, 5% глины	0,9100	0,38	0,17	15	180	76	0,121
14	Дистиллят автола-10 из нефти „Нефтяных Камней"	0,9340	3,37	0,44	3	45	400	0,476
15	Автол-10 из нефти „Нефтяных Камней", очищенный 150% фурфурола, 15% глины	0,9083	0,48	0,2	11	138	89	0,157
13	То же, очищен 150% фурфурола, 1% кислоты, 5% глины	0,9056	0,5	0,15	34	239	59	0,097
16	Дистиллят автола-10 балаханской масляной нефти	0,9116	2,31	0,2	65	225	—	0,125
17	Автол-10 из балаханской масляной нефти, очищенный 150% фурфурола, 15% глины	0,8996	0,77	0,13	14	155	125	0,141
13	То же, очищен 150% фурфурола, 1% кислоты, 5% глины	0,8986	0,8	0,1	38	302	86	0,076

1) Oil specimens; 2) specific gravity, d_4^{20}; 3) acid number, mg KOH; 4) coke, %; 5) АзНИИ stability, min; 6) induction period; 7) total oxidation time; 8) corrosion by Pinkevich's method, g/m²; 9) average oxidation rate from amount of oxygen absorbed, mg/min; 10) type 10 automotive oil (standard specimen); 11) type 10 distillate from Binagadinskoye crude oil; 12) type 10 from Binagadinskoye crude oil, refined with 150% furfurol and 15% clay; 13) the same, refined with 150% furfurol, 1% acid, and 5% clay; 14) type 10 distillate from Neftyanyye Kamni crude oil; 15) type 10 from Neftyanyye Kamni refined with 150% furfurol and 15% clay; 16) type 10 distillate from Balakhanskoye crude oil; 17) type 10 from Balakhanskoye crude oil refined with 150% furfurol and 15% clay.

Table 39 presents data showing the change in the aforementioned indices for different motor oils from Apsheron crude oils.

It can be seen that there is a simultaneous improvement in inhibition capacity, a decrease in oxidation rate, and a drop in corrosion rate as the oil distillates are more highly refined.

Under certain conditions, evaluation of motor-oil oxidation resistance from the amount and character of the final oxidation products (the sediment content and viscosity of the oxidized oil) yields only final results. The experimental conditions are of material importance in this case. For example, comparing the sediment formation determined by the PZZ method (oxidation at 150° for 2 h) with that determined by the NAMI method (oxidation at 200°C for 50 h), it can be seen that there is a difference in both the extent and rate of the oxidation processes (Table 40).

Actually, on the basis of the absolute percentage sediment content of the oxidized oil, substantially less sediment was formed with a shorter experiment duration and a reduced temperature. Oxidation is therefore relatively mild, but the average rate of the oxidation processes can be more clearly distinguished in this case. This is graphically shown by base oils from Bakinskoye and Eastern crude oils and in additive tests (with different concentrations of АН-22k mixed with СБ-3).

TABLE 40

Comparative Results of Determination of Sediment Formation (%) in Oils by PZZ Method and of Thermooxidation Resistance

1 Образцы масла	Метод ПЗЗ (т-ра 150°, время исп. 2 ч) 2	Термоокислительная стабильность (т-ра 200°, время исп. 50 ч) 3
Д-11 бакинское 4	2,71	6,76
ДС-11 НКЗ	0,36	5,53
АС-6 НКЗ	0,52	9,15
5 Машинное СУ	3,97	8,13
АС-9,5 НКЗ	0,755	5,88
АС-6 бакинское 4	3,69	8,42
АК-10 бакинское 4	1,54	13,75
Д-11 бакинское 4 + 10% СБ-3 + 1% АН-22	0,57	12,09
6 То же + 10% СБ-3 + 2% АН-22	0,92	15,29
" + 10% СБ-3 + 3% АН-22	0,7	16,49
" + 8% БФК-S	0,71	5,09
" + 8% БФК-S	0,71	4,01
" + 5% АЗНИИ-7	1,1	8,63
" + 5% А[illegible]7	1,2	11,67

1) Oil specimens; 2) PZZ method (temperature - 150°, test time, 2 h); 3) thermooxidation resistance (temperature 200°, test time, 50 h); 4) Bakinskoye; 5) Machine СУ; 6) the same.

§5. MOTOR-OIL VOLATILITY

The behavior of an ICE lubricating oil at high temperatures is governed both by its chemical stability and by its volatility. The overwhelming majority of modern motor oils are multicomponent mixtures. In order to evaluate and compare their volatilities, we therefore cannot use data on the relative amount of oil volatilized under given conditions.

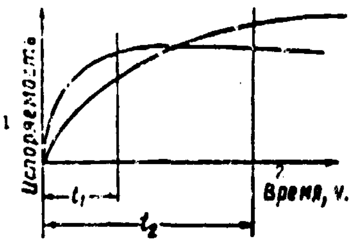


Fig. 11. Volatility curves. 1) Volatility; 2) time, h.

The inapplicability of this index to multicomponent mixtures is due to the fact that the vaporization rate for solutions is maximal at the beginning of the process and then decreases as the low-boiling fractions are removed from the mixture [36].

Under these conditions, the vaporization of two multicomponent solutions over definite time intervals t_1 and t_2 (Fig. 11) can be evaluated differently as a result of the difference in vaporization kinetics. On this basis, kinetic vaporization curves can be used to obtain a sufficiently complete characterization of a multicomponent mixture.

The investigations of V.M. Martynov [37] and F.K. Vol'nets [38] have shown that oil-vaporization kinetics can be described by the equation:

$$\frac{ast}{g_0} = \nu - b \lg (1 - \nu),$$

where a and b are constants,

s is the evaporation surface in cm^2,

g_0 is the initial weighed portion in g,

ν is the proportion of material vaporized, and

t is the time.

This expression can be used to compare the results obtained in evaluating oil volatility under different conditions.

In addition, the evaporation rate of lubricating materials having a low saturated-vapor tension is described by the equation [36]:

$$\lg V = A - \frac{B}{T},$$

where V is the evaporation rate in $g/cm^2 s^{-1}$,

T is the absolute temperature, and

A and B are constants.

Use of this equation to calculate evaporation rates under different test conditions makes it possible to obtain a quite clear

TABLE 41

Comparative Results of Determination of Oil Volatility (%) by PZZ Method and En_ne Volatility by Papok's Method

1 Образцы масла	2 Метод ПЗЗ (т-ра 150° С, время исп. 2 ч)	3 Метод Папок (т-ра 250°С, время исп. 30 мин)
Д-11 бакинское 4	10	88
ДС-11 НКЗ	8	80,1
АС-6 НКЗ	6	93,5
Машинное СУ 5	7	94
АС-9,5 НКЗ	9	76,5
АС-6 бакинское 4	19	93
АК-10 бакинское 4	12	—
МС-20 грозненское 6	10	66,3
Д-11 бакинское 4 +10 % СБ-3+1 % АН-22	10	82
То же 7 +10 % СБ-3+2 % АН-22	10	74,7
" +10 % СБ-3+3 % АН-22	10	75,8
" +5 % АзНИИ-7	11	—
" +8 % БФК	18	81
" +6 % БФК+4 % СБ-3	16	78,6
" +8 % БФК+8 % СБ-3	10	80,9
АС-6 НКЗ+8 % БФК	9,6	94

1) Oil specimens; 2) PZZ method (temperature – 150°C, test time, 2 h); 3) Papok's method (temperature – 250°C, test time, 30 min); 4) Bakinskoye; 5) Machine СУ; 6) Gruznenskoye; 7) The same.

characterization of the volatility of multicomponent solutions, a class to which motor oils belong. Table 41 is a comparison of the volatilities of a number of motor oils.

Processes other than evaporation, such as decomposition and oxidation, occur under given conditions. Oil-consumption kinetics are naturally also determined by the rate of the processes accompanying vaporization, which brings the determination conditions closer to operating conditions.

§6. PROPERTIES OF OILS CONTAINING THICKENING ADDITIVES

In engine starts at below-freezing temperatures, oil viscosity is known to determine both the possibility of starting (without preliminary heating) and the starting wear on the engine components, which amounts to 50-60% of total wear in winter. For example, the starting wear in the ГАЗ-51 engine, which operates with type 6 automotive oil, is known to be four times greater at a temperature of −24 or −25°C than at above-freezing temperatures (10°C). The engine wear during a single start is equivalent to that produced by 200-300 km of vehicle travel.

As for the possibility of starting, the resistance to crankshaft rotation when the oil viscosity is extremely high is so greatly increased that the starter cannot provide the minimum number of engine revolutions necessary for starting and it is impossible to start without first heating the engine.

According to the data of various researchers [39], the following viscosities are necessary for normal engine starting at the temperatures indicated:

Starting Temperature, °C	Kinematic Viscosity, cSt
−12	7200
−15	6500
−18	5100 to 8700
−23	1000 to 5400
−26	3000 to 3300

Moreover, high-quality SAE-30 distillate oil with a viscosity index of 86 has a viscosity of 18,000 cSt at −17.8°C, ДС-8 oil produced from Eastern crude oil has a viscosity of 18,000 cSt at −20°C, and AC-10 oil produced from Bakinskoye crude oil (with a viscosity index of 61) has a viscosity of 17,000 cSt at −10°C. This situation forces consumers to switch to special winter oils with reduced viscosity for cold weather, but some of these (AC-6) cannot provide the maximum permissible viscosity at starting temperatures below −20°C.

The lower-temperature properties of oils are especially important in the Soviet Union, where 50% of the nation has a cold-weather period (with temperatures below 0°C) lasting 130-300 days per year, while the average January temperature ranges from −20 to −50°C.

The problem of producing lubricating oils with a viscosity index permitting their use at any time of year, providing both normal starts at below-freezing temperatures and the requisite viscosity at engine working temperatures was solved by Ye.G. Semenido. He proposed a method of producing special oils (thickened oils) by dissolving a standard fractional compound of various polymer additives that improve solution rheological properties[1] in an low-viscosity oil base (3.5-4 cSt at 100°C) [40].

The use of polymer additives is based on the fact that, when small amounts of these compounds are added to a low-viscosity oil base, the viscosity index of the latter is changed only slightly, while the viscosity of the solution is greatly increased. The foregoing is clarified by the curves in Fig. 12.

Let us assume that a given oil should have a viscosity ν_1 at a working temperature t_{rab}. If this oil is produced by vacuum distillation of mazut, followed by refining, its viscosity at starting temperatures is too high (curve 3). In order to obtain an oil with good low-temperature properties, a low-viscosity oil with a sloping viscosity-temperature curve (1) is used and its viscosity at the

[1]/1172

working temperature is brought ν_1 by dissolving a polymer additive in it.

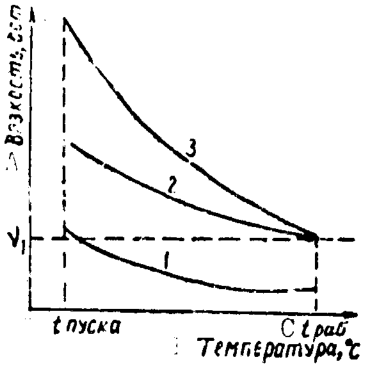


Fig. 12. Viscosity as a function of temperature. 1) Low-viscosity oil; 2) the same oil thickened by polymer additive; 3) ordinary oil. A) Viscosity, cSt; B) t_{puska}; C) t_{rab}; D) temperature, °C.

The so-called thickened oil thus produced, which has the requisite viscosity at t_{rab}, retains a viscosity index (curve 2) close to that represented by curve 1.

The effect involved in producing an oil with good viscosity-temperature properties by thickening a low-viscosity base is due principally to a change in the molecular composition of the polymer, which should provide a very slight thickening effect at low temperatures but a very pronounced one at high temperatures.

The best possible approaches to alteration of the operating properties of thickened oils by selection of effective additives are based on a sufficiently clear understanding of the physicochemical and physicomechanical principles of the thickening action of the additives most widely used at present as thickening agents for motor oils.

On the other hand, experience in the use of motor oils thickened with additives of this type has shown that great attention should be paid to the reversible and irreversible decrease in the viscosity of thickening-additive solutions in oils.

The effectiveness with which polymer additives can be used in motor oils is thus in large measure determined by the possibility of getting a clear idea of the two main action mechanisms of such additives, thickening and destruction, which are closely related.

Investigation of various aspects of the phenomena constituting the basis for the action of polymer additives touches on a number of rather general problems, prime among which are molecular-kinetic and thermodynamic relationships, the rheology of polymer solutions, the structural mechanics of polymer chains from the standpoint of their resistance to different types of energy factors, chemical analysis of polymer systems, and kinetic investigation of the possible transformations in such systems.

Polymer solutions in mineral oils are colloidal solutions of the macromolecules making up the liquid phase. A system of this type also occurs during prolonged interaction of the particles, which leads to their association. W. Ostwald [41] named such systems isocolloids.

A number of researchers support the theory that solutions of polymer additives in mineral oils have a colloidal or isocolloidal structure [39, 40]. However, there are some who feel it improbable that solutions of high-polymer compounds in oils are colloidal in nature. Thus, V.L. Val'dman showed [42] that a positive feature of polymer-containing oils is their less pronounced manifestation of the plasticity and thixotropy characteristic of colloidal systems at below-normal temperatures. It was found that the critical temperatures corresponding to the transition from the state where the solution behaves as a Newtonian fluid to the state where it displays the properties of a non-Newtonian fluid are 10-12° lower for polymer-thickened oils than for ordinary oils.

The thixotropy index, determined from the ratio of the maximum and minimum viscosities with a hysteresis loop, is 3-5 times greater for ordinary oils than for thickened oils.

However, since the experimental data obtained by the authors in question relate to oils differing in chemical nature, the influence of this factor naturally must be taken into account.

There are different interpretations of the mechanism underlying the rise in viscosity. Thus, the effect of polymers [43] is due in part to an additive influence. Polymers themselves are known to have viscosity-temperature curves with small slopes. Some of them, however, produce a greater effect than can be attributed to an additive action.

Evans [44] explained the influence of polymer additives on viscosity index as resulting from the differing solubility of the polymers, which can be in a state of true solution or of colloidal solution, depending on temperature. He advanced the hypothesis that system viscosity is influenced by an associative effect leading to formation of filamentous structures. Thus, there is an abrupt increase in viscosity at the critical point corresponding to the transition to the filamentous state.

A material influence on the variation in the viscosity of thickening-additive solutions is exerted by the change in the energy expended by the fluid stream in overcoming obstacles resulting from the differing shapes of the microparticles. In the simplest case (spherical particles), the increase in viscosity is described by the well-known Einstein equation [46]:

$$\eta = \eta_0 (1 + 2.5 \varphi),$$

where η and η_0 are the viscosities of the solution and medium and

is the portion of the total volume occupied by the particles.

For anisodiametric particles, we introduce a correction not for the subunit size but for the chain length L:

$$\eta = \eta_0 \left(1 + c_1 \frac{L^2}{a^2} \varphi + c_2 \frac{L^4}{a^4} \varphi^2\right),$$

where c_1 and c_2 are constants.

When the solution contains particles carrying an electric double layer, the viscosity is determined by the electroviscosity effect

$$\eta = \eta_0 \left\{1 + k\varphi \left[1 + \frac{1}{\lambda \eta_0 r^2} \left(\frac{\xi\varepsilon}{2\pi}\right)^2\right]\right\},$$

where λ is the electrical conductivity,

ε is the dielectric constant of the system,

ξ is the potential difference of the electric double layer,

r is the mean particle radius, and

k is a constant.

The differing behavior of polymer molecules in solution can be attributed to the fact that they are poorly "solvated," compact, and folded at low temperatures and highly "solvated" and thus elongated at high temperatures [39].

The degree of molecular solvation determines the achievable increase in viscosity index. Solvation is the interbonding of solute molecules and solvent particles. Hence it follows that the viscosity-temperature properties of thickened oils depend both on the characteristics of the polymer additive employed and on the nature of the solvent (low-viscosity base). The differing character of the interaction between polymer molecules and different solvents can be attributed to the fact that the polymer molecules attract one another in a poor solvent; the solvent is forced out of the coil under the action of the intermolecular forces. The average molecule is a mass of small volume. In a good solvent, a long-chain molecule is surrounded by a solvation shell, which prevents contact with other polymer molecules [48, 49]. The average molecule has a chain structure in this case. The polymer thus provides a low system viscosity in the former case and a high one in the latter case.

The effect of temperature on inherent viscosity also varies as a function of solvent nature. An increase in temperature in a poor solvent leads to straightening of the structure and hence to an increase in inherent viscosity, while a rise in temperature in a good solvent leads to a decrease in inherent viscosity.

The thickening effect of a linear polymer in a poor solvent thus increases with temperature.

Certain problems in the structural mechanics of thickening-additive molecules

According to current views, the attractive forces between two neutral micromolecules are essentially caused by a dispersion interaction.

In general form, the total interaction energy U of two particles can be expressed by the formula:

$$U = -\frac{1}{r^6}\left(\frac{r}{3}\frac{p_1^2 p_2^2}{kT} + p_1^2\alpha_2 + p_2^2\alpha_1 + \frac{3}{2}\frac{I_1 I_2}{I_1 + I_2}\alpha_1\alpha_2\right),$$

where r is the distance,

p_1 and p_2 are the dipole moments,

α_1 and α_2 are the polarization coefficients,

I_1 and I_2 are the polarization potentials,

k is Boltzmann's constant, and

T is the temperature.

The recently developed electromagnetic theory of attractive forces, which is the basis of the notion of the interaction of solids through radiative or fluctuating electromagnetic fields, has been extended to the interaction of liquid phases [52]. Polymer molecules, which are essentially characterized by a chain structure, undergo transformations in which their structure can either remain unchanged or be deformed. The aforementioned basic laws of particle interaction are applicable to both cases.

Under definite conditions, we can speak of the elastic properties of molecular structures or of the structural mechanics of chain macromolecules, a class to which thickening-additive molecules belong.

Investigations have been successfully conducted in the structural mechanics of polymers as a result of the development of effective techniques for x-ray diffraction, electron diffraction, and optical (infrared spectroscopy and molecular scattering) analyses.

The structure of polymer chains is characterized by definite interatomic distances, which are determined by the angles between the valence bonds and the structural repetition period.

Investigation of the structure of organic compounds has shown [53] that the minimum potential energy of two noncovalently bonded carbon atoms in organic molecules corresponds to a distance of 3.6 Å. If this distance is shorter, the structure is stressed.

During formation of chain macromolecules, in which the intermolecular bonding results from dispersion forces, their stability is governed by the thermal factor and by the flow-rate gradients.

According to Ya.N. Frenkel' [51], breakage of molecular chains results from weakening of the dispersion forces. The total number N of possible configurations that a linear chain molecule consisting of n subunits can adopt is $N = 2^{n-1}$. When the number of degrees of freedom for subunit arrangement is increased, there is also a rise in the number of theoretically possible isomers.

Not all isomeric configurations are equally probable in thermodynamic terms, so that the configuration corresponding to minimum potential energy is the most stable. Since noncovalently bonded carbon atoms undergo steric repulsion, differently constructed chains are subject to different stresses.

Moreover, the free intramolecular rotation of individual chain-molecule subunits results in formation of complex rotary isomers that produce a continuous transition from one configuration to another.

In addition to formation of rotary isomers, there is an inhibition of intermolecular rotation caused by electrostatic interactions or steric repulsion. This inhibition restricts internal rotation, either making it impossible or causing it to degenerate into vibration about a definite equilibrium position.

The frequency and amplitude of these vibrations are governed principally by the temperature, as can be seen from the expression for the total interaction energy. The vibration frequencies of rotary isomers differ spectrometrically [56].

On the basis of the foregoing, we can conclude that thermal movement promotes formation of clusters of molecular chains, since the statistical equilibrium of systems in which linear and compact configurations are equally probable is shifted toward linear chains at low temperatures and toward clusters at high temperatures.

A number of authors have established that there is a sharp drop in the number of rotary isomers when the temperature is reduced [57-61]. In addition to the intramolecular deformations described above, there are also valence-angle deformations, which enable us to speak of the elastic constants of a tetrahedral valence angle. A.I. Kitaygorodskiy [62] defines the elasticity coefficient of a tetrahedral valence angle as the force necessary to displace a covalently bonded atom by a unit length (1 Å) as a result of a change in the initial equilibrium valence angle ($k' = 0.5 \cdot 10^5$ dyn/cm), from which it can be calculated that $E = 4.92 \cdot 10^6$ kg/cm^2 for the methylene chain.

The theory of long chain molecules developed by Ya.N. Frenkel' [51] is based on their treatment as macroscopic bodies to which the premises of statistical physics and thermodynamics are applicable. Frenkel's theory can be used for molecules having no less than 100 subunits.

According to this theory

$$E = \frac{kT}{a\sqrt{z}},$$

where E is the modulus of elasticity,

k is Boltzmann's constant,

a is a constant (the chain length), and

z is the number of subunits.

The isomeric theory of polymer-macromolecule elasticity [65-67] attributes the elasticity of polymers to internal rotation. M.V. Vol'kenshteyn [63] distinguishes kinetic flexibility, which is a function of temperature and time, from thermodynamic flexibility, which is a function solely of the chain characteristic (cluster size, dipole moment, polarizability, etc.).

Mechanism of polymer destruction in thickened oils

Polymers used as viscosity improvers undergo chemical transformations under the action of heat, light, oxidizing agents, water, mechanical factors, ionizing radiation, etc.

The chemical character of the transformations that take place under the action of the aforementioned factors is governed by the conditions under which they occur and by the polymer structure. The optimum method for stabilizing polymer solutions in the main types of motor oils can be determined only if we know the nature of the reactions to be inhibited and the action mechanism of the stabilizers. Moreover, if we know the structure of a polymer and are able to control it, we can also regulate polymer-destruction reactions.

As is well known, polymer destruction can be caused by various factors, which can be classified as physical (ionizing, mechanical, ultrasonic, thermal, and light) and chemical (oxidizing agents, water, etc.). In both cases, destruction can obviously lead either to breakage of the main polymer chain or to alteration of its structure. It can be assumed that such physical factors as heat, which are the most common types of agent, ultimately induce chemical reactions. The energy concentration under the action of a mechanical factor has a more local character, so that the reactions initiated are more complex.

As is customary in technical literature, the term "depolymerization" is often replaced by "destruction." Since polymerization is the formation of long chain molecules from monomers or a mixture of monomers, depolymerization can mean only the reverse process, i.e., monomer formation.

General Factors in the Mechanism of Viscous-Additive Destruction

Both physical factors and chemical factors, which are governed principally by the oxidative medium, can cause a polymer chain to break or to undergo structural changes, which lead to a change in average molecular weight.

It can be regarded as established that most physically initiated depolymerization reactions proceed by a free-radical mechanism. The heat of depolymerization (the difference in its values, qualitatively explains the differing capacity for depolymerization. If depolymerization reactions proceed by a free-radical mechanism, then endothermal rupture of one C-C bond and endothermal formation of a double bond are energetically conjugated during separation of a monomeric subunit from a polymer chain.

As Lewis and Naylor showed [72], such conjugation occurs during breakage of any other bond if the rupture is followed by ring formation.

In addition to the purely chemical factors governing physically induced depolymerization reactions, one must also take into account the physical state of the depolymerized polymer. Specifically, depolymerization reactions take different pathways when the base in which the polymer is dissolved has different viscosities. Moreover, some influence can be exerted by the factors governing the structure of the polymer chain. For example, polymer structure can be characterized by the presence of a sort of "dislocation" or "weak point." Definite structural elements, which are often present in polymers in very small amounts, serve as such "weak points," where destruction reactions are physically induced or kinetic chains developed. These structural elements may be the terminal groups of the polymer molecules, points of ramification, oxygen-containing groups, etc.

Depolymerization can naturally be affected by catalytic agents present in the lubricating oil during service, etc.

The "weak points" play a substantially less important role during chemical initiation of destruction reactions than during physical initiation, since the effect of a chemically active initiating agent on definite structural groups (having a given chemical affinity for the agent) is of the same type. The course of such reactions obeys the laws of probability.

The overall pattern of depolymerization can be represented in the following manner on the basis of the theory of radical chain processes [73-76].

The reaction is induced by rupture of a carbon-carbon bond in the main chain:

$$M_n \rightarrow P_j^{\cdot} + P_{n-j}^{\cdot},$$
$$M_n \rightarrow P_{n-j}^{\cdot} + P_i^{\cdot} \text{ (terminal group)},$$

where M_n is the initial polymer macromolecule (with n subunits) and

P_j is the polymer radical (with j subunits).

Initiation can also occur as a result of rupture of weak bonds. Intramolecular chain transfer is considered to be a case of monomer detachment:

$$P_i \rightarrow P_{i-1} + M_1 - \text{monomer detachment}$$
$$P_i + M_n \rightarrow M_i + P_j + M_{n-j} - \text{chain transfer}$$
$$P_i + P_j \rightarrow M_i + M_j - \text{chain detachment}$$

If k is the bond-rupture rate constant and

α is the proportion of bonds broken,

$$\alpha = 1 e^{-kt} = 1 - e^{\tau},$$

the average residual macromolecule length is:

$$\overline{cL}_n(\tau) = \frac{n + \alpha(n - L)(L - 1)}{1 + \alpha(n - L)},$$

where L is the number of monomeric units in the shortest macromolecule.

The chain length during depolymerization is determined in the following manner:

$$\frac{1}{\varepsilon} = \frac{v_p + v_n + v_0}{v_n + v_0},$$

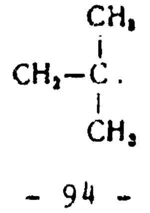
where $1/\varepsilon$ is the chain length and v_p, v_n, and v_0 are the probabilities of growth, transfer, and detachment respectively.

The tabular arrangement below gives the number of monomeric units for certain polymers, determined from the distance between the site of radical formation and the site of kinetic-chain detachment (*zip*) and calculated for thermal depolymerization:

Polymer	Monomer yield, %	L_{zip} (min)
Polymethylmethacrylate	>>95	>>200
Polyisobutylene	20	3.1
Polystyrene	40	3.1

Analyzing the depolymerization of polyisobutylene from the standpoint of the theory presented above, the broad range of molecular weights for the mixed thermal-destruction products and the low monomer yield noted in a number of investigations [77] can be explained in the following manner.

The two methyl substituents (CH_3 have a less marked stabilizing effect on the polymer radical than, for example, a substituent such as C_6H_5, which is present in the polystyrene macromolecule and, as can be seen from the data given above, is characterized by higher monomer yield. The radical



is sufficiently reactive to detach a hydrogen atom from the methylene groups of the macromolecule at a rate commensurable with the monomer-formation rate.

When we compare the behavior of polyisobutylene and polystyrene, it can be seen that the same effect is produced by the following combinations:

a high reactivity for the radical and a low reactivity for the H atoms on the secondary C atoms;

a low reactivity for the radical and a high reactivity for the H atom on the tertiary C atom of the macromolecule.

Cases in which the depolymerization products participate in new reactions are of practical significance for evaluating the ultimate results of polymer destruction in solutions.

Since, for example, the intermediate products in polymerization and depolymerization reactions are the same radicals, there should be a definite kinetic and thermodynamic equilibrium in the system. A number of authors have studied this equilibrium and it has been shown that the following processes are possible after formation of an active radical $R^{\cdot}$: a) chain growth, ramification with subsequent attachment of a monomer to the radical, formation of crosslinkages, etc. (polymerization); b) detachment of a monomer from the chain, chain rupture, decomposition of the hydrogen peroxide formed as a result of the reaction with oxygen, formation of initiating radicals, etc.(depolymerization).

Monomer detachment from the chain has a comparatively low activation energy, usually 18-25 kcal/mole, i.e., the process can occur with sufficient speed at 100°C. It is possible, however, for the reaction-initiation stage to have a higher activation energy.

As recent research has shown, the equilibrium of polymerization and depolymerization represented by polymerization and depolymerization curves tending toward a definite viscosity [78] is only a special case.

There is also a maximum temperature above which polymerization ceases or formation of unstable complexes takes place:

$$T_c = \frac{\Delta H}{2.303\, R \lg\left[\frac{A_1}{A_2}(M)\right]},$$

where ΔH is the thermal effect of polymerization.

Forces acting on the macromolecule in shear also cause rupture of the polymer chain. The relaxation phenomena observed in the system indicate that only the molecular aggregates are broken down, the structure of the molecules themselves remaining unchanged. Evaluation of depolymerization from the change in system viscosity therefore does not give a complete representation of the phenomenon.

Ultrasound, for example, can produce a reversible decrease in viscosity but an irreversible decrease is also possible. There is naturally no chain rupture in the first case, but this process does occur in the second case.

Macromolecule rupture under the action of mechanical forces is due to the stresses applied to the macromolecule as a result of rapid vibration or of oscillation of cavitation "cavities" in the solution.

Destruction has been explained as resulting from the action of the frictional forces between the solvent and the dissolved polymer [95]. Cases of destruction during cavitation [96] and under the action of ultrasound [97] in the presence of gases have been described. It has not been proved that destruction occurs under these conditions when no cavitation is present. The initial investigations of the action of ultrasound on polymer solutions proceeded from the fact that oxidation is a part of ultrasonic destruction (the process is activated by molecular oxygen).

It has been shown, however, that the effects obtained in air, nitrogen, and oxygen atmospheres at atmospheric pressure are almost identical, all other conditions being equal.

Investigation of the influence of ultrasound frequency on destruction [99, 100] has shown that the destruction rate is independent of frequency over the range 10-286 kHz, while the process is most efficient at 906 kHz and least efficient at 404 kHz over the range 906-404 kHz and at 232 kHz. The latter phenomenon is attributable to the simultaneous effect of the polymerizing capacity of ultrasound vibrations.

Bond Rupture

The great inertia of molecules having high molecular weights causes substantial forces to act on them.

The dependence of the bonding rate dx/dt on the average chain length P can be described by the equation [101]:

$$\frac{dx}{dt} = kN(P - P_f),$$

where k is a constant,

N is the Avogadro number, and

P_f is the maximum chain length during prolonged ultrasonic irradiation.

Jellinek and White [102, 103] calculated the average and weighted-average chain length during depolymerization. If

P_N is the average chain length,

P_n is the initial chain length, and

P_e is the maximum chain length at which the macromolecule is no longer capable of destruction,

$$P_N = \frac{P_n}{2P_e\left\{\frac{P_n-P_e-1}{P_e+1}[(1-\alpha)^{P_e+1}-1]-\frac{P_n-P_e}{P_e}[(1-\alpha)^{P_e}-1]\right\}-\alpha(1-\alpha)^{P_n-2}+(1-\alpha)^{P_e}[1+\alpha(P_n-P_e-2)]]}$$

$$\alpha = 1 - e^{-kt}$$

(k is the bond-rupture rate constant for molecules having a length $> P_e$); at $t \to \infty$, $\alpha = 1$ and

$$P_N = \frac{P_e+1}{2}$$

(here P_N is equivalent to P_f).

The weighted-average chain length is calculated in similar fashion:

$$P_w = \frac{2P_e^3}{3P_n}\left\{\frac{P_n-P_e-1}{P_e+1}[(1-\alpha)^{P_e+1}-1]-\frac{P_n-P_e}{P_e}[(1-\alpha)^{P_e}-1]\right\}+$$
$$-\frac{(1-\alpha)^{P_n-2}}{P_n}\left[\frac{2}{\alpha^2}-(P_n-1)^2\right]-$$
$$-\frac{(1-\alpha)^{P}}{P_n}\left\{\frac{2}{\alpha^3}-(P_n-P_e-2)\left[\frac{2}{\alpha}+\alpha(P_e-1)^2\right]-\right.$$
$$\left.-(2P_n-P_e-3)(P_e+1)\right\}+P_n(1-\alpha)^{P_n-1}.$$

The maximum molecular weight in this case is

$$P_w = \frac{2P_e}{3}.$$

Having determined P_w experimentally, P_e can be calculated for a given polymer solution. Knowing P_e and the initial molecular weight P_n, we can find $P_w = f(\alpha)$. Comparing the function $P_w = f(\alpha)$ with the experimental curve for $P_w = f(t)$ and proceeding from the corresponding values of t and α, we can find k.

The weighted-average molecular weight is calculated from Shtaudinger's formula

$$[\eta] = kM,$$

where $[\eta]$ is the characteristic viscosity,

M is the molecular weight, and

$k = 8.0 \cdot 10^{-3}$.

Low-temperature depolymerization conditions can be characterized in the following manner. When the main macromolecular chains are broken, the radicals formed cannot diffuse over any great distance or participate in secondary reactions leading to formation of stable molecules. Moreover, there is also a decrease in the shear forces, which affect macromolecular destruction, when the temperature is raised.

Use of viscosity improvers

The viscosity improvers known at present include polyisobutylenes, polymethacrylates (akrilonds), vinyl-ester polymers (vinipols), the copolymer of isobutylene with styrene synthesized at the INKhP Academy of Sciences Azerbaydzhan SSR (INKhP-20 additive), etc.

Satisfactory solubility in lubricating oil, resistance to thermal and mechanical destruction, and high thickening capacity are the properties required in a polymer used as a viscosity improver. Moreover, polymer additives should combine well with the additives generally employed to improve oil properties and should not be corrosive.

The principal characteristic of any polymer additive is its molecular weight, which governs its destruction resistance, solubility, and thickening capacity. Viscosity improvers are usually described by their average molecular weight, as determined by Shtaudinger's viscosimetric method [106]. Assuming that the viscosity of a polymer solution increases in direct proportion to its molecular weight, Shtaudinger proposed the following equation for polymers with filamentous molecules:

$$M = \frac{\eta_{уд}}{ck_m},$$

where η_{ud} is the specific viscosity, defined as

$$\eta_{уд} = \frac{\eta - \eta_0}{\eta_0},$$

η is the viscosity of the thickened oil in cSt,

η_0 is the base viscosity at the same temperature in cSt,

c is the polymer concentration in "basic" moles per liter, and

k_m is the polymer constant, which depends on the nature of the polymer and solvent.

The average molecular weight of the polymer is determined from this equation

Shtaudinger's principle is usually simplified by determining the viscosity (cSt) of a 30% polymer solution in toluol at 37.8°C as a function of relative molecular weight.

V.I. Sharapov [107] employed isooctane ($k_m = 1.75 \cdot 10^{-4}$) or carbon tetrachloride (k_m = $3.0 \cdot 10^{-4}$) as the solvent for calculating the molecular weight of isobutylene and evaluated *c* as

$$c = \frac{q \cdot 1000}{v \cdot 56{,}06},$$

where *q* the weighed portion of polyisobutylene,

56.06 is the molecular weight of isobutylene, and

v is the solvent volume.

Polyisobutylene produced commercially in accordance with Technical Specification MKhP (МХП) 1761-54 r is widely employed in the Soviet Union as a viscosity improver. S.S. Nametkin and M.R. Rudenko brought about synthesis of this compound in the USSR.

TABLE 42

Fractional [illegible]ition of Polyisobutylene with Different Ave[illegible] Molecular Weights

1 № фракции	2 Средний молекулярный вес					
	30 000		20 000		15 000	
	3 Мол. вес фракции	4 Колич. фракции, %	3 Мол. вес фракции	4 Колич. фракции, %	3 Мол. вес фракции	4 Колич. фракции, %
1	61 000	4,92	28 000	43,65	30 000	9,40
2	50 000	32,80	17 002	25,46	25 000	22,27
3	31 000	23,39	13 800	7,78	18 000	27,47
4	25 000	8,94	10 590	9,60	15 200	8,22
5	17 000	7,58	5 500	7,44	13 000	10,71
6	13 000	5,44	5 Остаток	4,80	9 000	7,61
7	8 500	3,42	"	—	7 000	7,07
8	4 000	10,82	"	—	5 Остаток	7,16

1) Fraction No.;
2) Average molecular weight;
3) Molecular weight of fraction;
4) Amount of fraction, %;
5) Residue.

The polymer is obtained by polymerization of isobutylene, $CH_2 = C(CH_3)_2$, in the presence of a catalyst (boron trifluoride or aluminum chloride).

The polyisobutylene molecule is linear and the structure of its main chain has the form

$$\ldots-C(CH_3)_2 \cdot CH_2 \cdot C(CH_3)_2 \cdot CH_2-\ldots$$

For practical convenience, this additive is often produced in the form of a 20% solution in oil (paraton) abroad.

Fraction-composition uniformity is of great importance for the operating properties of viscosity improvers, since the presence of high-molecular fractions reduces the destruction resistance of the additive, while low-molecular fractions reduce its thickening capacity.

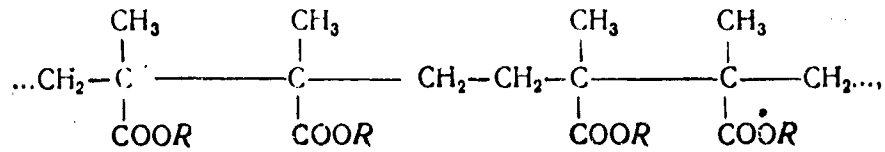
Table 42 shows the typical fraction composition of polyisobutylene with different average molecular weights.

The fraction composition of polyisobutylene with an average molecular weight of 20,000 is more homogeneous and therefore more suitable for viscosity-improvement purposes. This composition is used in producing commercial AK3 -6 and AK3 -10 oils at the Bakinskoye NPZ imeni XXII S"yezda KPSS [Petroleum Refining Plant imeni 22nd CPSU Congress].

Polymethacrylates are now being widely used as viscosity improvers (especially abroad, where they account for 50% of all polymer additives [14]). An important advantage of polymethacrylates over polyisobutylenes is the fact that they can produce a large increase in oil viscosity index when used in lower concentrations and in the form of lower-molecular polymers.

Polymethacrylates are produced by polymerization of esters of methacrylic acid, $CH_2 = CCH_3COOR$ in the presence of a catalyst (benzyl peroxide).

The polymethacrylate-macromolecule chain has the structure



where *R* are aliphatic radicals with from 4 to 22 carbon atoms.

Two types of polymethacrylates synthesized by Prof. Potolovskiy et al. have come into use in the USSR: polymethacrylate B (viscosity improver) and polymethacrylate Д (depressor).

A.M. Kuliyev et al. have suggested the product of the low-temperature copolymerization of isobutylene with styrene in the presence of aluminum chloride as a viscosity improver [108]. The isobutylene polymers obtained under these conditions had a molecular weight of 18,100-23,000, while the isobutylene-styrene copolymer had an average molecular weight of 11,700-22,000. The thickening capacity and viscosity index of these compounds were similar to and, in a number of cases, exceeded those of commercial polyisobutylene with a molecular weight of 17,000. The authors assumed that copolymers containing aromatic styrene rings would be more resistant to destruction.

A viscosity additive based on this principle (INKhP-20) is now undergoing thorough testing.

The increase in viscosity index is determined by the solubility of the polymer in the oil, which is evaluated from the ratio of the specific viscosity to the polymer concentration in the solution. This quantity has low values (from 0.01 to 0.10) for low-solubility polymers, which cause a large increase in viscosity index, and is higher (0.10-0.25) for soluble polymers, which produce only a slight rise in viscosity index.

This property can be utilized by adding to the polymer solution a poor oil-missible solvent that combines with the polymer, thus reducing the overall solubility of the latter.

Evans and Joung [109] made a thorough investigation of the partial solubility of a polymer in various oils having viscosity indices of from 13 to 111. They observed no precipitation of the polymer from solution when they added 10% paraton (polyisobutylene) and different amounts of compounds with no solvent action to the oils.

Some compounds have a specific effect, reducing the solution viscosity of 37.8°C with respect to its viscosity at 98.9°C, which caused a large increase in viscosity index. The authors attributed this phenomenon to the abrupt drop in polyisobutylene solubility at low temperatures when such compounds as (β-butoxyethyl)-phthalate, *n*-butylphthalate, or triethylene glycol-di-(2-ethylbutyrate) are added to the base.

This property has found practical application in a patent for a mixture of two polymers: polyisobutylene and polymethacrylate [120]. The patent uses a high-paraffin oil (with a viscosity of 5.1 cSt at 98.9°C) as the base, with 3% polyisobutylene (having a molecular weight of 12,000), 3% polymethacrylate (having a molecular weight of 17,000), and 12% of a product with no solvent action (dibutoxyethylphthalate) added. Use of the latter compound produces a sharp rise in viscosity index, as a result of the different critical solubility temperatures for the two polymers.

Polymer additives that, in addition to improving the viscosity index of oils, also give them other properties, such as detergent characteristics, have recently appeared. An important advantage of these additives is the fact that they contain no metals, thus being ash-free.

The recent use of oils with high contents of ordinary (metal-containing) additives in highly supercharged fuel-injection engines has resulted in the formation of substantial ash deposits on the working surfaces of the exhaust valves, which leads to poor fit and scorching. Operation of such engines with oils having high-ash additives is impossible. Development of highly effective ash-free additives is naturally of great importance.

Stability of Viscosity Improvers

Viscosity improvers have very little effect on oil properties other than viscosity and viscosity index. However, these additives have a tendency to break down under the action of high temperatures (200-250°C) and large shear stresses, since polymers of high molecular weight having very long chains rupture to form polymers having shorter chains under the action of definite energy factors, these fragments not being as effective as viscosity improvers.

TABLE 43

Change in Viscosity of Oil and Polyisobutylene Constituent

[1] Продолжительность работы, ч	[2] Масло на основе соляро-веретенных фракций с 3% полиизобутилена			
	[3] Вязкость при 100°C, *ccm*	[4] Колич. полиизобутилена, %	[5] Мол. вес	[6] Уменьшение мол. веса, %
0	13,9	3	21800	9
10	—	—	—	—
20	11,1	3,7	19900	9
30	—	—	—	—
41	11,9	3,6	17900	18

1) Operating time, h;
2) Oil based on solar-spindle fractions, containing 3% polyisobutylene;
3) Viscosity at 100°C, cSt;
4) Amount of polyisobutylene, %;
5) Molecular weight;
6) Decrease in molecular weight, %.

TABLE 44

Change in Viscosity of AC3п-6 and AC3п-10 Oil

[1] Продолжительность работы, ч	[2] Масло АС3п-10		[2] Масло АС3п-6	
	50°	100°	50°	100°
0	63,6	11,26	31,7	7,13
51	72,06	11,80	34,7	7,57

1) Operating time, h; 2) Oil.

Although the viscosity of oils containing viscosity improvers is reduced by high temperatures, vigorous agitation, and shear forces, the decrease is very small and is of no practical significance when such oils are used under normal engine-operating conditions [110]. Let us demonstrate this with an example.

Table 43 presents data on the change in the viscosity of a working oil and its polyisobutylene constituent, having a molecular weight of 20,000, in an B-2 engine [111], while Table 44 gives data on the change in the viscosity of AC3п-6 (AC-5 with 1% polyisobutylene and 10% CБ-3 additive) and AC3п-10 (AC-6 with 1% polyisobutylene and 10% CБ-3 additive) oils during operation in ГАЗ-51 engines during 600-hour stand test.

It can be seen from the data cited that polyisobutylene in an oil operating in an B-2 diesel under a relatively high load undergoes negligible destruction. No decrease in the viscosity

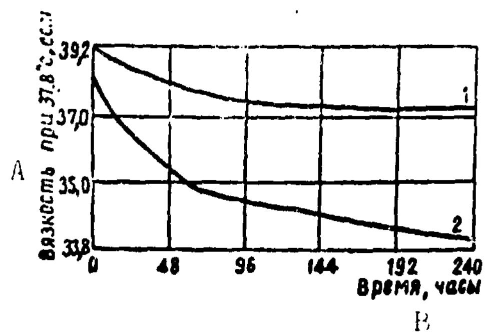


Fig. 13. Stability of thickened oils under the action of shear stresses. 1) Oil containing 2.5% by weight viscosity improver; 2) oil containing 6% by weight viscosity improver. A) Viscosity at 37.8°C, cSt; B) time, h.

of the thickened oils was generally detected in an ГАЗ-51 engine operating under large stand loads and at high temperatures. The normal oil-oxidation process and the associated rise in viscosity evidently cancelled the drop in viscosity resulting from polyisobutylene destruction.

The possibility of operating engines with oils containing thickening additives (polyisobutylene) without any material decrease in oil viscosity has, however, not lessened interest in procedures for laboratory evaluation of the destruction resistance of polymer additives. Such procedures would be especially helpful in comparative studies of this index in new polymer additives and in evaluating the influence of special stabilizing additives and multipurpose additives on polymer stability.

The literature describes different methods for evaluating the depolymerization resistance of viscosity improvers. Dzhordzhi [110] used a vaporization chamber with a capacity of 0.028 m^3 connected to the intake of a circulation pump, whose exhaust was then connected through a vaporization nozzle to the chamber. The nozzle has 6 apertures 2 mm in diameter and was 20 mm long. Using a pressure of 2.8-3.5 kg/cm^2 and a temperature of 60-65°C, 1.5 liters of oil was circulated for a prolonged period (240 h) at a rate of 210 liters/min.

Figure 13 shows the results of tests conducted by the method described above on two oils containing viscosity improvers.

Although the viscosity loss resulting from decomposition of the polymers was small in both cases, it can be seen that polymer 1 was more resistant to mechanical destruction than polymer 2.

An apparatus using the fuel pump of a Д-40 diesel engine is employed at the INKhP to evaluate the resistance of thickening additives to mechanical destruction. The tests are conducted in the following manner. A total of 500 cm^3 of the oil to be tested is poured into a tank holding about 1.0 liter, its temperature being automatically maintained at 60°C. The oil is picked up from the tank by a piston booster pump and supplied to a 4-plunger high-pressure fuel pump, which forces it through four pivot-type vaporizers adjusted to a delivery pressure of 150 kg/cm^2. The oil sprayed by the vaporizers flows into the tank and the cycle is repeated. The apparatus operates with a three-phase electric motor with a power of 1.0 kW and the pump speed can be varied.

The shear resistance of the polymer was determined by measuring the decrease in oil viscosity at 50°C, as a percentage of the initial viscosity, for which purpose 20-cm^3 samples were taken after 15 min and every hour thereafter.

The shear-speed gradient that developed under the experimental conditions was about 10^7 s^{-1}. The greatest drop in oil viscosity with this large a shear-speed gradient occurred during the first 15 min of the experiment, but the viscosity stabilized after the apparatus had been operating for 4 h. This made it possible to reduce the test time to 4 h.

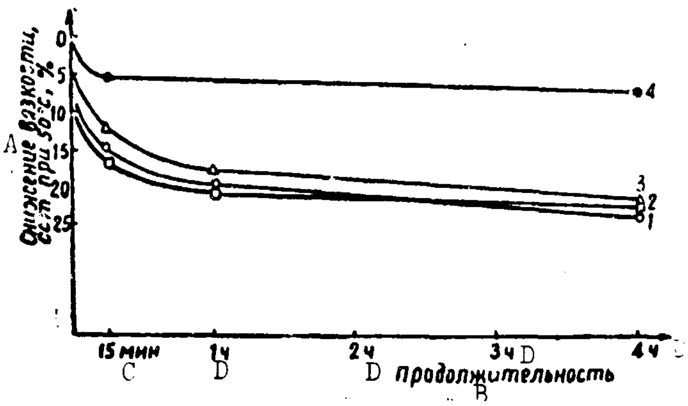


Fig. 14. Results of tests for resistance to mechanical destruction. 1, 2, 3) Spindle oil containing 3% polyisobutylene; 4) AK-10 oil containing 2.4% isobutylene-styrene copolymer. A) Decrease in viscosity, cSt at 50°C, %; B) time; C) min; D) h.

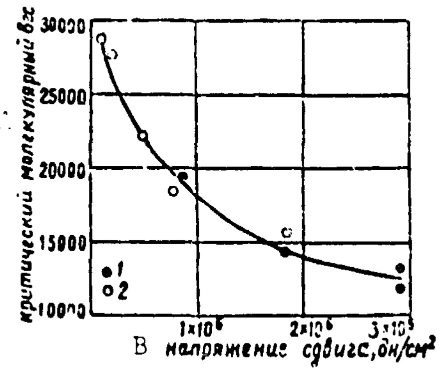


Fig. 15. Critical molecular weight of polymer as a function of shear stress. 1) MK-22 oil + 5% polyisobutylene (M = 21,000); 2) MK-8 oil + + 20% polyisobutylene (M = 30,000). A) Critical molecular weight; B) shear stress, dyn/cm^2.

The reproducibility of the test results was completely satisfactory. Thus, when the experiment with type 3 spindle oil thickened with 3% polyisobutylene (having a molecular weight of 17,000) was repeated three times, the decrease in viscosity over the experimental period was 23.8, 21.5, and 22.1%, with a maximum deviation of 6% from the average.

Figure 14 shows curves illustrating the results of test conducted on several oil specimens by the method described above.

The isobutylene-styrene copolymer synthesized at the INKhP (with a molecular weight of 7800) is noteworthy, since it proved to be the most resistant to mechanical destruction when mixed with AK-10 oil. (Experiments were conducted to evaluate the destruction resistance of AK-10 oil containing thickening additives in order to determine the feasibility of using such oils as all-weather transmission oils.)

K.I. Klimov and P.P. Zarudniy [112] conducted an interesting investigation of the mechanical destruction of polyisobutylene. By subjecting narrow polyisobutylene fractions with average molecular weight of 30,000, 22,600, 21,000, 16,000, 14,000, and 9000 to shear stresses of different magnitudes in a rotary apparatus of the type devised by V.A. Pavlov [113], they established that, during destruction with a given shear stress, the molecular weight of the polymer decreases and tends toward a definite value, which is constant for the stress in question. Each shear stress corresponds to a definite critical molecular weight for the polymer.

Use of a polymer with a molecular weight above the critical level causes it to undergo mechanical destruction to the molecular weight stable at the shear stress employed. These authors showed that the extent of destruction depend solely on the shear stress (and not on the shear-speed gradient, although the destruction rate increases as this factor rises).

The relationship between the critical molecular weight and the shear stress in the oil stream was also determined (see Fig. 15).

As has already been pointed out, polymer additives also undergo thermal depolymerization. In some cases, heating of oils thickened with such additives to 150-200°C and holding at this temperature for prolonged periods leads to a marked decrease in oil viscosity as a result of polymer destruction.

Thermal depolymerization can be substantially reduced by addition of stabilizers that prevent breakdown of the polymer molecules, such as tertiary amylphenol sulfide [114].

Ye.G. Semenido and N.I. Kaverina [114] proposed a method for evaluating the resistance of polymer additives to thermal destruction, which was subsequently modified by N.V. Shchegolev [27]. This modified procedure is employed at the InKhP.

The procedure basically runs as follows: weighed 10-gram portions of the product to be tested, poured into test tubes 18 mm in diameter and 260 mm long, are immersed in an oil bath at 200°C and held at this temperature for 12 h. The change in oil viscosity during the experiment is used to calculate the so-called viscosity-stability index [VSI](ПСВ) from the formula

$$\text{ПСВ} = \frac{\nu_{100}^{\text{конеч}}}{\nu_{100}^{\text{исходн}}} \cdot 100\%,$$

where $\nu_{100}^{\text{iskhodn}}$ is the viscosity of the initial oil at 100°C and

$\nu_{100}^{\text{konechn}}$ is the viscosity at 100°C after a 12-hour experiment.

This technique can also be used to evaluate the influence of multipurpose additives on polymer-containing oils, from the standpoint of compatibility.

Most multipurpose additives are known to have a stabilizing effect on polymers during high-temperature service. Nevertheless, there are additives that cause a sharp drop in viscosity or gel formation when added to thickened oils (principally those thickened with polymethacrylate). In cases of the latter type, the additives are said to be "incompatible" with the polymer.

Table 45 presents the results of tests conducted by the method described above on oils thickened with polyisobutylene and polymethacrylate mixed with various additives.

The data in the table indicate that polyisobutylene is sufficiently resistant to thermal destruction and is highly compatible with all the multipurpose additives tested. All the additives tested had a greater or lesser stabilizing effect on the resistance of polyisobutylene to thermal destruction, bringing the PSV to 98% in a number of cases (3% СБ-3 and 2% ДФ-11, АзНИИ-8).

A different pattern was obtained in evaluating the thermostability of polymethacrylate and its compatibility with additives (Table 46). Thus, use of the additives ЦИАТИМ-339 and ИП-22К lead to gel formation during the initial period of the tests, use of ВНИИ-360 caused a large (by a factor of 10) rise in viscosity, and use of ВНИИ-353 and ДФ-11 lead to a substantial drop in viscosity. These additives are thus incompatible with polymethacrylate.

The additives АзНИИ-5, АзНИИ-7, АзНИИ-8, СБ-3, and АзНИИ-ЦИАТИМ-1 are completely compatible with polymethacrylate, most of them having a stabilizing effect on the polymer.

S. Sirtori [115] also describes gel formation when a thickened oil containing an additive of the zinc dialkyldithiophosphate type is heated to 280°C and then cooled.

Ye.G. Semenido [2] has pointed out the relationship between this phenomenon and the chemical structure of polymethacrylates and multipurpose additives, assuming that the presence of divalent metals (barium and calcium) in the additives is of prime importance in this case.

Actually, the work of N.F. Poshlyakova et al. [116] showed that gels are formed when divalent-metal oxides are added to solutions of copolymers of metal methacrylate and methacrylic acid, as a result of salt-bond formation and of the physical interaction

TABLE 45

Evaluation of Resistance of Polyisobutylene to Thermal Destruction in Presence of Multipurpose Additives

1 Масло и присадка	2 Вязкость масла при 100° С, сст				5 ПСВ, %
	3 исходная	4 после нагрева, ч			
		3	6	12	
6 АС-6 с 1% полиизобутилена	10,96	—	—	10,37	94,6
7 То же + 2,5% БФК + 2,5% СБ-3	11,19	—	—	10,59	95,0
7 То же + 2,5% БФК + 2,5% СБ-3 + +2% ДФ-11	11,20	—	—	10,76	97
7 То же + 3% СБ-3 + 2% ДФ-11	10,77	—	—	10,45	98
8 Турбинное А + 5% полиизобутилена	30,2	29,8	28,8	27,6	91,5
7 То же + 3% АзНИИ-4	30,3	29,4	29,4	28,4	94,0
» + 3% АзНИИ-5	29,8	29,4	29,0	28,3	95,0
» + 3% АзНИИ-7	30,0	29,9	29,9	29,0	96,5
» + 3% АзНИИ-8	29,7	29,8	30,0	29,1	98,0
» + 3% АзНИИ-ЦИАТИМ-1	29,8	29,4	28,4	28,4	95,2
» + 3% ДФ-1	28,7	28,2	28,0	27,8	98,0

1) Oil and additive;
2) Oil viscosity at 100°C, cSt;
3) Initial;
4) After heating, h;
5) VSI, %;
6) With 1% polyisobutylene;
7) The same;
8) Turbine A + 5% polyisobutylene.

TABLE 46

Compatibility of Polymethacrylate B with Multipurpose Additives in Spindle Oil

1 Образец	2 Вязкость при 100° С, сст				5 ПСВ после 12 ч %	6 Заключение о совместимости
	3 до нагревания	4 после нагревания, ч				
		2	6	12		
7 Масло с 5% полиметакрилата	9,60	9,37	8,52	7,92	82,5	10 —
8 То же + 3% ЦИАТИМ-339	19,50	32,9	Гель 9	Гель 9	Гель 9	Несовместима
» + 3,5% ВНИИ-360	33,1	48,5	41,9	34,8	363	То же 8
» + 4,5% НП 22к	20,8	Гель 9	Гель 9	Гель 9	Гель 9	11 »
» + 3% АзНИИ-5	9,90	9,96	9,09	8,62	89,8	Совместима
» + 3% АзНИИ-7	10,1	14,7	9,38	8,35	87,2	»
» + 3% АзНИИ-8	10,8	12,3	9,43	8,58	89,4	»
» + 3% СБ-3	11,6	10,8	8,18	7,35	76,7	»
» + 3% АзНИИ-ЦИАТИМ-1	10,0	9,74	9,89	9,61	100	10 »
» + 3% ВНИИ-353	10,3	5,23	5,04	4,78	49,8	Несовместима
» + 2% ДФ-11	10,3	8,07	6,90	6,85	71,5	То же 8

1) Specimen;
2) Viscosity at 100°C, cSt;
3) Before heating;
4) After heating, h;
5) VSI after 12 h, %;
6) Compatibility;
7) Oil with 5% polymethacrylate;
8) The same;
9) Gel;
10) Incompatible;
11) Compatible.

of the polar salt groups, which are poorly soluble in the solvent used.

Combination of different amounts of salt groups produces cluster-like structures that organize the vacant points of the lattice structure, i.e., gel formation occurs.

The foregoing indicates the importance of evaluating the compatibility of viscosity improvers and multipurpose additives in each individual case.

Influence of Polymer Additives on Carbon-Deposit Formation in Engines

The development of carbureted engines with high compression ratios raised the problem of reducing carbon-deposit formation on the cylinder-piston components, since such deposits cause self-ig-

TABLE 47

Results of Tests by ИДМ-10-Ф Method

1 Показатели	АС-6		2 АС-6, загущенное полиизобутиленом		3 Д-11 товарное	
	17 Абс. результат	18 Баллы	17 Абс. результат	18 Баллы	17 Абс. результат	18 Баллы
4 Подвижность колец	19 Все свободны	0	19 Все свободны	0	19 Все свободны	0
5 Лак на юбке поршня, баллы	2,0	1,0	2,0	1,0	2,0	1,0
6 Нагары, г						
7 всего на поршне без днища	0,476	0,48	0,441	0,44	0,666	0,67
8 с 1-ой канавки и 1-го кольца	0,[illegible]76	0,33	0,161	0,80	0,121	0,60
9 со 2-ой канавки и 2-го кольца	0,014	0,17	0,018	0,090	0,032	0,16
10 с остальных канавок и колец	0,070	0,14	0,106	0,53	0,064	0,32
11 с бурта	0,019	0,10	0,020	0,10	0,014	0,07
12 с днища	0,22	0,22	0,27	0,27	0,08	0,08
13 с перемычек	0,003	0,01	0,006	0,03	0,004	0,02
14 Износ поршневых колец	0,095	0,48	0,034	0,17	0,126	0,63
15 Коррозия свинцовых пластин	2	0,02	0	0	1	0,01
16 Моторный индекс, баллы		2,90		3,42		3,56

1) Index;
2) AC-6 thickened with polyisobutylene;
3) Commercial Д-11;
4) Ring mobility;
5) Tars on piston skirt, points;
6) Carbon deposits, g;
7) Total from piston, exclusive of face;
8) First groove and first ring;
9) Second groove and second ring;
10) Remaining grooves and rings;
11) Shoulder;
12) Face;
13) Rod;
14) Piston-ring wear;
15) Lead-plate corrosion;
16) Motor index, points;
17) Absolute result;
18) Points;
19) All free.

nition of the working mixture and detonation and increase the fuel octane number required by the engine.

It was suggested that deposit formation could be reduced by using narrow light fractions thickened with viscosity improvers as motor oils.

Raymond and Socolofskiy [117] demonstrated that thickened oils have a favorable effect from the standpoint of deposit formation even when the engine has been previously contaminated.

W. Sweeney et al. [118] showed that, all other operating conditions being equal, use of thickened SAE 10W-30 oil reduces the amount of deposits by 42% in comparison with that observed for ordinary SAE-30 oil. However, this effect does not always occur: the type of polymer used is of great importance. According to the data of T. Salomon [39], there are polymers that themselves form deposits and increase the octane number required. For example, N.G. Puchkov [121] states that thickened oils require an increased (by a factor of about 1.5) detergent-additive concentration, as a result of the greater carbon-deposit formation in the engine produced by the partial thermal depolymerization of the viscosity improver and subsequent oxidation of its decomposition products.

In order to study the influence of polyisobutylene used as a viscosity improver on carbon deposition on engine components, several 10-hour tests with an ИТ-9/3 engine were conducted at the INKhP by the procedure used for engine testing of additive-free base oils (the ИДМ-10-Ф method) [119]. The tests were carried out with a coolant temperature of 150°C and an oil temperature of 85°C.

The procedure described above was used to evaluate the following specimens: commercial AC-6 oil from Bakinskoye crude petroleum, the same oil thickened with polyisobutylene to 11.5 sSt, and commercial Д-11 oil produced by the Zavod im. XXII S"yezda [22nd Congress Plant].

As is well known, Filippov's method provides for overall evaluation of oil engine properties in points (the so-called motor index), which constitutes the sum of separate evaluations of the cleanness of different areas of the pistons, ring mobility and wear, and the corrosion of a lead plate placed in the crankcase.

The results of the tests are given in Table 47.

As can be seen from the data in this table, addition of polyisobutylene had almost no effect on carbon deposition on the cylinder-piston components. In the case of both AC-6 oil without the polymer additive and of the thickened oil, the carbon deposition was somewhat less than when equally viscous thickened (at 100°C) Д-11 commercial diesel oil was used.

The results obtained give us grounds for assuming that the requirement of polyisobutylene-thickened oils for a higher additive concentration is due not to thermal depolymerization of the thickener molecules, as N.G. Puchkov stated, but to the reduced

TABLE 48

Results of Laboratory Evaluation of Thickened Oils

(1) Образцы: (2) присадки	(3) масла	(4) $T_{250}°$, мин	(5) Осадок, %	(6) Коррозия по НАМИ, г/м²	(7) Щелочность, мг КОН
4% Монто-613 (8) + 025% Сантолюб-493 (9)	Веретенное-3 (10)	48	10,8	1,4	2,75
	То же с полиизобутиленом (11)	71	9,76	5,65	2,19
	Д-11	51,5	8,47	6,0	2,96
9% Монто-613 (8) + 0,7% Сантолюб-493 (9)	Веретенное-3 (10)	76	10,9	1,75	6,36
	То же с полиизобутиленом (11)	110	8,0	0,95	5,01
	Д-11	103	5,47	Отсутствует (12)	6,45
8% БФК	Веретенное-3 (10)	22	10,5	190	4,96
	То же с полиизобутиленом (11)	40	8,42	166	4,53
	Д-11	48	4,0	41,3	—
8% СБ-3	Веретенное-3 (10)	8,5	11,8	416	0,80
	То же с полиизобутиленом (11)	11,5	8,98	415	0,70
	Д-11	26	10,0	274	—
5,2% БФК+2,8% СБ-3+1,2% ИНХП-21+0.00 5,% ПМС-200А	Веретенное-3	—	13,1	—	3,44
	То же с полиизобутиленом	—	11,54	—	3,29

1) Specimens;
2) Additive;
3) Oils;
4) min;
5) Deposits, %;
6) NAMI corrosion, g/m²;
7) Alkalinity, mg KOH;
8) Monto;
9) Santolyub;
10) Type 3 spindle;
11) The same, with polyisobutylene;
12) None.

susceptibility of thickened oils to the action of multipurpose additives.

We attempted to evaluate the comparative susceptibility of a polyisobutylene-thickened oil, the base oil (type 2 spindle oil), and equally viscous thickened Д-11 distillate oil to certain additives and additive compounds. We compared a number of the indices obtained for the additive-containing oils in laboratory determinations of thermostability by the GOST 9352-60 method, corrosive aggressiveness by the stringent NAMI method, residue after oxidation in ДК-2, and alkalinity (by potentiometric titration). The results of these determinations are given in Table 48.

In analyzing the results of the laboratory tests, it must be

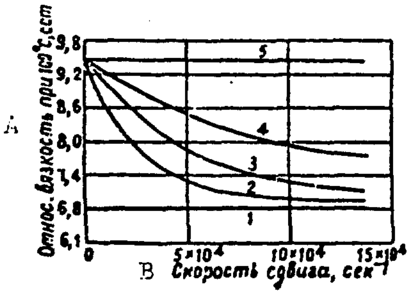


Fig. 16. Influence of viscosity improvers on relative oil viscosity at high shear speeds. 1) SAE-10 base oil; 2, 3, 4) the same oil with viscosity improvers *X*, *Y*, *Z*; 5) the same oil with high-viscosity residual component. A) Relative viscosity at 100°C, cSt; B) shear speed, s^{-1}.

noted that the polyisobutylene-thickened oil tended to have a lower alkalinity than that provided by the same additives for the oil base (type 2 spindle oil) or the commercial Д-11 oil. The polymers probably have a neutralizing effect on the alkaline additive, to some extent reducing its ability to neutralize the acidic products formed during oil oxidation and thus causing a decrease in the detergent power of the oil. T. Salomon [39] also observed a clear decrease in detergent efficiency in certain thickened oils when the viscosity improver to some extent neutralized the effect of the detergent.

Influence of Shear Speed on Viscosity of Oils Containing Polymer Additives

The lubricating-oil consumption of an engine depends principally on the viscosity acquired by the oil during service in the vicinity of the piston rings (where the temperature is 150°C or above). It is assumed in the USA that the oil consumption is governed by the viscosity at 148.9°C [110].

K. Dzhordzhi [110] showed that the consumption of equally viscous (at 98.9°C) oils can vary by as much as 50% as a result of the difference of 0.2-0.7 cSt in their viscosities at 148.9°C. Use of oils containing polymer additives, which have substantially better viscosity-temperature properties, should seemingly cause a substantial reduction in consumption over ordinary oils with the same viscosity at 100°C. No such effect is obtained, however: viscosity improvers have no material influence on motor-oil consumption [110].

In order to determine the causes of this discrepancy, K. Dzhordzhi employed a rotary viscosimeter to determine the relative viscosity of thin oil layers at high shear speeds.

Figure 16 shows the viscosities of a number of oils (100°C) at shear speeds of up to 140,000 s^{-1}.

Since additive-free distillate oils are Newtonian fluids at 100°C and their viscosity is independent of the shear speed, the SAE-10 base oil with a viscosity of 6.8 cSt and the mixture of this oil with a high-viscosity (9.5 cSt) residual component are represented on the graph by straight lines. The other three oils, which were prepared by thickening the SAE-10 base oil to 9.5 cSt at 100°C with three different viscosity improvers, are represented by curves, since their viscosity decreased as the shear speed increased.

TABLE 49

Shear Speed in Engine

1 Поршни и цилиндры			5 Подшипники коленчатого вала		
2 Скорость поршня, см/сек	3 Зазор между поршнем и цилиндром, см	4 Скорость сдвига, $сек^{-1}$	6 Скорость вращения см/сек	7 Зазор в подшипниках, см	4 Скорость сдвига, $сек^{-1}$
2,5	0,025	100	ø 5,08 cm	0,025	18800
2,5	0,0025	1000	n = 1800 об/мин (8)	0,0025	188000
750	0,025	30000		0,00025	1880000
750	0,0025	300000			
750	0,00025	3000000			

1) Pistons and cylinders; 2) Piston speed, cm/s; 3) Clearance between piston and cylinder, cm; 4) Shear speed, s^{-1}; 5) Crankshaft bearings; 6) Angular speed, cm/s; 7) Bearing clearance, cm; 8) r/min.

The curves in the figure show that mineral oils containing viscosity improvers are not Newtonian fluids and that their viscosities approximate to that of the base oil at high shear speeds. This also explains the inability of viscosity improvers to materially reduce motor-oil consumption over base-oil consumption.

It it interesting that not all polymer additives behave identically at high shear speeds. While the curves characterizing the mixture of SAE-10 oil with additives *X* and *Y* approximate to line 1 (the base oil) at shear speeds of 100,000 sec^{-1}, the mixture of SAE-10 oil with additive *Z* seems somewhat better from this standpoint.

The change in oil viscosity when the shear speed is increased is not irreversible. The viscosity of the test specimens, measured in an ordinary capillary viscosimeter at the end of the experiment, was found to coincide with the initial value obtained before the experiment for the same specimens.

Table 49 shows typical shear speeds that have a detrimental effect on oil in an engine [125].

As can be seen, the shear speeds in an engine reach very high levels. With a clearance of 0.0025 cm between the piston rings and cylinder walls, the oil film is subject to a shear speed of about 300,000 s^{-1}. Since the clearances in an operating engine are probably substantially less than 0.0025 cm, the actual shear speed is far greater than that mentioned above and may reach several millions of s^{-1} [110]. With this enormous shear speed, oils containing polymer additives will have a viscosity at the working temperatures of appropriate assemblies that is substantially less than the calculated figure.

This phenomenon is attributable to the orientation of the long polymer molecules in the rapidly flowing stream, so that they cease to present any obstacle to movement of the base-oil molecules.

A very interesting property of oils containing thickening additives is their ability to counteract the influence of high shear speeds when the temperature is raised. Thus, K. Dzhordzhi noted that shear speed has an effect on the viscosity of a thickened oil that exceeds 10^4 s^{-1} at 100°C, 10^3 s^{-1} at 38°C, and 10^{-2} s^{-1} at 21°C.

TABLE 50

Viscosity of Thickened Oils at High Shear Speeds

1 Сорт масла	2 Полимер	3 Количество его, %	4 Т-ра, °C	5 Вязкость исходная, *сст*	6 Увеличение вязкости от добавления полимера, %	7 Вязкость при большой скорости сдвига, *сст*	8 Временное снижение (%) по отношению: 9 к исходной	10 к приросту от добавления полимера
SAE 10W—30	11 Полиизобутилен 12 Полиметакрилат 13 Сополимер метакрилата	6,0 1,5 2,0	— 43,3 87,8	— 66,6 16,1	— 55,9 54,9	— 37,5 10,2	— 43,6 36,6	— 78,5 66,7
14 То же	13 Сополимер метакрилата	5,5	43,3 87,8	66,6 16,3	38,3 43,8	41,9 9,6	37,1 40,8	97,4 93,2
SAE 5W—30	12 Полиметакрилат	9,0	43,3 87,8	51,5 15,3	52,1 58,1	27,7 8,2	46,2 46,3	88,8 79,6
SAE 10W—30	11 Полиизобутилен	12,0	43,3 87,8	76,6 17,3	58,6 55,7	42,4 11,9	44,6 31,2	76,2 55,9
SAE 5W—20	12 Полиметакрилат	4,5	43,3 87,8	31,9 9,5	30,6 37,7	25,4 7,3	20,7 23,4	67,8 62,0

1) Oil; 2) polymer; 3) amount of polymer, %; 4) Temperature, °C; 5) initial viscosity, cSt; 6) increase in viscosity resulting from addition of polymer, %; 7) viscosity at high shear speed, cSt; 8) temporary decrease (%) with respect to; 9) initial; 10) increase resulting from addition of polymer; 11) polyisobutylene; 12) polymethacrylate; 13) methacrylate copolymer; 14) the same.

J. Musselman and S. Darling [122] established that the temporary decrease in the viscosity of a thickened oil under the action of high shear speeds in engines is governed by the type of polymer and its content in the oil, as well as by the oil temperature. This decreases ranges from 21 to 46% of the initial viscosity for different concentrations of different polymers. The decrease with respect to the rise in viscosity due to solution of the polymer in the base can amount to from 56 to 97% (see Table 50).

It has also been noted that a rise in temperature can inhibit the decrease in viscosity caused by high shear speed. It is thought that this is a very valuable specific property of thickened oils, having a favorable effect on engine operation.

During starting, when the oil is cold and its viscosity is high, the viscosity of polymer-containing oils decreases almost to that of the base oil under the action of high shear stresses and speeds. As a result, the wear during the first 5-10 min of cold-engine operation is reduced by a factor of 30-60 when thickened oils are used [123].

The temperature and shear speed increase during further operation, but the influence of shear speed is reduced at high temperatures and the decrease in viscosity reaches only 21-46% of the initial viscosity.

REFERENCES

1. Suleymanova, F.G., Author's abstract of Doctoral Dissertation. Baku, Izd-vo AN Azerb SSR, 1964.

2. Papok, K.K., Semenido, Ye.G. et al., Motornyye i reaktivnyye masla i zhidkosti [Motor and Jet Oils and Liquids]. Moscow, Gostoptekhizdat, 1964.

3. Nametkin, S.S., Khimiya nefti [The Chemistry of Petroleum]. Moscow, Izd-vo AN SSSR, 1951.

4. Papok, K.K. et al., "Khimiya i tekhnologiya topliv i masel," 1963, No. 10.

5. Zaslavskiy, Yu.S. et al., "Khimiya i tekhnologiya topliv i masel," 1959, No. 2.

6. Melvin-Kh'yuz, E.A., Fizicheskaya khimiya [Physical Chemistry]. Moscow, IL, 1962.

7. Zaslavskiy, Yu.S. et al., "Khimiya i tekhnologiya topliv i masel," 1959, No. 2; 1962, No. 8.

8. Kreyn, S.E. et al., Collection entitled: "Transport, khraneniye i primeneniye nefteproduktov" [Transportation, Storage and Application of Petroleum Products]. Gostoptekhizdat, 1952.

9. Chernozhukov, N.I., Kreyn, S.E., Losikov, B.V., Khimiya mineral'nykh masel [The Chemistry of Mineral Oils]. Gos-

toptekhizdat, 1951.

10. Ramayya, K.S., Sil's, R.Kh., Collection entitled "Prisadki k maslam i toplivam" [Oil and Fuel Additives]. Gostoptekhizdat, 1961.

11. Akhmatov, A.S., Molekulyarnaya fizika granichnogo treniya [The Molecular Physics of Boundary Friction]. Moscow, Fizmatgiz, 1963.

12. Deryagin, B.V., Chto takoye treniye? [What is Friction?] Moscow, Izd-vo AN SSSR, 1963.

13. Rebinder, P.A., Fiziko-khimicheskaya mekhanika – novaya oblast' nauki [Physicochemical Mechanics – a New Branch of Science]. Moscow, "Znaniye," 1958.

14. Ramayya, K.S., Collection entitled "Prisadki k maslam i toplivam." Gostoptekhizdat, 1946.

15. Fuks, G.I., Collection entitled "Prisadki k maslam i toplivam." Gostoptekhizdat, 1961.

16. Hardy, W.C., Collected Scientific Papers. Cambridge, 1936.

17. Bowden, F.P. and Tabor, D., Friction and Lubrication of Solids. Oxford, 1950.

18. Clayton, D.J., Appl. Phys., Suppl. No. 1, 1951, 187.

19. Fogg, A., Hunwicks, S.A., J. Inst. of Petroleum, 1940, 26, No. 195.

20. Conference on Lubrication and Wear, IME, London, 1957.

21. Matveyevskiy, R.M., Temperaturnyy metod otsenki predel'noy smazochnoy sposobnosti mashinnykh masel [Temperature Method of Evaluating Limit Lubricating Capacity of Machine Oils]. Izd-vo AN SSSR, 1956.

22. Block, H., SAE Transactions, 1939, 44, No. 5, 193.

23. Kragel'skiy, I.V., Treniye i iznos [Friction and Wear]. Mashgiz, 1962.

24. Rozenberg, Yu.A., Vinogradova, I.E., Smazka mekhanizmov mashin [Lubrication of Machine Parts]. Moscow, Mashgiz, 1961.

25. Chernozhukov, N.I., Kreyn, S.E., Okislyayemost' mineral'nykh masel [Oxidizability of Mineral Oils]. Gostoptekhizdat, 1955.

26. Zuidema, G.G., Ekspluatatsionnyye svoystva smazochnykh masel [Operational Properties of Lubricating Oils]. Gostoptekhizdat, 1957.

27. Emmanuel', N.Ya., "Zh. fiz. khimii," 1956, 30, No. 4.

28. Emmanuel', N.M., "DAN SSSR," 1956, 111, No. 6.

29. Bolland, J.L., Proc. Roy. Soc., 1946, A186, 218.

30. Bolland, J.L., Gee, G., Trans. Faraday Soc., 1946, 42, 236.

31. Denison, G.H., Ind. Eng. Chem., 1944, 36, 477.

32. Mulcahy, M.F.P., Trans. Faraday Soc., 1947, 45, 537.

33. Strannet, V., Woodward, A.E., Mesrobian, R.B., J. Phys. Chem., 1957, 61, 360.

34. Woodward, A.E., Mesrobian, R.B., J. Am. Chem. Soc., 1953, 75, 6189.

35. Zuidema, H.H., Chem. Revs, 1946, 38, 197.

36. Martynov, V.M., Kuchinskaya, N.D., "Khimiya i tekhnologiya topliv i masel," 1964, No. 6.

37. Martynov, V.M., Collection entitled "Metody issledovaniya neftey i nefteproduktov" [Methods of Studying Petroleum and Petroleum Products]. Gostoptekhizdat, 1955.

38. Vol'nets, F.K., "Zh. prikl. khimii," 1958, Vol. 32.

39. Salomon, T., Prisadki dlya smazochnykh masel [Additives for Lubricating Oils]. Translation from "Revue de l'Institute Francais du Petrole," 1956, IV, Vol. XI, No. 4.

40. Semenido, Ye.G., "Nauchno-tekhn. byull. TsIATIM" [TsIATIM [Central Scientific Research Institute for Aviation Fuels and Lubricants] Scientific Engineering Bulletin], 1941, No. 10-11.

41. Ostval'd, V., Osnovy kolloidnoy khimii, 1. St. Petersburg, 1911.

42. Val'dman, V.L., "Zh. tekhn. fiziki," 1946, Vol. XVI, No. 4; "Kolloid. zh.," 1947, Vol. IX, No. 3.

43. Horne, W.L. van, I.E.C., 1949, 41, 952-959.

44. Evans, H.C. and Joung, D.W., I.E.C., 1942, 34, 461-6.

45. Evans, H.C. and Joung, D.W., I.E.C., 1947, 39, 1678-81.

46. Einstein, A., Ann. Phys., 1906, 19, 289-306.

47. Mattews, J. Inst. Petrol., 1953, 39, 340.

48. J. Am. Chem. Soc., 1942, 74, 1557.

49. I.E.C., 1942, 34, 461.

50. Smolukhovskiy, M., Koll. L., 1916, 15, 194.

51. Frenkel', Ya.I., Kineticheskaya teoriya zhidkostey [Kinetic Theory of Fluids]. Moscow, Fizmatgiz, 1945; Frenkel', Ya.I., Vvedeniye v teoriyu metallov [Introduction to Theory of Metals]. Moscow, Fizmatgiz, 1950.

52. Livshits, Ye.M., ZhETF, 1959, 37, No. 1, 7.

53. Kitaygorodskiy, A.I., "DAN SSSR," 1961, 137, 116.

54. Urazovskiy, S.S., Molekulyarnyy polimorfizm [Molecular Polymorphism]. Izd-vo AN USSR, 1956.

55. Shtaudinger, G., Vysokomolekulyarnyye organizheskiye soyedineniya [High Molecular Organic Compounds]. Leningrad, 1935.

56. Midzuyema, S., Stroyeniye molekul i vnutrenniye vrashcheniya [Molecular Structure and Internal Rotation]. IL, 1957.

57. J. Phys. Chem., 1952, 18, 161.

58. J. Chem. Phys., 1951, 19, 1477.

59. "Zh. fiz. khimii," 1954, 29, 697.

60. J. Chem. Phys., 1949, 17, 258.

61. "Zh. fiz. khimii," 1954, 28, 1313.

62. Kitaygorodskiy, A.I., Organicheskaya kristallokhimiya [Organic Crystallochemistry]. Izd-vo AN SSSR, 1955.

63. Vol'kenshteyn, M.V., Yel'yashevich, M.A., Stepanov, P.I., Kolebaniya molekul [Molecular Oscillations], Vols. I and II. Moscow, Fizmatgiz, 1949.

64. J. Am. Chem. Soc., 1949, 71, 1320.

65. Vol'kenshteyn, M.V., Konfiguratsionnaya statistika polimernykh tsepey [Configurational Statistics of Polymer Chains], Izd-vo AN SSSR, 1959.

66. Vol'kenshteyn, N.V., "DAN SSSR," 1957, 38, 879; "Zh. fiz. khimii," 1952, 26, 1072.

67. Vol'kenshteyn, M.V., Stroyeniye i fizicheskiye svoystva molekul [Structure and Physical Properties of Molecules]. Izd-vo AN SSSR, 1955.

68. Georgi, C.W., Petrol. Ref., 1954, 33, No. 10.

69. Bidwell, J., Williams, R., SAE Trans., 1955, 63, 349.

70. Miller, I., Hartman, L., SAE Preprint, 1954, No. 308.

71. Marvell, C.S., The Chemistry of Large Molecules, Chapter 7. Interscience, New York, 1943.

72. Lewis, E.E., Naylor, M.A., J. Am. Chem. Soc., 1947, 69, 1968.

73. Simha, R., Wall, L.A., Blatz, P.J., J. of Polymer Sci., 1950, 5, 615.

74. Simha, R., Wall, L.A., Ibid, 1951, 6, 39.

75. Simha, R., Wall, L.A., Ibid, 1952, 56, 707.

76. Larson, R., Sc. Lubr., 1958, 10, No. 8.

77. Madorsky, S.L., Strans, S., Thompson, D., Williamson, L., J. Polymer Sci., 1949, 4, 639.

78. J. Am. Chem. Soc., 1945, 67, 785.

79. J. Am. Chem. Soc., 1945, 67, 2063.

80. Thompson, J.O., J. Phys. Coll. Chem., 1950, 54, 338.

81. I.J.C., 1938, 30, 176.

82. J. Am. Chem. Soc., 1943, 65, 2417.

83. J. Polymer Sci., 1947, 2, 463.

84. Chem. Abstr., 1939, 2438.

85. Chem. Abstr., 1942, 5644.

86. Chem. Abstr., 1944, 1141.

87. Chem. Abstr., 1946, 734.

88. Chem. Abstr., 1948, 3441.

89. Chem. Abstr., 1951, 345.

90. Chem. Abstr., 1952, 1312.

91. I.E.C., 1940, 32, 299.

92. Ber., 1936, 69B, 1091.

93. J. Polymer Sci., 1954, 12, 533.

94. Ber., 1934, 67B, 1159; J. Appl. Phys., 1953, 24, 1011.

95. Z. Electrochem., 1939, 45, 659.

96. J. Appl. Phys., 1950, 21, 171.

97. J. Polymer Sci., 1954, 13, 441.

98. Trans. Farad. Soc., 1950, 46, 996.

99. Z. Electrochem., 1949, 53, 28.

100. J. Chem. Phys., 1949, 46, 667.

101. Z. Phys. Chem., 1940, A186, 113.

102. J. Polymer Sci., 1951, 7, 21.

103. J. Polymer Sci., 1951, 6, 745, 757.

104. Rev. Phys. Chem. Jap., 1952, 22, 1.

105. Nature, 1947, 160, 647.

106. Shtaudinger, G., Vysokomolekulyarnyye organicheskiye soyedineniya. ONTI, 1935.

107. Sharapov, V.I., Candidate's Dissertation, Moscow, 1962.

108. Kuliyev, A.M., Sadykhov, Z.A., Levshina, A.A., "Azerb. khim. zh.," 1961, No. 3.

109. Evans, H.C. and Joung, D.W., I.E.C., 1942, 34, 461-6.

110. Dzhordzhi, K.V., Motornyye masla i smazka dvigateley [Motor Oils and Engine Lubrication]. Gostoptekhizdat, 1959.

111. Semenido, Ye.G., Sharapov, V.I., Shchegolev, N.V., Trudy nauchno-tekhn so'eshchaniya [Transactions of the Scientific Engineering Conference]. Gostoptekhizdat, 1961.

112. Klimov, K.I., Zarudniy, P.P., "Khimiya i tekhnologiya topliv i masel," 1959, No. 2.

113. Pavlov, V.P., Vinogradov, G.V., "DAN SSSR," 1957, 114, 5, 997.

114. Semenido, Ye.G., Ivanov, A.P., Kaverina, N.I., "Byull. izobreteniy," 1959, No. 2.

115. Sirtori Sandro, Transactions of the Vth International Petroleum Congress, Vol. V. Gostoptekhizdat, 1961.

116. Poshlyakova, N.F., Zubov, P.N., Kargin, V.A., "Kolloid. zh.," 1958, Vol. XX, No. 2.

117. Raymond and Socolofcky, Rapport Congress SAE. Atlantic City, June, 1954.

118. Sviney, Fleming, Mudi, IVth International Petroleum Congress, Vol. VII. Primeneniye nefteproduktov. Gostoptekhizdat, 1957.

119. Filippov, V.F., Metody issledovaniya neftey i nefteproduktov. Gostoptekhizdat, 1955.

120. British Patent 492,789, 2 November 1949.

121. Puchkov, N.G., Author's abstract of Doctoral Dissertation. Moscow, 1964.

122. Musselman, J., Darling, S., SAE Preprint No. 59. AM 3B-3, April 1959.

123. Wright, L., Autocar, 1955, Vol. 108, No. 3119, 354.

124. Fillipov, V.F., "Khimiya i tekhnologiya topliv i masel," 1964, No. 4.

125. Dzhordzhi, K., IVth International Petroleum Congress, Vol. VII. Gostoptekhizdat, 1957.

Manuscript Page No.	Footnote
86	[1] In 1867 the Americans Eames and Seely were awarded Patent No. 66,573, which presented the idea of improving the rheological properties of oils by dissolving India Rubber in them. The idea remained unused because of the instability of the natural rubber solutions.

Manuscript Page No.	Transliterated Symbols
59	д = d = dissotsiatsiya = dissociation
63	л = l = lak = tar
63	м = m = maslo = oil
86	раб = rab = rabochiy = working
87	пуска = puska = pusk = start
98	уд = ud = udel'nyy = specific
106	исходн = iskhodn = iskhodnyy = initial
106	конечн = konechn = konechnyy = final

Chapter 3

COMPARATIVE ENGINE CHARACTERISTICS OF OIL PRODUCED FROM AZERBAYDZHAN CRUDE OILS AND WAYS OF IMPROVING THEIR PROPERTIES

§1. EVALUATION PROCEDURE

Investigations related to improvement of oil and additive production technology, quality control for current production, introduction of new types of raw materials, synthesis and selection of oil additives, and classification of commercial oils necessitate engine testing of oils. Physicochemical test methods can be used to identify different types of lubricating oils and to check their properties. They are not suitable for evaluating the service characteristics of motor oils [1]. Various laboratory methods have been developed in recent years [2, 3], but evaluations of oil service characteristics made with these procedures do not completely conform to oil behavior in engines and it is therefore impossible to predict precisely the behavior of the oils under operating conditions.

One reliable method for evaluating motor-oil service characteristics is direct engine testing [2, 3, 4].

Different systems for evaluating and processing results are generally used in developing procedures for appraising the result of oil engine tests. In this connection, it is of interest to determine the extent to which each of them permits clearer differentiation of different types of oils and to which the oil appraisal obtained agrees with the behavior of the oil in the most commonly employed engines.

Researchers occupied in developing oil-test regimes did not take it upon themselves to design a special engine for this purpose but used serial- or mass-produced engines. When these engines went out of production, they were forced to switch to other models and the test regimes selected differed from those previously employed. It is characteristic that, in many cases, the test regime and procedure for engines of a given type differed substantially in different organizations. Such a situation could have arisen only as a result of improper selection of test procedures and regimes. In the absence of standard engines and stand-test methods for oils, objective comparison of results obtained in different laboratories is impossible.

The first attempts to test oils for tractor diesels by a unified procedure were made in 1950. For this purpose, the interested agencies agreed on a program in the procedure for 900-hour stand tests in serial-produced Д-35 tractor diesels. The tests were intended to establish the suitability of the oil tested for use in tractor diesels by comparison with results obtained in tests with a standard oil. The criteria for evaluating oil properties were the piston-ring mobility, the amount of deposits on the pistons, rings, oil filters, oil pan, and other components, the wearing of the main rod and crank components and cylinder sleeves, the oil consumption, the change in engine power and economy indices, and the physicochemical properties of the worked-out oil.

Despite a number of not entirely fortunate methodological aspects, these tests played some part in the organization of oil testing by a single procedure. Experience in its use made it possible to find ways of improving the method by seeking better test regimes, techniques for quantitative and qualitative evaluation of deposits and component wear, and a methodological basis for accelerated oil tests.

In addition to this method, a number of scientific research institutes have recently conducted brief preliminary oil tests in small-displacement single-cylinder engines.

In order to reduce the test time, oils are tested in an engine operating under a high-temperature regime. For this purpose, the coolant temperature is brought to 140-160°C and, in some cases, to 220°C (ethylene glycol is used as the coolant).

Thus, several variants of a procedure for accelerated oil tests in an ИТ-3 diesel engine (with a working volume of 652 ml) have been developed at the VNII NP [All-Union Scientific Research Institute of Petroleum and Gas Refining and Production of Artificial Liquid Fuels] under the supervision of V.F. Filippov [5]: anti-carbon-deposition and anticorrosion properties are determined in one case and the tendency of the oil to cause tar deposition on the first compression ring is determined in another.

Procedures have also been developed for evaluating other oil properties. One method devised at the VNII NP provides for determination of the thickness and character of the tar layer formed on the piston skirt of an ИТ9-2 carburetor apparatus, using a radioactive material applied along the piston genetrix in the zone of maximum tar formation.

The first lubricating-oil engine tests at the NII GSM [Scientific Research Institute of Fuels and Lubricants] (НИИ ГСМ) were conducted in an ИТ9-5 carburetor by the ГСМ-20 method and with an ОД-9 single-cylinder engine section.

A special single-cylinder apparatus for engine testing of УИМ-3-НАТИ oils was developed on the basis of the Д-54 tractor diesel (with cast-iron pistons) at the NATI (НАТИ) in 1957 [7].

Table 51 gives certain data on methods for evaluating oils in single-cylinder and full-sized engines. Stand-test methods have come into wide use and have undoubtedly been a great aid in determining the antioxidation, anticorrosion, detergent, and other pro-

TABLE 51

Certain Data on Procedures for Evaluating Motor Oils

1 № пп	2 Организация, разработавшая или применяющая метод	3 Марка двигателя	4 Режим испытаний: 5 Длительность, ч	6 л. с.	7 об/мин	8 т-ра, °C: 9 охлаждающей жидкости	10 масла в картере	11 Срок смены масла, ч	12 Цель испытания	13 Оценочные показатели	14 Название и назначение метода
1	2	3	4	5	6	7	8	9	10	11	12
1 2	ВНИИ НП	И19 2 И19-3	50 5Ј	3 3,8	1200 12ЈЈ	130 150— —170	100 120	33 50	Предварительная оценка антинагарных и антикоррозийных свойств масел с присадками 15	Количество отложений на поршне и кольцах, цвет лака в баллах ПЗВ коррозия свинцовых пластин 24	ИКМ-36 (масла для карбюраторных двигателей) ИДМ-50ф (масла для дизельных двигателей) 34
3 4	НИИ-25	ИТ9-5 ОД-9	2) 10	5,2 35	1500 1800	200 140	100 100— —105	— —	То же Предварительная оценка склонности масла к образованию отложений на поршне 16	То же Количество отложений на поршне и кольцах, лак на поршне в баллах ПЗВ, лак на металлических пластинках «свидетелях», анализ масла 25	ГСМ-20
5	ВНИИ НП	Д-40	120	40	1420	95—97	95— —100	12)	Предварительная оценка моторных свойств масел (типа ХД и серии 1) 17	Подвижности колец, количество отложений на поршнях, кольцах (оценка в системе баллов), износ гильз и колец 26	—
6	ВНИИ НП	Д-48 СМД-14	800	45 75	1500	90±3	88±3	240	Установление пригодности опытного образца масла для применения на тракторных дизелях 18	Подвижность колец, количество отложений на деталях двигателя, износ деталей, изменение мощностных и экономических показателей, расход масла, анализ отработанного ма[illegible] 27	—

TABLE 51 CONTINUED

7	ВНИИ НП	Д-28	450	280	1400	90±3	90±3	120	Установление соответствия моторных свойств опытного образца качеству масла ХД и масла серии I 19	Подвижность колец, количество отложений на деталях двигателя (оценка нагаротложений в системе баллов метода 344-Т) 28	Оценка масел класса ХЛ и серии I 35
8	ВНИИ НП ИНХП АН	ЯАЗ-204	140	50—100% $N_{E max}$	1300—2000	60—95	75—110	60	Предварительная оценка моторных свойств опытных образцов типа серии II и III 20	Подвижность колец, количество отложений на деталях двигателя, в ресивере, в продувочных окнах гильз 29	—
9	ВНИИ НП, ИНХП АН НАМИ	ЯАЗ-204	550	50—100% $N_{E max}$	1300—2000	50—95	75—110	50	Установление соответствия опытного образца масла качеству масла серии II и III 21	Подвижность колец, количество отложений на поршнях, кольцах в продувочных окнах гильз, в ресивере, износ деталей двигателей, изменение мощностных показателей двигателя 30	Оценка масел серии II и III 36
10	НАТИ, ИНХП АН, ВНИИ НП, НАМИ	УИМ-3 НАТИ УИМ-6	50 120	13 30	1300	135	100	50	Оценка эксплуатационных качеств моторных масел, предназначенных для тракторных и автомобильных двигателей 22	Подвижность поршневых колец, отложения на поршне и нерабочей зоне зеркала цилиндра (оценка производится в баллах), а также содержание железа в масле 31	Методика № 1 37
11	ВНИИ НП, ИНХП АН, НАМИ	ГАЗ-51	600	50—100% $N_{E max}$	1200—2800	80—80	85—85	10	Предварительная оценка моторных свойств масел (типа ХД и серии I) 17	Подвижность колец, количество отложений на поршнях, кольцах (оценка в системе баллов), износ гильз и колец 32	—
12	ВНИИ НП, ИНХП АН, НАМИ	ГАЗ-51	600	50—100% $N_{E max}$	1200—2800	80—85	85—90	100	Установление пригодности опытного образца масла для применения на карбюраторных двигателях 23	Подвижность колец, количество отложений на деталях двигателя, износ деталей, расход масла, анализ отработанного масла 33	—

Key to Table 51

1) No.; 2) organization that developed or uses method; 3) type of engine; 4) test regime; 5) duration, h; 6) hp; 7) rpm; 8) temperature, °C; 9) coolant; 10) crankcase oil; 11) oil-change time, h; 12) purpose of tests; 13) indices evaluated; 14) name and purpose of procedure; 15) preliminary evaluation of anti-carbon-deposition and anticorrosion properties of additive-containing oil; 16) the same, preliminary evaluation of tendency of oil to produce deposits on pistons; 17) preliminary evaluation of engine properties of oils (type ХД and series I); 18) determination of suitability of experimental oil for use in tractor diesel; 19) establishment that engine properties of test oil meet requirements for ХД and series I oils; 20) preliminary evaluation of engine properties of experimental series II and III oils; 21) establishment that experimental oil satisfies requirements for series II and III oils; 22) evaluation of service characteristics of motor oils intended for tractor and automobile engines; 23) establishment of suitability of experimental oil for use in carbureted engines; 24) amount of deposits on pistons and rings, tar color in points, VSI, lead-plate corrosion; 25) the same, amount of deposits on pistons and rings, tar deposits on pistons in point, VSI, tar deposits on standard metal plates, oil analysis; 26) ring mobility, amount of deposits on pistons and rings (in points), wear of cylinder sleeves and rings; 27) ring mobility, amount of deposits on engine components, component wear, change in engine power and economy indices, oil consumption, analysis of worked-out oil; 28)(ring mobility, amount of deposit on engine components (evaluation of carbon deposition on point scale, 344-T method); 29) ring mobility, amount of deposit on engine components, in oil pan, and in cylinder-sleeve exhaust ports; 30) ring mobility, amount of deposit on pistons, rings, cylinder exhaust ports, and oil pan, wearing of engine components, change in engine power indices; 31) ring mobility, deposits on pistons and nonworking portion of cylinder sleeves (in points), iron content of oil; 32) ring mobility, amount of deposits on pistons and rings (in points), wearing of cylinder sleeves and rings; 33) ring mobility, amount of deposits on engine components, component wear, oil consumption, analysis of worked-out oil; 34) ИКМ-36 (oils for laboratory engines), ИДМ-50Ф (oils for diesel engines); 35) evaluation of class ХД and series I oils; 36) evaluation of series II and series III oils; 37) method No. 1.

perties of motor oils during prolonged high-speed engine operation at high oil and coolant temperatures. It is thought that prolonged engine tests under stand conditions with a high-temperature regime permit adequate evaluation of oil performance under severe service conditions.

Stand conditions for engine testing of oils can be selected in such fashion that a satisfactory or unsatisfactory rating can be obtained for any oil (depending on the conditions chosen). With the engine operating for prolonged periods at high speed and high temperatures, oil stability and oxidation resistance is of decisive importance; when tests are conducted under mild conditions, with the engine idling at low temperatures, the contamination of the oil with products entering it from the combustion chambers is of greattest importance.

A number of the engine-test procedures we employed in investigating motor oils obtained from Azerbaydzhan crude oils are described below.

Procedure for Oil Screening Tests in ИТ 9-3 Engine (ИДМ-50Ф VNII NP)

The wide use of small ИТ-9 engines for oil tests is due to the fact that they permit evaluation of engine properties and classification of oils under actual engine-operating conditions with an appropriate fuel within a short time (less than 50 h) and with small amounts of experimental oil (less than 5 kg).

The design features of the ИТ 9-3 engine (variable compression ratio, regulable heating of oil and incoming air, and spray-cooled cooling system of thermosiphon-evaporator type) makes it possible to adjust the engine-operation regime, particularly its thermal aspects, over a broad range and to hold it within narrow limits. This permits use of the ИТ 9-3М engine for modeling of oil-service conditions in the most varied diesel engines.

The ИТ 9-3М engine is sufficiently sensitive to oil quality and can operate normally with oils of all series having viscosities between 6 and 22 cSt at 100°C. The high precision with which the components of the ИТ 9-3М engine are fabricated, their wear resistance, and the simplicity of engine assembly and servicing satisfy the requirements imposed on engines for oil screening tests.

The procedure in question has been designated as the ИДМ-К-50Ф method (diesel-oil testing by combined method for 50 h under supercharged regime).

This evaluation procedure is intended for МА (premium), МБ (Heavy Duty, HD(ХД)), МВ (series I), МГ (series 2), and МД (series 3) motor oils.

Engine oil properties are evaluated from the amount and character of the deposits on the piston and piston rings, from piston-ring mobility, from antiwear and anticorrosion properties, and from the change in the physicochemical indices of the oil during service in the ИТ 9-3М engine.

The procedure essentially consists in a brief test in a single-cylinder compressive-ignition ИТ 9-3М engine; the test lasts 50 h in 10-h stages. It is conducted under a special high-temperature regime based on preliminary investigations conducted with the ИТ 9-3М engine and on comparison of the results of tests conducted with different groups (series) of oils in the ИТ 9-3М engine with their behavior in various serial-produced engines under stand and operating conditions. Oil engine properties are determined by comparing the results obtained for the indices to be evaluated in tests conducted with a specimen and a standard in a given apparatus.

This method is intended for screening tests in synthesizing oil additives, in selecting additive compounds for given groups (series) of oils, in developing new technological processes for producing oils and additives, in introducing new types of raw materials, and in quality control and evaluation of commercial oils and additives.

In connection with the change in the purpose of the ИТ 9-3 apparatus, it has been reequipped for oil tests and the following modifications have been made in its construction:

1. The engine speed has been raised from 900 to 1200 r/min by changing the pulley on the electric motor.

2. In order to increase the reliability with which the thermal state of the engine is monitored, thermocouples have been installed in the center of the cylinder head, the exhaust pipe, the outlet tube from the cooling-system condenser, the water chamber used to cool the sprayer, the intake pipe, and the crankcase.

3. In order to improve the reproducibility of test results, the piston rings are lubricated by the spray method. For this purpose, the oil passage to the piston pin in the rod has been stopped up and holes 4 mm in diameter have been drilled in the upper end of the rod, the bushing, and the piston bosses.

4. A measuring device has been installed to determine the oil flow in the lubricating system.

5. The high-quality filter has been removed from the lubricating system and a cock has been installed for taking oil samples.

6. A device for attaching plates intended for determination of anticorrosion properties has been mounted on the inside of the crankcase lid.

The technical characteristics of the test apparatus are as follows:

1 Тип двигателя	2 Одноцилиндровый, с воспламенением от сжатия, четырехтактный форкамерный
3 Диаметр цилиндра	85,0 *мм*
4 Ход поршня	115,0 *мм*
5 Рабочий объем цилиндра	0,652 *м*³
6 Степень сжатия	13 от 7 до 23 14
7 Число оборотов двигателя	1200 *об/мин* 15
8 Максимальная эффективная мощность двигателя	4,8 *л. с.* 16
9 Система смазки	17 Комбинированная
10 Емкость системы смазки	3,0 *л* 18
11 Питание двигателя	19 При помощи одноплунжерного насоса и форсунки закрытого типа
12 Пуск и торможение двигателя	20 При помощи электромотор-генератора мощностью 5,8 *кв*

1) Type of engine; 2) single-cylinder, compressive-ignition, four-stroke, equipped with precombustion chamber; 3) cylinder bore; 4) piston stroke; 5) cylinder working volume; 6) compression ratio; 7) engine speed; 8) maximum effective engine power; 9) lubricating system; 10) lubricating-system capacity; 11) engine power supply; 12)

engine starting and stopping; 13) from; 14) to; 15) r/min; 16) hp; 17) combined; 18) liters; 19) with single-plunger pump and closed-type sprayer; 20) with electric motor-generator having power of 5.8 kW.

The test conditions are:

1	Продолжительность испытаний	50 ч 27
2	Число оборотов двигателя	1200±10 об/мин 28
3	Степень сжатия	15±0,2
4	Угол опережения впрыска топлива в градусах до ВМТ	15±0,5
5	Давление впрыска топлива	100±4 кг/см² 29
6	Топливо	30 Дизельное ГОСТ 305—58 с содержанием серы 0,9—1 %
7	Расход топлива	0,81 кг/ч 31
8	Т-ра воздуха, поступающего в двигатель	65±2°C
9	Т-ра воды, охлаждающей форсунку	25±2°C
10	Т-ра охлаждающей жидкости	
11	для масел базового, МА и МБ (премиум, ХД)	120±2°C
12	для масел МВ, МГ и МД (серии I, II, III)	160±2°C
13	Жидкость, охлаждающая цилиндр двигателей	Смесь этиленгликоля с водой 32
14	Т-ра масла в картере перед запуском двигателя	60±2°C
15	Т-ра масла в картере двигателя после выхода на режим	95±2°C
16	Давление масла в системе смазки	2±0,1 кг/см² 29
17	Количество испытуемого масла, заливаемого в двигатель	2600 г 33
18	Допустимый максимальный расход масла	40 г/ч 34
19.	Долив масла	35 Через каждые 10 ч работы двигателя
20	Количество доливаемого масла	400 г 33
21	Количество отработанного масла, оставляемого в двигателе после каждых 10 ч работы	2100 г 33
22	Отбор проб масла	
23	через 5 мин после запуска двигателя	100 г 33
24	по окончании испытаний	500 г 33
25	через каждые 10 ч работы	36 излишек сверх 2100 г
26	Противодавление на выхлопе	37 Не более 1 мм рт. ст. сверхатмосферного или должно быть равно атмосферному

1) Test time; 2) engine speed; 3) compression ratio; 4) intake-valve dwell angle, degrees to TDC (ВМТ); 5) intake pressure; 6) fuel; 7) fuel consumption; 8) temperature of incoming air; 9) temperature of water cooling sprayer; 10) coolant temperature; 11) for base, МА, and МБ (Premium, ХД) oils; 12) for МВ, МГ, and МД (series I, II, and III) oils; 13) liquid cooling engine cylinder; 14) oil temperature in crankcase before engine start; 15) oil temperature in crankcase after engine brought to operating regime; 16) oil pressure in lubrication system; 17) initial amount of test oil added to engine; 18) maximum permissible oil consumption; 19) oil added; 20) amount of oil added; 21) amount of used oil remaining in engine after each 10 h of operation; 22) oil samples taken; 23) 5 min after engine started; 24) at end of test; 25) after each 10 h of operation; 26) exhaust counterpressure; 27) h; 28) rpm; 29) kg/cm²; 30) GOST 305-58 diesel fuel with sulfur content of 0.9-1%; 31) kg/h; 32) mixture of ethylene glycol and water; 33) g; 34) g/h; 35) after every 10 h of engine operation; 36) excess above 2100 g; 37) no more than

1 mm Hg above atmospheric pressure or equal to atmospheric pressure.

Note. In testing oils intended for engines under severe thermal loads, the coolant and oil temperatures can be raised by 10 and 20° respectively.

In research work, tests on oils in groups В, Г, and Д can be conducted at a coolant temperature of 160-170 or 180° and an oil temperature of 100, 110, or 120°. The coolant temperature for oils in groups А and Б can be taken as 130 and 140° respectively. The test time can be reduced to 10 h in these cases.

The test results are evaluated by the modified SP-124/55 and 344-T methods [8], as well as from the weight of the deposits on the piston component.

Procedure for Testing Diesel Oils in УИМ-3-НАТИ Apparatus

These tests are intended to evaluate the tendency of oils to cause carbon deposition on the piston, piston rings, and nonworking upper portion of the cylinder sleeve and tar formation on the piston rings, as well as their ability to protect the friction surfaces against wear.

The УИМ-3-НАТИ apparatus is used to evaluate these properties for additive-containing oils intended for tractor diesels.

The apparatus consists of a single-cylinder engine with a general-purpose crankcase, auxiliary equipment, and measuring devices.

The УИМ-3 engine is a single-cylinder section of the block of a Д-54 tractor diesel mounted on a general-purpose crankcase.

The crankcase makes it possible to employ a number of different cylinder-block sections from tractor, automobile, and other vehicle or stationary engines having different types of fuel vaporization and a cylinder diameter of no more than 130 mm.

The dry-crankcase lubrication system has two closed channels, which provide separate lubrication of the engine mechanisms.

The sealed cooling system permits use of ethylene glycol, glycerol, and other material as coolants.

The technical characteristics of the УИМ-3 engine include:

Type of Engine	Four-stroke, compressive-ignition, noncompressor
Fuel-vaporization method	Eddy chamber, with cast diffuser
Piston	Cast iron, with spherical (spoon-shaped) concavity in face

Engine speed at rated power	1300 r/min
Rated power	13.5 hp
Cylinder bore	125 mm
Piston stroke	152 mm
Engine working volume	1.86 liter
Average effective pressure	5.05 kg/cm^2

A new engine or an engine equipped with new components in the rod-crankshaft mechanism undergoes 40-hour running-in in repeated 8-hour cycles.

The coolant temperature and the oil-discharge temperature should be 80-90°C under loaded conditions. The oil pressure in the main channel is adjusted to fall between 1.9 and 2.1 kg/cm^2 under all regimes.

Running-in is carried out with type 50 industrial oil (СУ; GOST 1707-51) containing 3% ЦИАТИМ-339 additive.

The engine is run in for 5 h before each oil test (Table 52).

In order to check the condition of the apparatus, control tests are conducted with type 50 industrial oil (machine СУ) GOST 1707-51 containing 3% ЦИАТИМ-339 additive before the tests are begun and and after 3-5 specimens have been tested; the rating obtained, using the methods described above, should be 15 ± 1 point. If such a rating is not obtained, it is necessary to find and correct the defect in the engine. All the tests are conducted with GOST 305-58 diesel containing 1.0 ± 0.5% sulfur.

The oil test is conducted with the engine operating under a constant regime and lasts 45 h. The test regime includes:

Test time	45 h
Fuel consumption	2.6 ± 0.02 kg/h
Crankshaft speed	1300 ± r/min
Coolant temperature	135 ± 2°C
Oil temperature at discharge (in main channel)	100 ± 2°C
Oil temperature at discharge (in auxiliary channel)	80 ± 3°C
Oil pressure in main channel	2 ± 0.1 kg/cm^2
Oil pressure in auxiliary channel	0.5 ± 0.1 kg/cm^2
Temperature of water leaving sprayer	50 ± 5°C

TABLE 52

Regime for 5-h Running-in

1 № пп.	2 Режим	3 Нагру‑ка двигателя, л. с.	4 Показатель тормоза, кг·м	5 Число оборотов коленчатого вала, об/мин	6 Длительность работы двигателя, мин
1	7 Холодная обкатка	—	—	10)	15
2	То же 8	—	—	1000	20
3	9 "	—	—	1300	15
4	Горячая обкатка	0	0	•	30
5	То же 8	1,8	1	•	30
6	"	3,6	2	•	30
7	"	5,5	3	•	30
8	"	7,3	4	•	30
9	"	9,1	5	•	30
10	"	10,9	6	•	30
11	"	12,7	7	•	30
12	"	13,6	7,5	•	10

Note. The oil is not changed after the 5-h running-in period.

1) No.; 2) regime; 3) engine load, hp; 4) braking index, kg·m; 5) crankcase speed, r/min; 6) engine operating time, min; 7) cold; 8) the same; 9) hot.

The results of the oil tests are evaluated from the amount of tar deposited on the piston rings, from the thickness and amount of the carbon deposits on the nonworking upper surface of the cylinder sleeve, and from the amount of deposits in the oil-ring gaps and drainage ports.

The evaluation is made by the ДВС 344-T negative system for appraising carbon deposits and wear [8].

Oil Test in the 1 Ч-10.5/13 Engine

The single-cylinder 1 Ч-10.5/13 engine is very similar in design and characteristics to such engines as the Д-35 and Д-54. It is consequently the most suitable for preliminary and screening tests.

Table 53 shows the main technical characteristics of the Д-35 engine.

The test lasts 100 h and is divided into 10 individual stages.

With the engine running at 90% of rated power, it is necessary to maintain constancy of fuel consumption (2.2 kg/h), water-discharge temperature (85°C), temperature drop ($T_{vykh} - T_{vkhed}$ = 5-10°C), oil pressure (3 atm), and oil temperature (90-95°C).

The engine-operation regime for each stage is shown in Table 54.

TABLE 53

Characteristics of Д-35 and 1 Ч-10.5/13 Engines

1 Показатели	Д-35	1Ч-10,5/13
2 Тип двигателя	15 Бескомпрессорный 4-тактный дизель	15 Бескомпрессорный 4-тактный дизель
3 Способ смесеобразования	16 Вихревая камера	16 Вихревая камера
4 Номинальная мощность, *л. с.*	40	10
5 Число цилиндров	4	1
6 Диаметр цилиндра, *мм*	105	105
7 Ход поршня, *мм*	130	130
8 Число оборотов, *об/мин*	1400	1500
9 Степень сжатия	17	18
10 Удельный расход топлива при номинальной мощности, *г/э л. с. ч*	220	220
11 Наибольшее давление горения, *кг/см²*	55—60	50—60
12 Среднее эффективное давление, *кг/см²*	5,35	5,35
13 Средняя скорость поршня, *м/сек*	6,5	6,5
14 Давление впрыска топлива, *кг/см²*	100—140	100—140

1) Index; 2) type of engine; 3) fuel-vaporization method; 4) rated power, hp; 5) number of cylinders; 6) cylinder bore, mm; 7) piston stroke, mm; 8) engine speed, r/min; 9) compression ratio; 10) specific fuel consumption at rated power, g per effective hp per h; 11) maximum combustion pressure, kg/cm^2; 12) average effective pressure, kg/cm^2; 13) average piston speed, m/s; 14) fuel-injection pressure, kg/cm^2; 15) noncompressor, four-stroke diesel; 16) eddy chamber.

TABLE 54

Characteristics of Stages

1 Режим	2 Число оборотов в минуту	3 Продолжительность
4 Холостой ход	500	15 *мин* 7
5 То же	1500	15 *мин* 7
90% номинальной 6 мощности	1500	8 4ч 15 *мин* 7
100% " "	1500	15 *мин* 7
4 Холостой ход	1500	15 *мин* 7
90% номинальной 6 мощности	1500	8 4ч 15 *мин* 7
100% " "	1500	15 *мин* 7
4 Холостой ход	1500	15 *мин* 7
9 Итого	—	10 ч 8

1) Regime;
2) Engine speed;
3) Duration;
4) Idle;
5) The same;
6) Of rated power;
7) Min;
8) h;
9) Total.

The evaluation is made by the ДВС 344-T negative method for appraising carbon deposits and wear [8].

In addition to engine-test procedures with single-cylinder engines, serial-produced automobile and tractor engines are widely used for stand oil tests.

Short- and long-term tests in ГАЗ-51, ЯАЗ-204, МЗМА-402, КМД-46, Д-40, and other engines are the most widely employed in research involving stand screening tests of new oils and oil additives and for modern Soviet engines.

Some of these test procedures are briefly described below.

Short-term 100-hour Oil Tests in ГАЗ-51 Automobile Engine Under Stand Conditions

These tests are conducted to make a preliminary appraisal of the engine properties of experimental oils intended for carbureted automobile engines. The procedure essentially consists in comparing the results of tests with an experimental specimen and the results of tests with a standard oil in the same engine; the indices compared are piston-ring mobility, amount of deposits on pistons, piston rings, and piston grooves, engine-component wear, change in oil physicochemical properties, and amount of deposits on filters.

The standard oil is the oil customarily used for the ГАЗ-51 engine (as recommended by the manufacturer).

Before an experimental specimen is subjected to 100-hour tests in the ГАЗ-51 engine, the physicochemical properties of the oil should be determined. The preliminary tests are carried out in laboratory equipment specialized for oil testing (e.g., the ИТ 9-3 apparatus) and should show any tendency toward tarring of the piston rings, formation of tar, carbon deposits, sludge, or resinous deposits on the components, corrosive properties, additive filterability, etc.

New engines or engines having new cylinder-piston or rod-crankshaft components are prepared for oil testing in the following manner.

TABLE 55

Running-in Regime

1 Режим	2 Число оборотов коленчатого вала в минуту	3 Продолжительность
4 Холостой ход	600	15 мин 9
10 л. с. 5	800	30 мин 9
15 л. с. 5	1200	1 ч 10
25 л. с. 5	1600	1 ч 10
35 л. с. 5	2000	1 ч 10
40 л. с. 5	2 00	1 ч 10
45 л. с. 5	2400	45 мин 9
6 Полное открытие дросселя	2800	5 мин 9
25 л. с. 5	1600	15 мин 9
4 Холостой ход	1200	10 мин 9
7 Остановка		
8 Итого	—	6 ч 10

1) Regime; 2) crankshaft speed; 3) duration; 4) idle; 5) hp; 6) throttle full open; 7) shutdown; 8) total; 9) min; 10) h.

The cylinder head is removed and, with the pistons at BDC (HMT), holes are cut in the working surfaces of the cylinders at a distance of 9 mm from the top, in order to measure the wear by the hole method devised by the Institute of Machine Building, Academy of Sciences of the USSR [AN SSSR] (AH CCCP). The holes are cut and measured with an УПОИ apparatus (general-purpose wear-determination apparatus). A total of 16 holes are cut in each cylinder, uniformly distributed about its circumference.

After the holes have been cut, the engine must be run in for 48 h. Table 55 shows the running-in regime, which is repeated 8 times.

Oil is added to the upper level-indicator mark at 6-hour intervals, 10 min after the engine has been shut down.

Oil changes are made after the engine has been running for 6, 12, and 30 h and at the end of the running-in period (48 h). The oil and water-discharge temperatures are held at 80-85°C. The standard oil is used for running-in.

The fuel is type A-70 automobile gasoline and the same batch of fuel is used for each series of tests.

The oil-filter elements for an entire series of tests in a given engine are preliminarily tested for pass capacity and pressure loss in a special stand. The pass capacities of the filters should not differ by more than 20%. It is determined with pressures of 1.5, 2.0, 2.5, and 3 kg/cm^2 in front of the filter at an oil temperature of 75°C. The spark and carburetor advance are adjusted in accordance with the instructions furnished by the ГАЗ Plant.

After the running-in period, the engine is disassembled and its components are cleaned of deposits and measured micrometrically. The component dimensions should be within the tolerances established for a new engine: the cylinder eccentricity and taper should be no more than 0.02 mm and the clearance between the piston skirt and cylinder should be 0.024-0.036 mm (with the piston diameter measured perpendicular to the piston-boss axis). The piston-ring closure gap is measured in the cylinder where the ring will operate and should be 0.2-0.4 mm. The requisite gap between the piston ring and groove wall is 0.050-0.082 mm for the first compression ring and 0.035-0.067 mm for all other rings. All the rings should move freely in the grooves under the action of their own weight. The holes should also be measured and the piston rings weighed.

After assembly and adjustment, the engine is ready for tests.

The engine is run in for 2 h with the oil to be tested at the beginning of each 100-h test. Table 56 gives the running-in regime.

The water-discharge and oil temperatures are held at 80-85°C. An oil change is made after the engine has been operating for 20 min and at the end of the running-in period. The oil-filter element is changed after running-in, fresh test oil is poured in, and a new oil filter is installed, having previously been soaked in the test oil and left to stand for 24 h in order for the excess oil to run off. The filter is weighed before installation in the engine and

TABLE 56

Running-in Regime

1 Режим	2 Число оборотов коленчатого вала в минуту	3 Продолжительность, мин
4 Холостой ход	1200	15
5 Остановка для смены масла	1200	20
25 л. с. 6	1600	30
35 л. с. 6	2000	30
45 л. с. 6	2400	30
7 Холостой ход	1200	15
8 Остановка		
9 Итого	—	—

1) Regime;
2) Crankshaft speed, rpm;
3) Duration, min;
4) Idle;
5) Shutdown for oil change;
6) hp;
7) Idle;
8) Shutdown;
9) Total.

again when changed. The filter should also be left to stand for 24 h before weighing, so that the excess oil can run off. The low-quality filter and the high-quality filter housing are cleaned by rinsing after the running-in period.

A total of 5.4 kg of the test oil is poured into the engine crankcase. The test time is 102 h. The oil and high-quality filter are changed after 51 h; the low-quality filter and the high-quality filter housing are again rinsed at this time. The test consists of 34 stages, the regimes for which are given in Table 57.

The oil temperature is held at 83-93°C. The fuel consumption with the throttle full open and a crankshaft speed of 2000 r/min should be 13.4-13.6 kg/h, while the spark-advance angle should be 18-20° (checked at the beginning of the test, on switching to the 0.75 P_e regime, at 2800 r/min and with the throttle full open at 1600 r/min). The engine shutdown lasts 10 min. Oil is added to the upper level-indicator mark after 9 h, at the end of the shut-down period. The amount of oil added to the engine and the amount removed are recorded.

The knob of the low-quality filter is given two turns after each engine shutdown at the end of a 3-hour cycle. The following oil samples are taken during the test: for general analysis after 20 min of engine operation (400 g), for determination of iron content after 1 h 10 min at 2100 r/min (100 g), for general analysis after 27 h of engine operation (400 g), and for general analysis and determination of iron content after 51 h (at the end of the cycle).

TABLE 57

Test Regime

[1] Режим	[2] Количество оборотов в минуту	[3] Время, мин
[4] Пуск и прогрев двигателя	600	15
[5] Холостой ход	600	10
0,5 Pe, n*. [6]	1400	35
0,75 Pe, n. [6]	2100	35
[7] Полное открытие дросселя	2800	15
[5] Холостой ход	600	10
0,75 Pe, n. [6]	2800	35
[7] Полное открытие дросселя	1600	15
[8] Холостой ход и охлаждение двигателя по т-ры выходящей воды 40° C и масла 50° C	600	10
[9] Итого	—	3 ч 10

*P_e, n. is the effective pressure corresponding to the rated power indicated by the engine manufacturer. The water-intake temperature is held at 78-88°C.

1) Regime; 2) engine speed; 3) time, min; 4) engine start and warm-up; 5) idle; 6) P_e, n.; 7) throttle full open; 8) idle, engine cooled, water-discharge temperature – 40°C, oil temperature – 50°C; 9) total; 10)h.

The engine operating regime is monitored by measuring the engine speed, load, fuel consumption, coolant-water intake and discharge temperatures, crankcase-oil temperature, exhaust-gas temperature, intake vacuum, air-intake temperature, amount of gases entering the crankcase, and oil-line pressure. The amount of gases blown by into the crankcase is measured at the beginning and end of the 51-h engine operating cycle, with the throttle full open and engine speed of 2800 and 1600 r/min.

The test results are evaluated by the ДВС 344-T negative method for appraisal of carbon deposits and wear [8].

Short-term 120-hour Oil Tests in ЯАЗ-204 Engine Under Stand Conditions

These tests are conducted to make a preliminary evaluation of the engine properties of experimental oils for automobile diesels.

The procedure essentially consists in comparing the results of tests conducted with the experimental oil and those of tests conducted with a standard oil in the same engine; the indices used include piston-ring mobility, amount of deposits on pistons, piston rings, and piston grooves, engine-component wear, change in oil physicochemical properties, and amount of deposits on filters.

The standard oil is the oil customarily employed for the ЯАЗ-204 engine (that recommended by the manufacturer).

Tests are conducted with the standard oil at the beginning and end of each series of experiments, in order to determine the change in engine condition.

The physicochemical properties of the experimental oil should be determined before the tests. It is desirable that the test be conducted in laboratory equipment specialized for oil testing (e.g., the ИТ 9-2 or ИТ 9-3 apparatus), in order to show up any tendency toward ring scuffing, formation of tars, carbon deposits, or resin deposits on the components, corrosive properties, additive filterability, etc.

TABLE 58

Running-in Regime

1 Гежим	2 Число оборотов в минуту	3 Продолжительность, *мин*
4 Холостой ход	1000	15
20 *л. с.* 5	1000	12
50 *л. с.* 5	1500	30
90 *л. с.* 5	1800	30
6 Полная подача топлива	2000	30
4 Холостой ход	1000	3
7 Остановка		
8 Итого	—	2 ч 9

1) Regime;
2) Engine speed, r/min;
3) Duration, min;
4) Idle;
5) hp;
6) Throttle full open;
7) Shutdown;
8) Total;
9) h.

A new engine or an engine with new cylinder-piston and rod-crankshaft assemblies is used for testing each series of oils. In order to prepare the engine, it is disassembled and its components are cleaned of carbon and other deposits, rinsed in kerosene, and measured micrometrically. The component dimensions and assembly clearances should meet the tolerances specified for the new engine. All the piston rings are replaced with new ones. The first compression ring should not be chromium-plated. The rings should move freely in the piston grooves under the action of their own weight.

In order to measure the wear by the hole method developed by the Institute of Machine Building, Academy of Sciences of the USSR, holes are cut in the working surfaces of the cylinder sleeve. A total of 16 holes are cut in a band 21.0 mm from the top of the sleeve at intervals of 22.5° about its circumference, while bands of 8 holes at intervals of 45° are cut in belts 27.5 and 40 mm from the top. The first hole in each belt is cut into the side of the sleeve facing the heating element. The holes are numbered counterclockwise. A micrometer is used to measure the thickness of the sleeve wall around the belts and at the points where the holes are cut (moving 5-6 mm clockwise from each hole). The points at which the wall thickness is measured are carefully recorded (especially with respect to sleeve height).

The pumps and vaporizers are checked in a special apparatus before running-in and before each test. Their delivery rate, the tightness of the plunger assemblies, the pressure required to open the control valve, the fuel leakage, and the type of flow are determined. The hydraulic characteristics of the sprayer are established before running-in. The characteristics of the pumps and nozzles should satisfy technical specifications.

The elements of the high-quality oil filter are selected so as to have similar pass capacities for each series of tests in a given engine. The pass capacity is determined in a special apparatus with oil pressures of 1.5, 2.0, 2.5, and 3.0 kg/cm^2 in front of the filter and an oil temperature of 75°C. The pass capacities of the filter elements should not differ by more than 20%.

After the engine has been assembled and adjusted, it is run in with standard oil and standard diesel fuel for 100 h. Table 58 shows the regimes under which the engine should operate during this period.

The regime is repeated in 50 cycles. The fuel consumption at full throttle and 2000 r/min is adjusted to 24.8-25.2 kg/h. The discharge temperature of the coolant water is held at 80-85°C, while the crankcase-oil temperature is kept at 70-75°C (forced cooling of the crankcase is permissible). The difference between the water intake and discharge temperatures should not exceed 10°C. The oil is changed after 2, 6, 12, 24, 36, 50, and 100 h of engine operation. The low-quality oil filter is rinsed and the oil is poured off from the high-quality filter housing during each oil change. The oil-filter element is replaced after operation for 50 h.

At the end of the running-in period, the engine is disassembled and its components are cleaned of deposit. The holes are measured, the piston rings are weighed, and the components are measured micrometrically, their wear being the index evaluated.

The two upper compression rings of each piston are replaced with new non-chromium-plated rings before each test. One oil ring on each of two pistons is also replaced, using rings removed from the engine before running-in. After assembly and adjustment, the engine is ready for tests.

A 20-h running-in in 2-h stages, under the regimes described above, is carried out before each 120-h test. Oil changes are made after 2, 6, and 12 h of running-in. Oil is added as needed. The high-quality oil-filter element is left unchanged throughout the entire 20-h period. The low-quality filter element is rinsed during each oil change. The hot engine is adjusted at the end of the running-in period and its fuel consumption at 2000 rpm is checked. The fuel consumption at full throttle and 2000 r/min should be 24.8-25.2 kg/h. The evenness of cylinder operation at 2000 and 1500 r/min is then checked and governor points are established at 1000, 1200, 1500, 1800, and 2000 r/min; the nonuniformity of cylinder operation should not exceed 3% of the highest value obtained.

When the engine has been adjusted, the oil with which running-in was carried out is poured off, the high- and low-quality filters are rinsed, and a high-quality filter element that has been weighed and checked for pass capacity is installed. The engine crankcase is filled with 15 kg of fresh oil. The engine is started and operates under regimes shown in Table 59.

Each stage constitutes 10 h of operation. The test consists of 12 stages. The engine is stopped after each stage and oil is added (the amount of oil added during each test is kept constant as far as possible).

The pass capacity of the high-quality oil filter is determined during each 10-h stage, with the engine operating at full throttle and 1500 rpm. The oil is changed after operation for 60 h and both filter elements are replaced. The filter elements removed are weighed after they have been permitted to stand for 24 h for oil drainage. A second 60-h test cycle is carried out after the oil change.

The engine operating regime is monitored by measuring the torque, engine speed, coolant-water intake and discharge temperatures, crankshaft-oil temperature, receiver temperature, oil-line pressure, fuel pressure, receiver air pressure, exhaust-gas pressure, and intake vacuum.

The oil consumption during the test period is recorded (taking into account the oil initially introduced into the engine, that added, the samples taken, and the losses from the engine).

The fuel consumption is measured for all the loaded regimes during all the 10-h stages. It should be 24.8-25.2 kg/h at full throttle and 200 rpm throughout the entire test.

Crankcase-oil samples (350 g) are taken from the oil line with the engine idling after operation for 20 min and 10, 20, 30, 40, 50, and 60 h in each 60-h cycle. Samples are also taken of the oil drained from the crankcase and filter housings.

The test results are evaluated by the ДВС 344-T negative method for appraisal of deposits and wear [8].

Short-term 100-hour Oil Tests in Д-35 Tractor Engine Under Stand Conditions

These tests are conducted in order to make a preliminary evaluation of the engine properties of experimental oils for tractor diesels.

The procedure essentially consists in comparing the results

TABLE 59

Test Regime

[1] Режим	[2] Число оборотов в минуту	[3] Продолжительность
[4] Холостой ход (прогрев)	1000	5 мин [11]
10% подачи топлива [5]	1000	25 мин [11]
40% " "	1000	1 мин [11]
50% " "	1100	1 ч [12]
[6] Полная подача топлива	1000	1 ч [12]
[7] То же	1300	1 ч [12]
"	1500	1 ч [12]
"	1700	1 ч [12]
"	1900	1 ч [12]
"	2000	1 ч [12]
75% подачи топлива [5]	1500	30 мин [11]
50% " "	1000	30 мин [11]
10% " "	1000	30 мин [11]
[8] (охлаждение)		
[9] Остановка и охлаждение двигателя до температуры масла 50° C		
[10] Итого	—	10 ч [12]

Note. The water-discharge temperature at speeds below 1500 rpm is held at 55-60°C, the crankcase-oil temperature is held at 100-105°C, and the water-discharge temperature at speeds above 1700 r/min is kept at 85-90°C.

1) Regime; 2) engine speed, rpm; 3) duration; 4) idle (warmup); 5) throttle; 6) full throttle; 7) the same; 8) cooling; 9) shutdown and cooling of engine to oil temperature of 50°C; 10) total; 11) min; 12) h.

of tests made with an experimental oil and those of tests made with a standard oil in the same engine; the indices employed include piston-ring mobility, amount of deposits on pistons, piston rings, and piston grooves, engine-component wear, change in oil physicochemical properties, and amount of deposits on filters.

The standard oil is the oil customarily used for the Д-35 engine (that recommended by the manufacturer).

The physicochemical properties of the experimental oil should be determined before the tests. It is desirable that tests be conducted in laboratory equipment specialized for oil testing (e.g., the ИТ 9-2 or ИТ 9-3 apparatus) before the tests in the Д-35 engine, in order to show up any tendency toward piston-ring scuffing, formation of tars or carbon and resin deposits on the components, corrosive properties, additive filterability, etc.

In order to prepare a new engine (or an engine having a new cylinder-piston or rod-crankshaft assembly), it is disassembled and the components are cleaned of carbon and other deposits and rinsed in kerosene.

TABLE 60

Running-in Regime

1 № пп	2 Режим	3 Число оборотов в минуту	4 Длительность режима
1	5 Холостой ход	500	30 мин 10
2	6 То же	1000	30 мин 10
3	"	9 На регуляторе	20 мин 10
4	25% номинальной 7 мощности	"	20 мин 10
5	40% " "	"	20 мин 10
6	5 Холостой ход	9 500	30 мин 10
7	6 То же	9 На регуляторе	11 30 мин 10
8	25% номинальной 7 мощности		1 ч 30 мин 10
9	40% " "		1 ч 30 мин 10
10	50% " "	"	1 ч 30 мин 10
11	70% " "	"	1 ч 30 мин 10
12	80% " "	"	15 мин 10
13	8 Полная нагрузка	"	15 мин 10
14	5 Холостой ход	"	30 мин 10

1) No.;
2) Regime;
3) Engine speed, rpm;
4) Duration;
5) Idle;
6) The same;
7) Rated power;
8) Full load;
9) Governed;
10) min;
11) h.

After cleaning and rinsing, the pistons, piston rings, and cylinder sleeves are measured micrometrically. The component dimensions should be within the tolerances set for a new engine. The eccentricity and taper of the cylinder sleeves should be no more than 0.05 mm and the clearance between the piston skirt and cylinder sleeve should be 0.175-0.260 mm (along the major axis of the ellipse).

The chromium-plated first compression rings are replaced with unplated rings. Special attention is paid to ring selection. The ring gap, measured in a standard cylinder with a diameter of 100 mm, should be 0.4-0.7 mm. The rings on ifferent pistons should have the same gaps. The permissible ring clearance in the piston grooves is 0.08-0.13 mm for the first and second compression rings and 0.05-0.10 mm for all the other rings. All the rings should move freely in the grooves under the action of their own weight.

The high-quality oil-filter elements for an entire series of tests in a given engine are preliminarily checked for pass capacity and pressure loss in a special apparatus. The pass capacities of the elements should not differ by more than 20%. This factor is determined with pressures of 1.5, 2.0, and 2.5 kg/cm^2 in front of the filter and an oil temperature of 75°C.

The fuel pump and nozzles should be adjusted for uniform delivery and advance angle, checking the spray pressure and quality.

After the engine has been assembled and adjusted, it must be run in. The length of the running-in period has been set at

62 h 30 min. Table 60 shows the running-in regime. The running-in cycle covering stages 1-6 is carried out once, while that covering stages 7-14 is repeated 8 times. Oil is added first after operation for 10 h and every 15 h thereafter. The crankcase-oil temperature under the loaded regimes is held at 75-80°C, while the coolant-water discharge temperature is kept at 80-85°C. Forced water cooling of the crankcase is permissible. A standard oil is employed for running-in. The fuel is a standard fuel.

TABLE 61

Test Regime

1 Режим	2 Число оборотов в минуту	3 Длительность режима
4 Холостой ход	50	5 мин 8
40% номинальной 5 мощности	6 На регуляторе	5 мин 8
95% " "	"	9 ч 40 мин 8
40% " "	"	5 мин 8
4 Холостой ход	500	5 мин 8
	7 Итого	10 ч 9

1) Regime;
2) Engine speed, rpm;
3) Duration;
4) Idle;
5) Rated power;
6) Governed;
7) Total;
8) Min;
9) h.

At the end of the running-in period, the engine is disassembled and its components are cleaned of deposits. The piston rings are weighed and the components are measured micrometrically, their wear being the characteristic to be evaluated. The magnetic crankcase plug must be replaced by a nonmagnetic one. The engine is then assembled and mounted on a stand ready for tests.

A second 10-h running-in under the same regimes is carried out before each test; the engine crankcase is filled with 11.5 kg of the test oil and a new filter element is installed in the high-quality oil filter.

At the end of the running-in period, the crankcase oil must be drained and weighed, the element of the low-quality oil filter is rinsed and weighed, the housing of the high-quality filter is rinsed, and a previously checked and weighed high-quality element is installed. The adjustment of the fuel system is checked. A total of 11.5 kg of fresh test oil is then poured into the crankcase and the engine is ready for tests. Each test lasts 100 h and is divided into 10 individual stages (see Table 61). The following conditions must be maintained with the engine operating at 95% of its rated power: fuel consumption – 7.1-7.3 kg/h, water-discharge temperature – 93-97°C, water-temperature drop (T_{vykh} – T_{vkhod}) – 5-10°C, oil pressure P_n = 1.5-2.0 kg/cm², and oil temperature – 90-95°C.

The engine operating regime is monitored by measuring the engine speed, load, fuel consumption, coolant-water intake and discharge temperatures, crankcase-oil temperature, exhaust-gas temperature (for each cylinder), amount of gases blown by into the crankcase, and oil-line pressure. The readings of all the instruments are recorded in the test book every 30 min and at the end of each stage; the amount of gases blown by into the crankcase and the fuel consumption are recorded every 2 h.

The engine is shut down after each 10 h of operation. The water-intake temperature must be reduced to 75-80°C during the idle period before each shutdown.

The duration of the shutdowns between stages is held to about 45 min. After each stage, the oil must be drained from the crankcase and filter housings. After drainage for 30 min, the collected oil is weighed and fresh oil is added to bring the total amount in the crankcase to 11.5 kg. If less than 1.2 kg of oil has been burned over any 10-h period, 1.2 kg of oil is taken from that drained and an equal amount of fresh oil is added.

After each 10 h of engine operation, oil samples weighing 150 g are taken from the oil line with the engine running (before shutdown), while 350-g samples are taken 30 min after startup and at the end of each stage. The oil is taken through a cock installed near the low-quality filter.

The test results are evaluated by the ДВС 344-T negative method for appraising deposits and wear [8].

Long-term 480-hour Oil Tests in ЯАЗ-204 Automobile Engine Under Stand Conditions

This procedure is intended to establish the suitability of the experimental oil for use in automobile engines. It involves comparison of the results of tests with the experimental oil and those of tests with a standard oil in an ЯАЗ-204 engine; the indices evaluated include change in engine power and economy, engine-component wear, engine-component corrosion, piston-ring mobility character and amount of deposits on engine components, oil consumption, and change in oil physicochemical properties. The standard

TABLE 62

Running-in Regime

1 Режим	2 Число оборотов в минуту	3 Продолжитель-ность, мин
4 Холостой ход	1000	15
30 л. с. 5	1000	15
50 л. с. 5	1500	30
90 л. с. 5	1800	30
6 Полная подача топлива	2000	30
7 Итого	—	2 ч 8

1) Regime; 2) engine speed, rpm; 3) duration, min; 4) idle; 5) hp; 6) full throttle; 7) total; 8) h.

oil is the oil customarily used in the ЯАЗ-204 engine (that recommended by the manufacturer).

The tests include preliminary running-in, a second running-in after disassembly and reassembly, determination of control characteristics, and engine operation under a long-term regime for 480 h.

Before the long-term tests, the experimental oil must be subjected to physicochemical analysis in accordance with the GOST's or Arbitrary Technical Specifications; it is also recommended that it be tested in laboratory equipment and be subjected to short-term tests in a full-sized engine, using a standard oil for comparison (the physicochemical analyses and laboratory tests are neglected in short-term 120-h oil tests in the ЯАЗ-204 engine). The engine is run-in with standard oil for 50 h before testing; Table 62 gives the running-in regime.

Operation for 2 h constitutes a single stage and the running-in consists of 25 stages. The water-discharge temperature is held at 80-85°C. The radiator used to cool the engine can be replaced by a mixing tank. The crankcase-oil temperature is held at 70-75°C, but forced water cooling of the crankcase is not permitted. A single oil change is made after 15 min of engine operation during the first running-in; changes are made after operation for 2, 6, and 12 h during the second running-in. Oil is added 15 min after the shutdown period at the end of each 10 h of engine operation.

TABLE 63

Test Regime

1 № пп	2 Режим	Число оборотов коленчатого вала в минуту 3	Продолжительность 4
1	5 Холостой ход (прогрев)	1000	30 мин 11
2	40% подачи топлива6	1000	1 ч 12
3	50% " "	1000	1 ч 12
4	7 Полная подача топлива	1100	1 ч 12
5	8 То же	1300	1 ч 12
6	"	1500	1 ч 12
7	"	1700	1 ч 12
8	"	1900	1 ч 12
9	"	2000	1 ч 12
10	75% подачи топлива6	1500	30 мин 11
11	50% " "	1000	30 мин 11
12	9 Холостой ход (охлаждение)	1000	30 мин 11
	10 Остановка и охлаждение двигателя до температуры воды 40° С и температуры масла 50° С		

1) No.; 2) regime; 3) crankshaft speed, rpm; 4) duration; 5) idle (warmup); 6) throttle; 7) full throttle; 8) the same; 9) idle (cooling); 10) shutdown and cooling of engine to water temperature of 40°C and oil temperature of 50°C; 11) min; 12) h

At the end of the 50-h running-in period, the engine is disassembled for removal of deposits, inspection, and micrometric component measurement. The cylinder sleeves, pistons, piston rings, (gap, height, and width), piston grooves, piston pins, upper rod bushings, rod and crank necks, and rod and crank bearing bushings are measured. The piston rings and bearing bushings are measured After measurement and reassembly, the engine is run in for a second 50-h period with the test oil, under the same regimes previously employed. The engine is not disassembled after the second running-in, but its characteristics are determined and the long-term test is begun.

The engine characteristics (evenness of cylinder operation at 2000 r/min and loaded speed characteristic at 2000, 1500, and 1000 r/min) are determined at the beginning and end of the test, with control and working sprayer pumps.

The pumps are tested for delivery capacity and spray quality before installation in the engine and at end of each test.

The high-quality oil filters for use throughout the entire test are checked for pass capacity in a special apparatus. The pass capacity is determined with a pressure of 1.5, 2, 2.5, and 3.0 kg/cm^2 in front of the filter and an oil temperature of 75°C; the deviations in pass capacity should not exceed 20% of the average value.

The long-term test is conducted in 10-h stages, using the regimes shown in Table 63.

The water-discharge temperature is held at 55-60°C during stages 1-6 (see Table 63) and at 85-95°C during stages 7-11. The radiator can be replaced by a water-mixing tank to cool the engine.

The oil temperature for stages 1-6 is not stipulated. The crankcase-oil temperature for stages 7-11 is held at 100-110°C; forced water cooling of the crankcase is permitted. The fuel consumption at full throttle and 2000 rpm should be 24.8-25.2 kg/h.

The oil and filter elements are changed after operation for 60 h; oil is added after each 10 h of operation.

The following information is recorded after every 30 min of engine operation throughout the test: engine speed, load, water intake and discharge temperatures, crankcase-oil temperature, exhaust-gas temperature, oil pressure before low-quality filter and in oil line, crankcase-gas pressure, exhaust-gas pressure, receiver pressure, and intake vacuum. The fuel consumption is measured for each loading regime.

The amount of deposits on the high- and low-quality oil-filter elements is determined from the difference in the element weight before installation in the engine and after removal from the engine with each oil change. Before installation in the engine, the high-quality filters are soaked in oil and weighed after being permitted to drain for 24 h; the same procedure is followed with the filters removed from the engine.

Oil samples (0.5 liter) are taken from the oil line in front of the low-quality filter with the engine idling during the first, third, fifth, and seventh 60-h cycles, after the engine has been operating for 20 min and for 10, 20, 30, 40, 50, and 60 h. All the oil samples are used for determination of viscosity at 50 and 100°C, acid number, tar content, ash, and mechanical-impurity content.

The amount of oil initially introduced into the engine, the samples taken, the oil added, and that drained are all recorded.

Servicing of the engine during the tests is carried out in accordance with the manufacturer's instructions.

At the end of the test, after the control characteristics have been determined, the engine is disassembled for inspection. The amount of carbon and tar deposits is determined and the components are subjected to micrometric measurement.

The amount of deposits on the pistons and rings is determined after rinsing in gasoline, by weighing before and after the deposits are removed. The amount of carbon deposited in the combustion chambers is determined by weighing the deposits, which are removed with a scraper. The deposits are analyzed by a special method.

Piston-ring mobility is evaluated immediately after the engine is disassembled and before the pistons are rinsed with gasoline, from the force necessary to remove the rings in the piston grooves. A ring is considered to be free if it moves under the action of its own weight, tight if it moves when a slight force is exerted on it, very tight when a considerable force is required to move it with difficulty, and frozen if it cannot be moved at all. A ring can be frozen over its entire circumference or only partially. The arch, in degrees, over which the ring is frozen is noted.

Long-term 900-hour Oil Tests in Д-35 Tractor Engine Under Stand Conditions

This procedure is intended to establish the suitability of an experimental oil for use in tractor diesels. It involves comparison of the results of tests conducted with experimental and standard oils in a Д-35 engine; the criteria employed include the change in engine power and economy, engine-component wear, engine-component corrosion, piston-ring mobility, character and amount of carbon and tar deposits on engine components, oil consumption, and change in oil physicochemical properties.

The standard oil is the oil customarily used in the Д-35 engine (that recommended by the manufacturer).

The tests include preliminary running-in, a second running-in after disassembly and reassembly, determination of control characteristics, and engine operation under a long-term test regime for 900 h.

Before long-term tests are made, the experimental oil must be subjected to physicochemical analysis in accordance with the GOST or Arbitrary Technical Specifications; it is also recommended that it undergo tests in laboratory equipment and short-term tests

TABLE 64

Running-in Regime

№ п. п. [1]	Режим [2]	Число оборотов коленчатого вала в минуту [3]	Продолжительность [4]
1	Холостой ход [5]	500	30 мин [11]
2	То же [6]	1000	30 мин [11]
3	"	На регуляторе [10]	20 мин [11]
4	25% номинальной мощности [7]	"	20 мин [11]
5	40% " "	"	20 мин [11]
6	Холостой ход [5]	500 [10]	30 мин [11]
7	То же [6]	На регуляторе	30 мин
8	25% номинальной мощности [7]	"	1 ч 30 мин [12, 11]
9	40% " "	"	1 ч 30 мин [12, 11]
10	50% " "	"	1 ч 30 мин [12, 11]
11	70% " "	"	1 ч 30 мин [12, 11]
12	80% " "	"	15 мин [11]
13	Полная подача топлива [8]	"	15 мин [11]
14	Холостой ход [5]	"	30 мин [11]
	Итого [9]		10 ч [12]

1) No.; 7) Rated power;
2) Regime; 8) Full throttle;
3) Crankshaft speed, rpm; 9) Total;
4) Duration; 10) Governed;
5) Idle; 11) min;
6) The same; 12) h.

in a full-size engine, with a standard oil for comparison (the physicochemical analyses and laboratory tests are omitted in short-term 100-h tests in the Д-35 engine).

The engine is disassembled before the tests and components that do not meet technical specifications are replaced. Running-in is then carried out with a standard oil; the running-in regime is shown in Table 64.

The running-in cycle covering stages 1-6 is carried out once, while that covering stages 7-14 is repeated 8 times. The water-discharge temperature and crankcase-oil temperature are held at 80 ± 5°C under the loaded regimes. The engine-operation indices are recorded in the test book at the end of each stage.

Oil is added first after 10 h and then after every 7.5 h of engine operation, 15 min after the engine has been shut down, bringing the oil level up to the top indicator mark. The oil is changed once during running-in, after the engine has been operating for 30 min.

When the oil consumption is high, the engine must continue to be run in under the regime covering stages 7-14. After running-in, the engine is disassembled for removal of deposits, examination, and measurement of its components. The cylinder sleeves, pistons, piston rings (gap, height, and width), upper rod bushings, rod and crank necks, and rod and crank bearing bushings are measured. The piston rings and bearing bushings are weighed.

After measurement and reassembly, the engine is again run in for 10 h with the test oil. The oil is changed after this running-in and the engine characteristics are recorded.

The engine characteristics (evenness of cylinder operation and governor characteristics) are recorded at the beginning and end of tests with control and working injectors. In addition, the condition of the engine is monitored by determining the control point $N_{e\ maks}$ from the governor characteristic with G_t = 8.3 kg/h at 1400 r/min after every 200 h of engine operation under the long-term test regime. Adjustments are made when necessary.

TABLE 65

Test Regime

№ п. п. [1]	Режим [2]	Число оборотов коленчатого вала в минуту [3]	Продолжительность [4]
1	[5] Холостой ход (прогрев)	[9] 500	15 мин [10]
2	[6] То же	На регуляторе	15 мин [10]
3	$0,9P_e$	•	4 ч [11] 15 мин [10]
4	[7] Перегрузка по оборотам	[9] 1260	15 мин [10]
5	[5] Холостой ход	На регуляторе	15 мин [10]
6	$0,9P_e$	•	4 ч [11] 15 мин [10]
7	[7] Перегрузка по оборотам	1260	15 мин [10]
8	[5] Холостой ход	500	15 мин [10]
9	[8] Остановка двигателя	500	15 мин [10]

1) No.;
2) Regime;
3) Crankshaft speed, r/min;
4) Duration;
5) Idle (warmup);
6) The same;
7) Speed overload;
8) Engine shutdown;
9) Governed;
10) min;
11) h.

In preparing the engine for tests, the fuel system is checked and adjusted on special stands, the spray quality and pressure are determined, the hermeticity of the injectors and plunger couples is checked, the instant at which the high-pressure pump begins to deliver fuel is determined, and the uniformity of fuel delivery to the cylinders is adjusted.

The high-quality oil filters for the entire test should be checked for pass capacity in a special apparatus. The pass capacity is determined with a pressure of 1.5, 2.0, 2.5, and 3.0 kg/cm^2 in front of the filter and an oil temperature of 75°C. The deviations in filter pass capacity should not exceed 20% of the average value.

The long-term test is carried out in 10-h stages, using the regimes indicated in Table 65.

The long-term test consists of 9 cycles, each with 10 stages.

The water-discharge temperature is held at 90 ± 3°C under the loaded regimes. The radiator can be replaced by a mixing tank for cooling the engine. The water-temperature gradient between the intake and discharge should be 5-10°C. The crankcase-oil temperature is held at 80 ± 5°C under loaded regimes. Forced water cooling of the crankcase is permissible.

The fuel consumption at full throttle and 1400 r/min should be 8.3 ± 0.05 kg/h. Oil is added after the engine has been operating for 10 h. The rated power actually obtained in the stand at full throttle is 8.3 ± 0.05 kg/h at 1400 r/min.

The oil and filter elements are changed after 100 h. The following data are recorded during the test: engine speed, load, fuel consumption, water intake and discharge temperatures, crankcase-oil temperature, exhaust-gas temperature, oil pressure before low-quality filter and in oil line, and crankcase- and exhaust-gas pressures. These data are noted every 30 min and at the end of each stage. The gases blown by into the crankcase are measured once during each stage, with the engine operating at $0.9\ N_e$.

The amount of deposits on the low- and high-quality oil-filter elements is determined from the difference in element weight before installation in the engine and after removal during the oil change. Before installation in the engine, the high-quality elements are soaked in oil and weighed after being left to stand for 24 h for drainage; the same procedure is repeated when they are removed from the engine.

Oil samples of 0.5 liter are taken from the oil line behind the low-quality filter with the engine idling during the second, fifth, seventh, and ninth cycles before fresh oil is added, after the engine has been operating for 20 min and for 20, 60, and 100 h, as well as at the end of the other cycles. The samples are used for determination of viscosity at 50 and 100°C, acid number, tar content, ash, and content of mechanical impurities. The amount of oil initially introduced into the engine, the oil samples taken, the oil added, and that drained are all recorded.

Technical servicing of the engine during the test is carried out in accordance with the manufacturer's instructions.

At the end of the test, after its control characteristics have been determined, the engine is disassembled for inspection. The amount of carbon and other deposits is determined and the components are measured micrometrically. The amount of deposits on the pistons and rings is determined after they have been rinsed in gasoline, by weighing before and after removal of the deposits.

Piston-ring mobility is evaluated immediately after the engine is disassembled and before the pistons have been rinsed with gasoline, from the force necessary to move the rings in the piston grooves. A ring is considered to be free if it moves under the action of its own weight, tight if it can be moved by a small force, and frozen if it cannot be moved at all. A ring can be frozen over its entire circumference or only partially. The arc, in degrees, over which the ring is frozen is recorded.

Long-term 2000-hour Oil Tests in КДМ-46 Tractor Engine Under Stand Conditions

A new КДМ-46 engine is run in for 60 h under a special regime before tests are made with it. After the engine has been run in, it is adjusted in accordance with the manufacturer's instructions and is ready for long-term tests, which are conducted in 10-hour stages under the regimes shown in Table 66.

TABLE 66

Test Regime

1 Режим	2 Число оборотов в минуту	3 Продолжительность
90 л. с. 4	1000	1 ч 7
80 л. с. 4	1000	7 ч 7
5 Максимальный	1000	1 ч 7 45 мин 8
0	600	15 мин 8
6 Итого		10 ч 7

Note. $N_{e\ maks}$ is assumed to conform to the GOST for the КДМ-46 engine.

1) Regime;
2) r/min;
3) Duration;
4) hp;
5) Maximum;
6) Total;
7) h;
8) min.

Before and after tests with the engine, its main components are examined, weighed, and measured micrometrically for determination of component wear, type and amount of deposits, onset of component and fuel-system corrosion (visually), and piston-ring mobility.

The cylinder sleeves, piston rings, piston grooves, crank necks, and crank and rod bearing bushings, are measured. The piston rings and assembled pistons and rings are weighed. The control characteristics of the engine (apparent performance, loaded performance at 1000 rpm, and evenness of cylinder functioning) are determined at the beginning and end of the test.

The fuel-system components are checked before and after the test; the hydraulic seal and pressure are determined with a maximeter and the fuel-delivery rate is found.

The amount of deposits on the piston components is determined from the weight difference before and after removal of the deposits.

The amount of deposits on the low- and high-quality oil filters is determined from the difference in filter weight before installation in the engine and after removal; the low-quality filters are weighed after operation for 120 h, while the high-quality filters are weighed after 240 h. The composition of the deposits trapped by the high-quality oil filter is determined. The oil is changed after 120 h, in accordance with the manufacturer's instructions. This interval is arbitrarily taken to be one cycle.

The change in oil physicochemical properties is determined by analysis of samples. These are 0.5 liter in volume and are taken before fresh oil is added, after the engine has been operating for 20 min and for 30, 60, and 120 h during the second, fifth, ninth, thirteenth, and fifteenth cycles, as well as when the oil is drained at the end of each cycle. The amount of oil initially introduced into the engine, the samples taken, the oil added, and that drained are all recorded.

Engine servicing and maintenance during the stand tests are carried out in accordance with the manufacturer's instructions.

Long-term 600-hour Oil Tests in ГАЗ-51 Automobile Engine Under Stand Conditions

This procedure is intended to establish the suitability of an experimental oil for use in carbureted automobile engines. It essentially consists in comparing the results of tests conducted with the experimental oil and a standard oil in an ГАЗ-51 engine; the criteria employed include the change in engine power and economy, engine-component wear, engine-component corrosion, piston-ring mobility, amount and type of deposits on engine components, oil consumption, and change in oil physicochemical properties.

The standard oil is the oil customarily used for the ГАЗ-51 engine (that recommended by the manufacturer). The tests include preliminary running-in for 48 h, a second running-in for 2 h after disassembly and reassembly, determination of control characteristics, and engine operation under a long-term test regime for 600 h.

The tests are conducted with a new valveless crankcase-ventilation system.

Before testing, the experimental oil must be subjected to physicochemical analysis in accordance with the GOST's or Arbitrary Technical Specifications; it is also recommended that it undergo tests in laboratory equipment and short-term tests in a full-size engine, with a standard oil for comparison. The engine is run in with a standard oil for 48 h before testing. The running-in regime is shown in Table 67.

Six hours of operation constitutes a single stage. The running-in process consists of 8 stages. The crankcase-oil and water-discharge temperatures are held at 80-85°C. The oil is changed after the engine has been operating for 6, 12, and 30 h. Oil is added every 6 h (10 min after the engine has been shut down).

After the engine has been run in for 48 h, it is disassembled for inspection, the deposits are removed, and the components are subjected to micrometric measurement: the cylinders, pistons, piston rings (gap, height, and width), upper rod bushings, crankshaft, and crank and rod bearing bushings are measured. The piston rings and bearing bushings are also weighed.

After the micrometric measurements have been made and the engine reassembled, a second 2-h running-in is carried out with the

TABLE 67

Running-in Regime Before Micrometric Measurements

Режим [1]	[2] Число оборотов в минуту	Продолжительность [3]
Холостой ход [4]	800	15 мин [9]
10 л. с. [5]	800	15 мин [9]
15 л. с. [5]	1200	1 ч [10]
25 л. с. [5]	1600	1 ч [10]
35 л. с. [5]	2000	1 ч [10]
40 л. с. [5]	2400	1 ч [10]
45 л. с. [5]	2800	45 мин [9]
Полное открытия дрос-селя [6]	2800	5 мин [9]
25 л. с. [5]	1600	15 мин [9]
Холостой ход [4]	1200	10 мин [9]
Остановка [7]		
[8] Итого	—	6 ч [10]

1) Regime;
2) Engine speed, r/min;
3) Duration;
4) Idle;
5) hp;
6) Full throttle;
7) Shutdown;
8) Total;
9) min;
10) h.

TABLE 68

Running-in Regime After Micrometric Measurements

Режим [1]	[2] Число оборотов в минуту	Продолжительность, мин [3]
[4] Холостой ход [4]	1200	20
[5] Остановка для смены масла		
[4] Холостой ход	1200	15
25 л. с. [6]	1600	30
35 л. с. [6]	2000	30
45 л. с. [6]	2800	30
[4] Холостой ход	1200	15
[7] Остановка		
[8] Итого	—	2 ч [9] 20 мин [10]

1) Regime;
2) Engine speed, r/min;
3) Duration, min;
4) Idle;
5) Shutdown for oil change;
6) hp;
7) shutdown;
8) Total;
9) h;
10) min.

test oil under the regimes shown in Table 68.

The crankcase-oil and water-discharge temperatures are held at 80-85°C during running-in. Oil changes are made 20 min after running-in starts and at the end of the running-in period. The engine is not disassembled after the second running-in; its governor characteristics are determined the oil is changed, and the long-term test is then conducted.

The high-quality oil filters for all the tests are checked for pass capacity in a special apparatus. The pass capacity is determined with a pressure of 1.5, 2.0, 2.5, and 3.0 kg/cm² in front of the filter and an oil temperature of 75°C. The deviations in filter pass capacity should not exceed 20% of the average value.

The long-term tests are carried out in 3-h stages, the regimes for which are given in Table 69.

Three hours of operation constitutes a single stage. A long-term test consists of 200 stages.

TABLE 69

Test Regime

[1] № п п.	[2] Режим	[3] Количество оборотов в минуту	[4] Время работы, мин
1	[5] Пуск и прогрев двигателя	600	15
2	[6] Холостой ход	600	10
3	0,5 P_e, н*. [7]	1400	35
4	0,75 P_e, н. [7]	2100	35
5	[8] Полное открытие дроссельной заслонки	2800	15
6	[6] Холостой ход	600	10
7	0,05 P_e, н. [7]	2800	35
8	[8] Полное открытие дроссельной заслонки	1500	15
9	[9] Холостой ход и охлаждение двигателя до т-ры выходящей воды 40° C и масла 50° C	600	10
	[10] Итого	—	3 ч [11]

*P_e, n. is the average effective pressure corresponding to the rated power indicated in the manufacturer's instructions.

1) No.; 2) regime; 3) engine speed, r/min; 4) operating time, min; 5) engine start and warmup; 6) idle; 7) P_e, n; 8) full throttle; 9) idle and cooling of engine to water-discharge temperature of 40°C and oil temperature of 50°C; 10) total; 11) h.

The water-discharge temperature is held at 83 ± 5°C. The difference between the water-intake and water-discharge temperatures should be 5-10°C. The crankcase-oil temperature is held at 88 + 5°C. Forced water cooling of the crankcase is permitted. The fuel consumption at full throttle and 2000 r/min should be 13.4-13.6 kg/h, while the spark-advance angle should be 18-20° (this is checked when the governor characteristics are determined before the long-term test).

The oil and high-quality filter element are changed after the engine has run for 51 h. Oil is added after every 9 h of engine operation, 10 min after shutdown, bringing the level up to the upper indicator mark.

The following data are recorded during the test: engine speed, brake load, water-intake and water-discharge temperatures, crankcase-oil temperature, exhaust-gas temperature, oil pressure before low-quality filter and in oil line, intake vacuum, air-intake temperature, crankcase-gas pressure, exhaust-gas pressure, and fuel consumption. These indices are noted at the end of each stage. The gases blown by into the crankcase are measured every other stage.

The amount of deposits on the high-quality oil filter is determined from the difference in filter weight before installation in the engine and after removal during the oil change.

Oil samples (0.5 liter) are taken from the oil line with the engine idling after 20 min and 51 h of each 51-h cycle.

The samples are used to determine viscosity at 50 and 100°C, acid number, ash, tar content, and total mechanical-impurity content, separating the impurities into organic and inorganic constituents.

The amount of oil initially introduced into the engine, the samples taken, the oil added, and that drained from the engine are all recorded by weight.

After every 102 h of engine operation, the carburetor fuel nozzle is rinsed and the cylinder compression is measured.

Servicing of the engine and adjustment of the carburetor and spark-advance angle are carried out in accordance with the manufacturer's instructions. Tests are conducted with type A-70 automobile gasoline from a single batch.

After the governor characteristics have been determined at the end of the test, the engine is disassembled for inspection, the amount of deposits on the components is determined, and the components are measured micrometrically.

The amount of deposits on the pistons and rings is determined after they have been rinsed with gasoline and dried, by weighing them before and after removal of the deposits. Piston-ring mobility is evaluated immediately after disassembly of the engine and before the pistons have been rinsed with gasoline, from the force necessary to move the rings in the piston grooves. A ring is considered to be free if it moves under the action of its own weight, tight if a slight force is required to move it, very tight if it can only be moved with difficulty by a considerable force, and frozen if it cannot be moved at all. A ring can be frozen over its entire circumference or only partially. The arc, in degrees, over which the ring is frozen is noted.

§2. ENGINE CHARACTERISTICS OF BASE OILS FROM AZERBAYDZHAN CRUDE OILS

Crude oils produced from different regions of the Apsheron Peninsula and the Caspian Sea differ greatly in the types and properties of the hydrocarbons composing them. The large number of crude oils refined to produce lubricating oils, the many refining methods employed, and the variety of additives used make it possible to obtain an almost unlimited variety of motor oils with the most varied physical and service properties.

The great diversity of motor-oil production methods results from a combination of extensive research and design work and a great deal of production experience.

The physical and engine properties of an oil depend on the raw material from which it is produced, the method and extent of refining, and the additives used.

It can be said that the purpose of oil additives is to improve the properties of highly refined, high-quality mineral oils. Additives cannot compensate for poor oil quality or poor refining.

It must be emphasized that internal combustion engines [ICE] (ДВС) are designed for very different purposes and operating conditions, so that lubrication of their components with an appropriate oil is of prime importance if they are to operate at full capacity.

Although the lubrication requirements for diesel and spark-ignition engines are theoretically identical, more stringent requirements are usually imposed on lubricating oils for diesels. The incomplete combustion in these engines leads to formation of soot and resins, while the more complex hydrocarbon structure of diesel fuel makes it possible for far large amounts of soot and resins to be produced than in spark-ignition gasoline engines. This tendency toward soot and resin formation accounts for the more stringent requirements imposed on lubricating oils for diesel engines. In general, diesels have a greater tendency toward ring scuffing and piston contamination as a result of the accumulation and combustion of soot and resins on the heated surfaces. The crankcase oil is also more rapidly and severely contaminated with soot and resins, which leads to carbon deposition on the oil filters and internal engine surfaces in most cases.

A preliminary engine appraisal of oils produced from Azerbaydzhan crude oils, which differ in raw-material quality, extent of refining, and additive efficiency, makes it possible to evaluate certain functional characteristics of such motor oils before long-term testing in real engines. Diesel and automobile oils obtained from a promising mixture of Apsheron crude oils subjected to different degrees of refining were preliminarily engine-tested by the methods described above.

Engine Characteristics of Winter Diesel Oils

Investigations of the engine characteristics of Д-8 winter diesel oils produced from the crude-oil mixture mentioned above were conducted with three oil specimens: a standard specimen of СУ machine oil containing 3% АзНИИ-4 additive, Д-8 oil refined with 150% furfurol and containing 3% АзНИИ-7 additive, and Д-8 oil refined with 200% furfurol and containing 3% АзНИИ-7 additive.

TABLE 70

Brief Technological Characterization of Oil Samples

1 Образец	2 Технологическая характеристика	3 Сокращенное наименование
4 Д-8, очищенное 150% фурфурола, с 3% присадки АзНИИ-7	6 Дизельное масло селективной очистки для работы двигателей в зимних условиях из перспективной смеси нефтей, очищенное 150% фурфурола, 1% серной кислоты и 5% гумбрина. К базовому маслу добавлено 0,5% депрессатора АзНИИ и 3% присадки АзНИИ-7	8 Д-8 (150% фурфурола)
5 Д-8, очищенное 200% фурфурола с 3% присадки АзНИИ-7	7 То же, очищенное 200% фурфурола	9 Д-8 (200% фурфурола)

1) Sample; 2) technological characterization; 3) abbreviation; 4) Д-8, refined with 150% furfurol, containing 3% АзНИИ-7 additive; 5) Д-8, refined with 200% furfurol, containing 3% АзНИИ-7 additive; 6) selectively refined diesel oil for engine operation under winter conditions, produced from crude oil mixture refined with 150% furfurol, 1% sulfuric acid, and 5% gumbrin. АзНИИ depressor (0.5%) and АзНИИ-7 additive (3%) added to base oil; 7) the same, refined with 200% furfurol; 8) Д-8 (150% furfurol); 9) Д-8 (200% furfurol).

Table 70 gives a brief technological characterization of the Д-8 diesel-oil specimens tested.

Preliminary Evaluation of Engine Properties of Д-8 Oils in Single-Cylinder 1Ч-10.5/13 Engine

Before conducting short-term engine tests in the serial-prod-

TABLE 71

Results of Preliminary Tests on Д-8 Diesel Oils

1 Образец	2 Показатели оценки				
	3 Износ I и II компрессионных колец, мг	4 Средний износ комплекта колец, мг	5 Нагар, г		
			6 с колец	7 с канавок	8 с днища
9 Эталонный образец	156	42	0,07	0,14	0,42
Д-8 (150% фурфурола) 10	127	36	0,11	0,20	0,94
Д-8 (200% фурфурола) 10	120	35	0,03	0,35	0,58

1) Specimen; 2) indices evaluated; 3) wearing of first and second compression rings, mg; 4) average wearing of ring set, mg; 5) carbon deposits, g; 6) rings; 7) grooves; 8) piston face; 9) standard specimen; 10) furfurol.

uced ЯАЗ-204 automobile engine, the experimental oils were checked in a single-cylinder 14 engine by the method developed by the Engine-Test Department of the АзНИИ НП. The results of these tests are given in Table 71.

The results of the preliminary engine-characteristic evaluation enables us to conclude that the oils subjected to both types of refining reduce ring wear by an average of about 15-20%. The Д-8 (150% furfurol) oil reduces compression-ring wear by 18.6% in comparison with the standard specimen and total ring wear by 14.3%. The corresponding figures for the Д-8 (200% furfurol) oil are 23.9 and 16.7%. The refined oils yielded better results than the standard oil with respect to carbon deposition on the main engine components.

Short-term Stand Tests of Д-8 Oils in ЯАЗ-204 Engine

At this stage of the investigation, a definitive evaluation of the engine characteristics of the Д-8 diesel oils was made by comparing the characteristics of the test oils on the basis of the results of short-term stand tests in a four-cylinder serial-produced ЯАЗ-204 engine, using the VNII NP method. The test results are given in Tables 72-74.

The data characterizing the wear for the main components of the ЯАЗ-204 engine (see Table 72) indicate that the piston-ring wear decreases as Д-8 oil is more highly refined. Thus, Д-8 oil (200% furfurol) yielded a compression-ring wear that averaged 24% less than that produced by the same oil refined with 150% furfurol, while oil-ring wear was 14% lower.

The refined oils yielded somewhat poorer results with respect to a number of wear indices (oil-ring wear and compression-ring wear from change in ring gap). However, with respect to the main index usually employed for evaluating the antiwear efficiency of additive-containing oils, compression-ring wear from change in weight, the Д-8 (150% furfurol) and Д-8 (200% furfurol) gave figures 31 and 45% lower than the standard oil respectively.

Table 73 gives a comparative characterization of the oils with respect to the amount and character of the carbon deposits on the main engine components.

The Д-8 (150% furfurol) oil yields the same carbon deposition on the rod-piston components as the standard oil. Greater refinement improves oil antideposit characteristics: the carbon deposition for the Д-8 (200% furfurol) oil is 47% lower than that for the Д-8 (150% furfurol) oil.

No difference was observed between the two Д-8 oil specimens with respect to ring mobility. They yield fewer free rings than the standard oil but a somewhat smaller number of frozen rings: two, as against three for the standard oil.

Table 74 presents data characterizing the change in oil physicochemical properties.

TABLE 72

Wearing of Main Components of ЯАЗ-204 Engine

1 Показатели износа	2 Эталонное масло	Д-8 (150% фурфурола) 3	Д-8 (200% фурфурола) 3
4 Износ компрессионных колец (по потере веса), кг			
I	45	136	96
II	439	167	165
III	227	160	78
IV	187	158	116
5 В среднем на кольцо	227	155	114
6 То же по изменению зазора в стыке колец, мк			
I	50	75	50
II	150	150	125
III	75	75	50
IV	50	75	75
5 В среднем на кольцо	57	96	75
7 Износ маслосъемных колец (по потере веса), мг			
V	57	129	58
VI	79	91	54
VII	75	93	107
VIII	70	82	38
5 В среднем на кольцо	70	99	84
6 То же по изменению зазора в стыке колец, мк			
V	110	170	117
VI	125	117	100
VII	110	110	133
VIII	150	130	147
5 В среднем на кольцо	124	144	124
8 Средний износ шатунных вкладышей (мг) на один			
9 верхний	594	189	401
10 нижний	142	42	165

1) Wear indices; 2) standard oil; 3) furfurol; 4) compression-ring wear (from weight loss), kg; 5) average per ring; 6) the same, from change in ring gap, μ; 7) oil-ring wear (from weight loss), mg; 8) average wear for single rod bushing (mg); 9) upper; 10) lower.

It can be seen from the data in this table that the kinematic viscosity of refined Д-8 oils in a ЯАЗ-204 engine changes less rapidly than that of the standard oil. The same is also true of the increase in iron content in the worked-out oil. The acidity and tar content of the refined oils undergo a greater change. The ash content decreases in all cases, but more rapidly for the standard oil. The mechanical-impurity content is the same for the standard and Д-8 (150% furfurol) oils, but decreases for the Д-8 (200% furfurol) oil.

These tests enable us to draw the following conclusions.

1. Preliminary evaluation of the engine characteristics of the oils tested in an 14 engine shows that Д-8 oils subjected to both types of refining reduce wear in comparison with СУ machine oil, but carbon deposition is more severe than for the latter oil.

TABLE 73

Carbon Deposition and Ring Mobility in ЯАЗ-204 Engine

Показатели оценки [1]	Эталонное масла [2]	Д-8 (150% фурфурола) [3]	Д-8 (200% фурфурола) [3]
4 Нагарообразование, г			
5 на кольцах	2,41	3,93	1,72
6 в канавках поршней	3,5	3,050	1,51
7 на днищах поршней,	4,5	3,25	2,14
8 Всего	10,41	10,23	5,37
9 Подвижность компрессионных колец			
10 свободные	18	11	11
11 прихваченные	3	2	2
12 плотные	13 Нет	3	3

1) Indices evaluated;
2) standard oil;
3) Furfurol;
4) Carbon deposition, g;
5) On rings;
6) In piston grooves;
7) On piston faces;
8) Total;
9) Compression-ring mobility;
10) Free;
11) Welded;
12) Tight;
13) none.

The Д-8 (200% furfurol) oil is better in all engine-test indices than the Д-8 (150% furfurol) oil.

2. The oil subjected to both types of refining provide better characteristics than the standard with respect to all basic indices (compression-ring wear from change in weight). The Д-8 (150% furfurol) oil is equivalent to СУ machine oil with respect to carbon deposition, ring mobility, and change in oil properties, while the Д-8 (200% furfurol) oil halves carbon deposition without improving ring mobility.

Greater refinement of Д-8 oil thus provides somewhat higher diesel-service indices.

Testing of Д-11 Diesel Oils Produced from Prospective Crude-Oil Mixture

We investigated the engine characteristics of 8 specimens of Д-11 diesel oils:

A standard specimen — commercial diesel oil produced by the BNZ im. XXII S'yezda KPSS and containing АзНИИ-4 additive;

A standard specimen — commercial diesel oil produced by the NNZ im. Dzhaparidze and containing АзНИИ-4 additive;

TABLE 74

Change in Principal Physicochemical Indices of Worked-out Oil

Образец[1]	Показатели[2]	Время отбора проб[3]: 20 мин[4]	10 ч[5]	20 ч[5]	30 ч[5]	40 ч[5]	50 ч[5]	60 ч[5]	Изменение показателей[6]: абс.[7]	%
СУ+3% АзНИИ-4	[9] Кинематическая вязкость при 100°, сст	7,976	8,382	8,595	9,244	9,543	9,659	9,676	1,700	21,5
	[10] Механические примеси, %	0,06	0,06	0,22	0,12	0,1	0,07	0,09	0,03	50
	[11] Зола, %	0,25	0,25	0,27	0,27	0,29	0,29	0,30	0,05	—
	[12] Железо, мг/л	6	11	48	52	94	51	94	88	1345
	[13] Кислотное число, мг КОН	0,20	0,22	0,31	0,28	0,26	0,29	0,30	0,10	50
	[14] Кокс, %	0,45	0,65	0,9	1,2	1,4	1,35	0,8	0,35	78
Д-8 (150% фурфурола[8])	[9] Кинематическая вязкость при 100°, сст	8,654	9,542	9,819	8,895	9,521	9,827	9,757	1,113	13,1
	[10] Механические примеси, %	0,024	0,029	0,020	0,027	0,038	0,026	0,037	1,013	54
	[11] Зола, %	0,25	0,16	0,13	0,19	0,20	0,25	0,23	—	—
	[12] Железо, мг/л	13	83	32	39	78	64	72	59	455
	[13] Кислотное число, мг КОН	0,04	0,08	0,08	0,10	0,08	0,13	0,15	0,11	275
	[14] Кокс, %	0,55	0,66	0,71	0,93	1,17	1,31	1,70	1,15	210
Д-8 (200% фурфурола[8])	[9] Кинематическая вязкость при 100°, сст	8,946	8,824	9,780	9,446	9,412	9,697	9,927	9,981	10,9
	[10] Механические примеси, %	0,36	0,17	0,2	0,06	0,12	0,05	0,065	—	—
	[11] Зола, %	0,34	0,22	0,14	0,14	0,25	0,26	0,31	—	—
	[12] Железо, мг/л	54	47	28	24	210	185	255	201	372
	[13] Кислотное число, мг КОН	0,05	0,11	0,10	0,12	0,13	0,08	0,12	0,07	140
	[14] Кокс, %	0,55	0,53	0,51	0,51	0,79	0,96	1,11	0,56	100

1) Specimen; 2) index; 3) sampling time; 4) min; 5) h; 6) change in index; 7) absolute; 8) furfurol; 9) kinematic viscosity at 100°, cSt; 10) mechanical impurities, %; 11) ash, %; 12) iron, mg/liter; 13) acid number, mg KOH; 14) tars, %.

TABLE 75

Brief Technological Characterization of Oil Specimens Tested

1 Образец	2 Технологическая характеристика
3 Д-11, очищенное 200% фурфурола, 1, 2 и 3% кислоты с 3% присадки АзНИИ-7	8 Дизельное масло селективной очистки из перспективной смеси нефтей, очищенное 200% фурфурола, 1, 2 и 3% кислоты и 5% гумбрина. К базовому маслу добавлено 0,2% депрессатора АзНИИ и 3% присадки АзНИИ-7
4 Д-11, очищенное 250% фурфурола, 1, 2% кислоты с 3% присадки АзНИИ-7	9 То же, очищенное 250% фурфурола и 1 и 2% кислоты
5 Д-11, очищенное 350% фурфурола, 1% кислоты с 3% присадки АзНИИ-7	10 То же, очищенное 350% фурфурола и 1% кислоты
6 Д-11, очищенное 200% фенола с 3% присадки АзНИИ-7	11 То же, очищенное 200% фенола
7 Д-11, очищенное 250% фенола с 3% присадки АзНИИ-7	12 То же, очищенное 250% фенола

1) Specimen; 2) technological characterization; 3) Д-11, refined with 200% furfurol and 1, 2, or 3% acid, containing 3% АзНИИ-7 additive; 4) Д-11, refined with 250% furfurol and 1 or 2% acid, containing 3% АзНИИ-7 additive; 5) Д-11, refined with 350% furfurol and 1% acid, containing 3% АзНИИ-7 additive; 6) Д-11, refined with 200% phenol, containing 3% АзНИИ-7 additive; 7) Д-11, refined with 250% phenol, containing 3% АзНИИ-7 additive; 8) selectively refined diesel oil from crude oil mixture, purified with 200% furfurol, 1, 2, or 3% acid, and 5% gumbrin. АзНИИ depressor (0.2%) and АзНИИ-7 additive (3%) added to base oil; 9) the same, refined with 250% furfurol and 1 or 2 % acid; 10) the same, refined with 350% furfurol and 1% acid; 11) the same refined with 200% phenol; 12) the same, refined with 250% phenol.

Д-11 oil, refined with 200% furfurol and 1% acid, containing 3% АзНИИ-7 additive;

Д-11 oil, refined with 250% furfurol and 1% acid, containing 3% АзНИИ-7 additive;

Д-11 oil, refined with 250% furfurol and 2% acid, containing 3% АзНИИ-7 additive;

Д-11 oil, refined with 350% furfurol and 1% acid, containing 3% АзНИИ-7 additive;

Д-11 oil, refined with 200% phenol, containing 3% АзНИИ-7 additive;

Д-11 oil, refined with 250% phenol, containing 3% АзНИИ-7 additive.

Table 75 gives a brief technological characterization of these specimens.

Before conducting short-term stand tests in an ЯАЗ-204 engine, the service characteristics of a number of the Д-11 oil specimens and of the standard oils were checked in a single-cylinder, four-stroke compressive-ignition engine of the 1Ч 10.5/13 type. Table 76 presents the results of these tests.

Analysis of the data in Table 76 establishes that greater refinement of the Д-11 distillation by use of a greater percentage of the selective solvent (furfurol) causes a rise in compression-ring wear. Thus, the wear for the first and second rings increases by 17% when the extent of refining is increased from 200 to 350% furfurol. Carbon deposition on the main engine components, however, is reduced.

TABLE 76

Results of Preliminary Tests on Д-11 Diesel Oils in Single-Cylinder 1Ч Engine

1 Образец	2 Износ компрессионных колец, мг		5 Нагарсобразование, мг			
	3 I и II	4 Среднее на кольцо	6 с колец	7 с канавок	8 с днищ	9 всего
10 Эталонное масло (БНЗ им. XXII съезда КПСС)	176	50	38	72	230	340
11 Эталонное масло (БНЗ. им. Джапаридзе)	317	100	100	175	300	875
Д-11 (200% фурфурола[12], 1% кислоты[13])	58	16	208	322	385	915
Д-11 (200% фурфурола, 2% кислоты)	67	21	162	487	289	938
Д-11 (200% фурфурола, 3% кислоты)	50	16	190	290	370	850
Д-11 (250% фурфурола, 1% кислоты)	—	89	30	330	122	482
Д-11 (250% фурфурола, 2% кислоты)	103	34	250	250	200	700
Д-11 (250% фурфурола, 10% кислоты)	68	19	70	140	1020	1230

1) Specimen; 2) compression-ring wear, mg; 3) I and II; 4) average per ring; 5) carbon deposition, mg; 6) rings; 7) grooves; 8) piston face; 9) total; 10) standard oil (BNZ im. XXII S"yezda KPSS); 11) standard oil (BNZ im. Dzhaparidze); 12) furfurol; 13) acid.

Increasing the extent of acid-contact refining of Д-11 (200% furfurol) oil from 1 to 2% acid causes a slight increase in wear and carbon deposition. A further increase (to 3%) reduces these indices to the same level as for 1% acid.

Refinement of Д-11 (250% furfurol) distillate with 2% acid causes total carbon deposition and deposition on the rings and grooves to increase by an average of 40% in comparison with refinement with 1% acid.

The wear characteristics of all the Д-11 diesel oils tested are greater than for the standard commercial oils. Only Д-11 (250% furfurol and 1% acid) oil had an antideposition properties equivalent to those of the standard commercial BNZ im. XXII S"yezda KPSS oil.

TABLE 77

Wear for Main Components of ЯАЗ-204 Engine After Short-term Tests with Д-11 Diesel Oils Containing АзНИИ-7 Additive

1 Показатели износа	Эталонное масло БНЗ им. XXII съезда 2	Эталонное масло БНЗ им. Джапаридзе 3	Д-11 (2.0% фурфурола 4, 1% кислоты 5)	Д-11 (250% фурфурола 4, 1% кислоты 5)	Д-11 (2.50% фурфурола 4, 2% кислоты 5)	Д-11 (3.0% фурфурола 4, 1% кислоты 5)	Д-11 (200% фенола 12)	Д-11 (250% фенола 12)
6 Износ компрессионных колец (по потере веса), *мг*								
I	55	37	52	37	60	109	55	64
II	152	143	87	71	112	192	109	148
III	66	81	84	58	62	142	123	86
IV	64	46	74	60	85	265	87	113
7 В среднем на кольцо	87	78	74	57	80	177	93	102
8 То же по изменению зазора, *мк*								
I	55	40	30	0	50	50	0	100
II	150	136	60	90	75	150	180	200
III	50	100	30	65	75	75	60	25
IV	75	29	30	52	100	150	100	200
7 В среднем на кольцо	82	88	38	57	75	106	85	131
9 Износ маслосъемных колец (по потере веса), *мг*								
I	15	26	46	18	52	82	11	38
II	12	30	46	21	66	137	22	43
III	14	33	35	16	91	90	22	34
IV	18	29	34	21	78	89	21	48
7 В среднем на кольцо	15	20	40	19	72	98	19	41
8 То же по изменению зазора, *мк*								
I	87	53	20	30	33	50	0	—
II	92	100	30	51	75	150	40	50
III	61	50	30	42	50	25	25	66
IV	61	57	30	40	100	100	10	66
7 В среднем на кольцо	75	67	27	41	64	103	20	51
10 Средний износ на один нагруженный вкладыш шатунного подшипника, *мг*	97	182	121	91	114	87	85	—
11 То же на ненагруженный	24	64	61	20	17	—	26	28

1) Wear index; 2) standard oil (BNZ im. XXII S"yezda); 3) standard oil (BNZ im. Dzhaparidze); 4) furfurol; 5) acid; 6) compression-ring wear (from weight loss), mg; 7) average per ring; 8) the same, from change in gap, μm; 9) oil-ring wear (from weight loss), mg; 10) average wear for one loaded rod-bearing bushing, mg; 11) the same, for unloaded bushing; 12) phenol.

TABLE 78

Carbon and Tar Deposition and Ring Mobility in ЯАЗ-204 Engine After Short-Term Tests on Д-11 Diesel Oils Containing АзНИИ-7 Additive

[1] Показатели моторной оценки	Эталонное масло БНЗ им. XXII съезда [2]	Эталонное масло БМЗ им. Джапаридзе [3]	Д-11 (200% фурфурола) [4]	Д-11 (250% фурфурола [4], 1% кислоты) [5]	Д-11 (250% фурфурола [4], 2% кислоты) [5]	Д-11 (350% фурфурола) [4]	Д-11 (200% фенола) [6]	Д-11 (250% фенола) [6]
[7] Нагарообразование на поршневых кольцах, г	2,35	2,2	3,2	2,7	3,2	2,7	2,9	2,7
[8] Нагарообразование в канавках поршней, г	2,17	2,3	4,8	2,47	5,0	2,9	3,52	2,9
[9] Нагарообразование на днищах поршней, г	3,45	2,7	5,7	4,9	8,8	3,5	3,25	3,1
[10] Суммарное нагарообразование, г	7,97	8,2	13,7	10,07	17,0	9,1	9,67	8,7
[11] Число свободных компрессионных колец	15	13	13	13	13	16	13	13
[12] Число компрессионных колец с ограниченной подвижностью (плотных)	1	3	3	3	2	—	—	1
[13] Число компрессионных колец, полностью потерявших подвижность (прихваченных)	—	—	—	—	3	—	—	2

1) Engine-test indices; 2) standard oil (BNZ im. XXII S"yezda); 3) standard oil (BMZ im. Dzhaparidze); 4) furfurol; 5) acid; 6) phenol; 7) carbon deposition in piston rings, g; 8) carbon deposition in piston grooves, g; 9) carbon deposition on piston faces, g; 10) total carbon deposition, g; 11) number of free compression rings; 12) number of compression rings with restricted mobility (tight); 13) number of frozen compression rings.

In order to make a more thorough appraisal of the engine characteristics of the test oils under operating conditions in high-supercharged serial-produced automobile engines, where oils of the Д-11 type are most widely used, we conducted short-term stand tests of various oil specimens of this type.

Table 77 shows the wear characteristics of the oils, Table 78 shows the carbon deposition on the engine components, and Table 79 shows the change in oil physicochemical properties.

The data in Table 77 enable us to establish that use of 250% furfurol as the selective solvent is the optimum type of refinement, bringing the oil quality to a higher level than that of standard oils.

A somewhat more complex relationship obtains for the indices characterizing carbon deposition and piston-ring mobility in engines operating with Д-11 oils subjected to different degrees of refining.

First of all, none of the refined Д-11 oils are equivalent in total carbon deposition on the main engine components to the standard commercial oils. Use of 250% phenol for refining yields better results than 200% phenol (8.7 and 9.67 g respectively).

Increasing the degree of acid-contact refining of furfurol-processed Д-11 oils causes an increase in carbon deposition.

Increasing the refinement of Д-11 oils with furfurol to 350% reduces total carbon deposition to 9.1 g, as against 13.7 g for 200% furfurol and 10.07 g for 250% furfurol. The best piston-ring mobility indices are also obtained in this variant (350% furfurol).

As can be seen from the data in Table 79, the change in viscosity is greatest for the standard specimens (5 and 1.6%) and for the Д-11 (250% furfurol and 2% acid) oil, amounting to 6.5% in the latter case. The changes in viscosity are almost identical for specimens refined with 200 and 250% phenol (11.6 and 11.5% respectively) and somewhat greater for those refined with 200, 250, and 350% furfurol (22-24%).

The acidity of Д-11 oil refined with 200% furfurol or 200% phenol remains almost constant during the test, while that of the standard VNZ im. XXII S"yezda oil increases by a factor of more than 3. The acidity of the Д-11 (250% furfurol) and Д-11 (250% phenol) oils is almost doubled. The change in the acidity of the standard VNZ im. Dzhaparidze oil is slight (38%).

The increase in the tar content of the oils can be assumed to be almost identical in all cases, the rise being 250-350%. The change in coke content is greatest in the Д-11 (250% furfurol and 2% acid) oil.

Short-term tests in a ЯАЗ-204 engine have thus established that Д-11 oil refined with 250% furfurol, 1% acid and 5% gumbrin and containing 3% АзНИИ-7 additive and 0.2% depressor is better than the standard commercial oils produced by the VNZ im. XXII

TABLE 79

Change in Physicochemical Properties of Д-11 Oils

1 Образец	2 Время отбора проб	3 Кинематическая вязкость при 100°С, *сст*	4 Механические примеси, %	5 Зола, %	6 Железо, *мг/л*	7 Кислотное число, *мг* KOH	8 Кокс, %
1	2	3	4	5	6	7	8
Эталонное масло Д-11 (ГОСТ 5304—54)	После 20 *мин*	10,63	0,04	0,057	1,2	0,26	0,31
	„ 10 *ч*	10,83	0,08	0,055	1,5	0,38	0,34
	„ 20 *ч*	10,79	0,11	0,043	[illegible]	0,64	0,41
	„ 30 *ч*	10,75	0,14	0,048	8	0,44	0,61
	„ 40 *ч*	10,[illegible]	0,22	0,049	10	0,54	0,71
	„ 50 *ч*	11,31	0,26	0,055	13	0,34	0,96
	„ 60 *ч*	11,14	0,34	0,060	13	0,36	1,21
	Увеличение абс.	0,51	0,30	0,003	11,8	0,10	0,90
	показателя, %	5	750	5	—	38	261
Эталонное масло Д-11 БНЗ им. XXII съезда КПСС	После 20 *мин*	12,01	0,09	0,03	0,2	0,15	0,43
	„ 10 *ч*	11,65	0,04	0,02	1,7	0,21	0,25
	„ 20 *ч*	11,45	0,11	0,08	4,2	0,36	0,53
	„ 30 *ч*	11,73	0,11	0,03	2,7	0,36	0,71
	„ 40 *ч*	11,83	0,07	0,04	6,5	0,42	0,81
	„ 50 *ч*	12,25	0,09	0,05	8,2	0,45	0,93
	„ 60 *ч*	12,20	0,13	0,06	17	0,54	1,31
	Увеличение абс.	0,19	0,04	0,03	16,8	0,39	0,88
	показателя, %	1,5	44	100	—	260	205
Д-11 (200% фурфурола)	После 20 *мин*	10,28	0,43	0,12	4,5	0,07	0,48
	„ 10 *ч*	10,53	0,59	0,08	10	0,05	0,49
	„ 20 *ч*	11,34	0,64	0,06	13,7	0,07	0,81
	„ 30 *ч*	11,47	0,73	0,12	16	0,07	0,85
	„ 40 *ч*	12,01	0,76	0,14	18,5	0,06	1,42
	„ 50 *ч*	12,47	0,77	0,16	20,75	0,08	1,55
	„ 60 *ч*	12,88	0,83	0,20	20,5	0,07	1,68
	Увеличение абс.	2,60	0,40	0,08	16	0	1,20
	показателя, %	24	94	65	—	0	250
Д-11 (250% фурфурола, 1% кислоты)	После 20 *мин*	10,60	0,065	0,14	1,5	0,01	0,41
	„ 10 *ч*	11,71	0,038	0,10	5,5	0,05	0,57
	„ 20 *ч*	12,03	0,08	0,11	9,0	0,05	0,70
	„ 30 *ч*	12,23	0,088	0,16	11,5	0,06	1,04
	„ 40 *ч*	12,94	0,085	0,18	13,2	0,07	1,24
	„ 50 *ч*	12,91	0,092	0,20	14,5	0,06	1,2[illegible]
	„ 60 *ч*	13,14	0,083	0,21	18,7	0,08	1,47
	Увеличение абс.	2,54	0,018	0,07	17,2	0,01	1,46
	показателя, %	24	27	50	—	100	355
Д-11 (250% фурфурола, 2% кислоты)	После 20 *мин*	9,79	0,04	0,15	32	0,024	0,58
	„ 10 *ч*	9,76	0,063	0,25	197	0,065	0,59
	„ 20 *ч*	9,83	0,05	0,22	14	0,089	0,60
	„ 30 *ч*	9,90	0,102	0,29	23	0,065	0,63
	„ 40 *ч*	[illegible]	0,104	0,29	37	0,073	0,65
	„ 50 *ч*	10,13	0,096	0,30	24	0,089	0,66
	„ 60 *ч*	10,42	0,105	0,34	23,5	0,11	0,79
	Увеличение абс.	0,63	0,065	0,19	—	0,086	0,21
	показателя, %	5,5	16	12	—	350	36
Д-11 (350% фурфурола)	После 20 *мин*	9,49	0,012	0,14		0,02	0,64
	„ 10 *ч*	9,89	0,012	0,29	55	0,06	0,98
	„ 20 *ч*	10,38	0,03	0,42	72	0,07	1,01
	„ 30 *ч*	10,53	0,05	0,52	53	0,09	1,26

TABLE 79 CONTINUED

1	2	3	4	5	6	7	8
	[13] После 40 ч [17]	10,59	0,08	0,76	888	0,05	—
	„ 50 ч	13,75	0,10	0,77	83	0,13	1,92
	„ 60 ч	11,56	0,12	0,30	225	0,09	2,30
	[15] Увеличение абс.	2,07	0,108	0,17	218	0,07	1,36
	показателя, %	22	90	30	—	350	260
Д-11 (200% [16] фенола)	[13] После 20 мин [14]	10,76	0,055	0,18	4	0,05	0,20
	„ 10 ч	10,76	0,045	0,11	12	0,05	0,32
	„ 20 ч	11,07	0,038	0,05	5	0,06	0,38
	„ 30 ч	11,41	0,041	0,07	9,5	0,06	0,60
	„ 40 ч	11,47	0,055	0,11	6,5	0,06	0,72
	„ 50 ч	11,86	0,053	0,12	6,5	0,05	1,93
	„ 60 ч	12,61	0,049	0,18	20	0,05	1,07
	[15] Увеличение абс.	1,25	—	0	16	0	0,87
	показателя, %	11,6	—	0	—	0	435
Д-11 (250% [16] фенола)	[13] После 20 мин [14]	10,83	0,013	0,08	2	0,03	0,24
	„ 10 ч	11,44	0,01	0,06	31	0,12	0,34
	„ 20 ч	11,10	0,012	0,07	38	0,16	0,52
	„ 30 ч	11,26	0,009	0,10	50	0,20	0,73
	„ 40 ч	11,17	0,017	0,12	69	0,18	0,89
	„ 50 ч	11,74	0,018	0,17	88	0,17	1,31
	„ 60 ч	12,07	0,019	0,26	51	0,14	0,84
	[15] Увеличение абс.	1,24	0,006	0,18	59	0,05	0,60
	показателя, %	11,5	50	225	—	75	250

1) Specimen;
2) Sampling time;
3) Kinematic viscosity at 100°C, cSt;
4) Mechanical impurities, %;
5) Ash, %;
6) Iron, mg/liter;
7) Acid number, mg KOH;
8) Tars, %;
9) Standard Д-11 oil (GOST 5304-54);
10) Standard Д-11 oil (BNZ im. XXII S"yezda KPSS);
11) Furfurol;
12) Acid;
13) After;
14) min;
15) Increase in absolute index, %;
16) Phenol;
17) h.

S"yezda and VNZ im. Dzhaparidze with respect to engine-component wear, but are slightly inferior to these oils with respect to carbon deposition and change in physicochemical properties.

Testing of Д-14 Summer Diesel Oils from Prospective Crude-Oil Mixture

We investigated the operating characteristics of the following diesel oils intended for summer service in fast-stroke super-

TABLE 80

Brief Technological Characterization of Oil Specimens Tested

1 Образец	2 Технологическая характеристика	3 Сокращенное наименование
4 Д-14, очищенное 250% фенола с 3% присадки АзНИИ-7	7 Дизельное масло селективной очистки для работы двигателя в летних условиях из перспективной смеси нефтей, очищенное 250% фенола, 2% серной кислоты и 5% гумбрина	9 Д-14 (250% фенола)
5 Д-14, очищенное 300% фенола с 3% присадки АзНИИ-7	8 То же, очищенное 300% фенола	10 Д-14 (300% фенола)
6 Д-14 на базе деасфальтизата с 3% присадки АзНИИ-7		11 Д-14 (деасфальтизированное)

1) Specimen; 2) technological characterization; 3) abbreviation; 4) Д-14, refined with 250% phenol, containing 3% АзНИИ-7 additive; 5) Д-14, refined with 300% phenol, containing 3% АзНИИ-7 additive; 6) Д-14, based on deasphaltizate, containing 3% АзНИИ-7 additive; 7) selectively refined diesel oil for engine operation under summer conditions, produced from prospective crude-oil mixture, refined with 250% phenol, 2% sulfuric acid, and 5% gumbrin; 8) the same, refined with 300% phenol; 9) Д-14 (250% phenol); 10) Д-14 (300% phenol); 11) Д-14 (deasphalted).

charged engines:

a standard oil – commercial selectively refined Д-14 diesel oil produced by the VNZ im. XXII S"yezda and containing 3% АзНИИ-4 additive and АзНИИ depressor;

Д-14 oil, refined with 250% phenol, containing 3% АзНИИ-7 additive;

Д-14 oil, refined with 300% phenol, containing 3% АзНИИ-7 additive;

Д-14 oil, produced from deasphaltizate, containing 3% АзНИИ-7 additive.

Table 80 gives a brief technological characterization of these oil.

In order to make a comparative evaluation of certain service characteristics of the test oils, we conducted short-term stand tests in a КДМ-46 tractor engine. Commercial low-sulfur diesel fuel was used for the 250-h test, whose results are given in Table 81.

The data in this table indicate that none of the oils tested were equivalent in quality to the standard oil with respect to engine-component wear. Thus, the average piston-ring wear when the engine was operated with Д-14 oils refined with 250 or 300% phenol was 20% greater than for commercial Д-14 oil; the corresponding wear for the oil produced from deasphaltizate was 54% greater than that for the standard oil.

Carbon deposition was identical for the standard and Д-14 (250% phenol) oils, but a greater number of free rings was observed for the latter oil. An increase in refinement to 300% caused a decrease in antideposition properties.

The ring scuffing observed in all cases indicates that none of the oils tested provide normal operating conditions for this type of engine.

Table 82 shows the change in the physicochemical properties of the oils.

As can be seen from the data in this table, the smallest change in viscosity was for the Д-14 (250% phenol) and deasphaltizate-base oils, amounting to 8.3 and 5.6% respectively. The change for the Д-14 (300% phenol) oil was 15.4%.

The best results for other indices were yielded by the deasphaltizate-base Д-14 oil, which exhibited no noticeable change in principal physicochemical constants.

The tests conducted enable us to draw the following conclusions.

1. Piston-ring wear for Д-14 oils refined with 250 and 300% phenol was 20% higher than for commercial Д-14 oil. The wear for Д-14 oil based on deasphaltizate was 54% higher than for the standard oil.

Carbon deposition was identical to the standard for the Д-14 (250% phenol) oil and ring-mobility indices were somewhat better. Increasing the degree of refinement to 300% phenol caused a deterioration with respect to carbon deposition and ring mobility. Carbon deposition was also greater for the Д-14 oil produced from deasphaltizate and piston-ring mobility was identical to that for the standard specimen.

3. The best results with respect to change in physicochemical properties were obtained for the deasphaltizate-based Д-14 oil containing АзНИИ-7 additive.

TABLE 81

Results of Short-term Stand Tests of Д-14 Oils in КДМ-46 Engine

1 Показатели износа	2 Эталонное масло	3 Д-14 (250% фенола)	4 Д-14 (300% фенола)	5 Д-14 (деасфальтизированное)
6 Износ компрессионных колец (по потере веса), мг				
I	182	243	210	317
II	232	213	255	355
III	204	288	281	281
7 В среднем на кольцо	206	248	249	317
8 То же по изменению зазора, мк				
I	75	87	87	62
II	75	75	87	200
III	75	112	112	300
7 В среднем на кольцо	75	92	95	187
9 Средний износ одного маслосъемного кольца по потере веса, мг	679	792	662	609
8 То же по изменению зазора, мк	650	875	719	707
10 Нагар, г				
11 с колец	1,59	1,07	1,25	1,96
12 с днищ	0,92	2,60	3,05	9,62
13 с канавок	8,43	6,40	11,05	11,33
14 Всего нагара	10,94	10,07	15.35	22,91
15 Подвижность колец				
16 свободные	16	18	14	17
17 плотные	—	1	—	—
18 прихваченные	4	1	6	3

1) Wear index; 2) standard oil; 3) Д-14 (250% phenol); 4) Д-14 (300% phenol); 5) Д-14 (deasphalted); 6) compression-ring wear (from weight loss), mg; 7) average per ring; 8) the same, from change in gap, μm; 9) average wear for one oil ring, from weight loss, mg; 10) carbon deposits, g; 11) rings; 12) piston face; 13) grooves; 14) total deposits; 15) ring mobility; 16) free; 17) tight; 18) frozen.

TABLE 82

Change in Physicochemical Properties of Д-14 Oils

Образец	Время отбора проб	Кинематическая вязкость при 100°С, сст	Механические примеси, %	Зола, %	Железо, г/т	Кокс, %	Кислотное число, мг КОН
1	2	3	4	5	6	7	8
Эталонное масло	После 10 ч	12,81	0,08	0,11	26	0,56	0,42
	» 20 ч	12,90	0,12	0,12	38	0,63	0,46
	» 30 ч	13,21	0,14	0,12	39	0,59	0,69
	» 40 ч	13,16	0,11	0,12	27	0,65	0,43
	» 50 ч	13,94	0,28	0,11	33	0,78	0,64
	» 60 ч	13,59	0,10	0,12	28	0,72	0,34
	» 70 ч	14,21	0,07	0,13	31	0,76	0,38
	» 80 ч	14,36	0,17	0,13	31	0,84	0,75
	» 90 ч	14,40	0,14	0,14	42	0,81	0,37
	» 100 ч	14,23	0,04	0,15	52	0,85	0,63
	» 110 ч	14,50	0,02	0,13	43	0,87	0,70
	» 120 ч	14,33	0,03	0,12	31	0,74	0,54
	Увеличение абс.	1,52	—	0,01	5	0,18	0,12
	показателя, %	11,9	—	10	19,2	32	23
Д-14 (250% фенола)	После 10 ч	14,47	0,054	0,42	44	0,84	0,08
	» 20 ч	14,53	0,012	0,39	40	1,01	0,09
	» 30 ч	14,59	0,023	0,41	14	1,06	0,11
	» 40 ч	15,02	0,029	0,40	11	1,10	0,16
	» 50 ч	15,14	0,028	0,41	5,5	1,20	0,17
	» 60 ч	15,05	0,029	0,35	28	1,25	0,21
	» 70 ч	15,23	0,049	0,46	22	1,30	0,20
	» 80 ч	15,34	0,03	0,47	14	1,33	0,16
	» 90 ч	14,41	0,24	0,83	142	1,37	0,20
	» 100 ч	14,24	0,39	1,05	302	1,81	0,17
	» 110 ч	17,06	0,074	1,09	230	1,70	0,20
	» 120 ч	15,68	0,11	0,54	102	1,71	0,14
	Увеличение абс.	1,21	0,056	0,12	58	0,87	0,06
	показателя, %	8,3	100	28	131	100	75
Д-14 (300% фенола)	После 10 ч	12,93	0,032	0,40	72	0,67	0,09
	» 20 ч	13,28	0,023	0,50	106	0,75	0,08
	» 30 ч	—	—	—	—	—	—
	» 40 ч	13,00	0,074	0,47	49	0,91	0,05
	» 50 ч	13,16	0,048	0,52	64	0,92	0,16
	» 60 ч	13,50	0,067	0,45	50	1,01	0,11
	» 70 ч	14,14	—	0,50	84	1,02	-
	» 80 ч	14,20	0,047	0,49	43	1,02	0,15
	» 90 ч	15,05	0,028	0,54	46	1,04	0,21
	» 100 ч	14,57	0,028	0,53	30	1,05	0,12
	» 110 ч	14,57	0,039	0,55	78	1,10	0,25
	» 120 ч	14,94	0,033	0,55	43	1,16	0,24
	Увеличение абс.	2,01	0,001	0,15	—	0,49	0,17
	показателя, %	15,4	3	36	—	73	240
Д-14 (деасфальтизированное)	После 10 ч	15,94	0,010	0,59	16	1,1	0,24
	» 20 ч	17,59	0,14	0,73	14	1,02	0,34
	» 30 ч	15,84	0,024	0,79	9	1,21	0,25
	» 40 ч	18,52	0,015	1,01	23	1,42	0,54
	» 50 ч	16,75	0,024	0,92	29	1,53	0,44
	» 60 ч	15,23	0,010	0,34	14	1,60	0,28
	» 70 ч	15,64	0,017	0,69	22	1,09	0,21

TABLE 82 CONTINUED

1	2	3	4	5	6	7	8
Д-14 (деасфальтизировано) [11]	[12] После 80 ч [13]	15,76	0,012	0,69	34	1,03	0,18
	» 90 ч	19,58	0,015	0,62	19	1,07	0,20
	» 100 ч	—	0,024	0,64	27	1,12	0,18
	» 110 ч	16,58	0,010	0,60	13	1,10	0,20
	» 120 ч	16,85	0,010	0,57	12	1,11	0,20
	[14] Увеличение абс. показателя, %	0,92 5,6	0 0	- -	- -	0,01 —	— —

1) Specimen; 2) sampling time; 3) kinematic viscosity at 100°C, cSt; 4) mechanical impurities, %; 5) ash, %; 6) iron, %; 7) tars, %; 8) acid number, mg KOH; 9) standard oil; 10) phenol; 11) deasphalted; 12) after; 13) h; 14) increase in absolute index, %.

Investigation of Engine Characteristics of Oils Produced by Deasphaltization

Expansion of petroleum raw-material reserves and modification of the types of crude oils processed to produce high-quality oil distillates is inseparably related to selection of new oil-refining processes optimum for given conditions.

For a number of years, the Institute of Petrochemical Processes, Academy of Sciences of the Azerbaydzhan SSR, has been investigating the effectiveness of deasphaltization.

The goal of research on the properties of oils produced by this new technological process has been to establish optimum regimes for certain types of refining and to determine the extent to which the oils produced, when mixed with additives, satisfy the requirements imposed on motor oils by the planned new oil classification.

Work conducted at the Oil Technology Laboratory under the supervision of R.Sh. Kuliyev established that separate purification of the deasphaltization products of petroleum asphalt from the Neftyanyye Kamni deposit and of type 10 automobile oil from the same crude oil before compounding to produce Д-11 oil entailed a number of difficulties related to the unsatisfactory filterability of the deasphaltizate during contact refining.

In order to solve this problem, it was suggested that a deasphaltizate with its viscosity reduced by dilution with refined type 10 distillate be used for contact refining.

The resultant decrease in viscosity, as well as the acidic medium created by mixing the refined acidic distillate with the deasphaltizate, substantially improved compound filterability during contact refining. Д-11 oil produced from deasphaltizates of Neftyanyye Kamni petroleum asphalt (НК) and type 10 automobile oil, jointly refined, was tested in mixtures with Monsanto additives recommended for production of HD (ХД) compounds of series 1, 2, and 3.

The next stage was selection of the optimum compound of Balakhanskoye crude-oil asphaltizate (БМН) with type 6 automobile oil, refined with 1 or 2% acid, and with type 10 oil, also refined with 1 and 2% acid. The engine properties of these specimens were determined in an ИТ 9/3 apparatus by the ИДМ-10Ф method. The test results are presented in Table 83.

The data in this table show that the base oils tested had almost the same engine index, equivalent to that of commercial Д-11 oil from the VNZ im. XXII S"yezda KPSS.

Long-term engine tests are necessary for more complete analysis and definitive engine evaluation of the properties of these oils. Short-term screening tests can be used only to find the best of the specimens tested. Only more prolonged testing under stand conditions can provide a full evaluation of this specimen.

TABLE 83

Results of Tests by ИДМ Method

1 Образец	Мотор-ный ин- 2 декс
3 Д-11 (бак.) завода им. XXII съезда	9,2 –13,3
Д-11 (НКЗ)	11,7
4 Д-11 на базе деасфальтизата БМК и автола 6, очищенного 1% кислоты	10,4
5 То же, 2% кислоты	13,9
6 Д-11 на базе деасфальтизата БМН и автола 10, очищенного 1% кислоты	14,5
5 То же, 2% кислоты	13,8
7 Д-11 на базе деасфальтизации гудрона НК и автола 10 (совместная очистка)	10,3

1) Specimen; 2) engine index; 3) Д-11 (Bakinskoye), VNZ im. XXII S"yezda; 4) Д-11 based on БМК deasphaltizate and type 6 automobile oil, refined with 1% acid; 5) the same, 2% acid; 6) Д-11 based on БМН deasphaltizate and type 10 automobile oil, refined with 1% acid; 7) Д-11 based on НК petroleum-asphalt deasphaltizate and type 10 automobile oil (joint refining).

Long-term Stand Tests on Oils Produced by Deasphaltization of Neftyanyye Kamni mazut and Petroleum Asphalt

In order to make a comparison of engine characteristics, we tested an oil obtained by deasphaltization of Neftyanyye Kamni mazut and containing 10% АЗНИИ-7 and СБ-3 additives in a ratio of 1:2 and an oil produced by deasphaltization of Neftyanyye Kamni petroleum asphalt mixed with automobile oil and containing 10% of a similar compound additive. The tests were carried out for 140 h in a ЯАЗ-202 engine; their results are given in Table 84.

The compression- and oil-ring wear indices were similar in both cases; a somewhat better result with respect to carbon deposition and ring mobility was obtained for the oil based on petroleum-asphalt deasphaltizate.

TABLE 64

Results of Short-term Tests in ЯАЗ-204 Engine (% of Standard)

1 Показатели	2 Эталон ДСП-11	3 Масло на базе диасфальтизата мазута с 10% АзНИИ-7 и СБ-3	4 Масло на базе деасфальтизата гудрона с 10% АзНИИ-7 и СБ-3
5 Износ компрессионных колец по потере веса			
I	100	61	77
II	100	81	38
III	100	124	65
IV	100	90	100
6 В среднем на кольцо	100	75	74
7. То же маслосъемных колец			
I	100	95	90
II	100	85	85
III	100	79	20
IV	100	77	75
6 В среднем на кольцо	100	83	80
8 Износ вкладышей шатунных подшипников по потере веса, в среднем на один			
9 верхний	100	91	50
10 нижний	100	118	43
11 Подвижность поршневых колец			
12 свободные	12	15	14
13 плотные	3	1	1
14 прихваченные	1	0	1
15 Нагары			
16 с колец	100	70	45
17 с канавок	100	62	90
18 с колец и канавок	100	64	78
19 с днищ	100	134	100

1) Index; 2) standard ДСП-11; 3) oil based on mazut deasphaltizate containing 10% АзНИИ-7 and СБ-3; 4) oil based on petroleum-asphalt deasphaltizate containing 10% АзНИИ-7 and СБ-3; 5) compression-ring wear, from weight loss; 6) average per ring; 7) the same, for oil rings; 8) average wear per rod-bearing bushing, from weight loss; 9) upper; 10) lower; 11) piston-ring mobility; 12) free; 13) tight; 14) frozen; 15) carbon deposits; 16) rings; 17) grooves; 18) rings and grooves; 19) piston faces.

TABLE 85

Piston-Ring and Cylinder Wear

1 Показатели	Д-11+3% ЦИАТИМ-339	Масло на базе деасфальтизата мазута с 10% АзНИИ-7 и СБ-3 2	Масло на базе деасфальтизата гудрона с 10% АзНИИ-7 и СБ-3 3
4 Износ компрессионных колец по потере веса, *мг*			
I	—	379,3	297,1
II	—	1055,3	349,8
III	—	901	185,9
IV	—	900	117,1
5 В среднем на кольцо	259	810	238
6 То же маслосъемных колец, *мг*			
I	—	48,5	40,1
II	—	49,3	28,0
III	—	29,6	30,6
IV	—	45	36,2
5 В среднем на кольцо	—	43,1	33,7
7 Износ компрессионных колец по увеличению зазора, *мм*			
I	—	0,20	0,15
II	—	0,875	0,25
III	—	1,075	0,08
IV	—	1,020	0,12
5 В среднем на кольцо	0,145	0,792	0,15
8 То же маслосъемных колец, *мм*			
I	—	0,30	0,13
II	—	0,25	0,10
III	—	0,20	0,13
IV	—	0,25	0,10
5 В среднем на кольцо	—	0,25	0,12
9 Износ компрессионных колец по радиальной толщине, *мк*			
I	—	50	45
II	—	170	47
III	—	160	29
IV	—	140	19
5 В среднем на кольцо	—	130	37
10 То же маслосъемных колец, *мк*			
I	—	40	24
II	—	30	31
III	—	20	15
IV	—	20	15
5 В среднем на кольцо	—	28	28
11 Износ компрессионных колец по высоте, *мк*			
I	—	18	29
II	—	5	7
III	—	2	6
IV	—	10	5
5 В среднем на кольцо	—	8	12
12 То же маслосъемных колец, *мк*			
I	—	1	6
II	—	2	3
III	—	2	7
IV	—	3	5
5 В среднем на кольцо	—	2	4
13 Средний износ гильз цилиндра, *мк*	34	40	22

1) Index; 2) oil based on mazut deasphaltizate containing 10% АзНИИ-7 and СБ-3; 3) oil based on petroleum-asphalt deasphaltizate containing 10% АзНИИ-7 and СБ-3; 4) compression-ring wear, from weight loss, mg; 5) average per ring; 6) the same for oil rings, mg; 7) compression-ring wear, from increase in gap, mm; 8) the same for oil rings, mm; 9) compression-ring wear, from radial thickness, μm; 10) the same for oil rings, μm; 11) compression-ring wear, from height, μm; 12) the same for oil rings, μm; 13) average cylinder-sleeve wear, μm.

TABLE 8̈6

Wear for Crankshaft-rod Components

Показатели 1	Д-11+3% ЦИАТИМ-339 2	Масло на базе деасфальтизата гудрона с 10% АзНИИ-7 и СБ-3 3	Масло на базе деасфальтизата мазута с 10% АзНИИ-7 и СБ-3 4
5 Износ шеек коленчатого вала, *мк*			
6 шатунных	0	8	1
7 коренных	0	2,5	0
8 Износ втулки верхней головки шатуна, *мк*	3	8	—
9 Износ вкладышей шатунных подшипников по потере веса, *мг*			
10 на один верхний	44	167,0	62,2
11 на один нижний	12	80,9	32,7
12 Износ вкладышей коренных подшипников по потере веса, *мг*			
10 на один верхний	44	41,0	27,2
11 на один нижний	196	85,6	54,9
13 Износ поршней (*мк*) по изменению			
14 наружного диаметра	4	10,7	7
15 диаметра в бобышках	9	5	1
16 Износ поршневого пальца, *мк*	2	1,5	8

1) Index; 2) Д-11 + 3% ЦИАТИМ-339; 3) oil based on petroleum-asphalt deasphaltizate containing 10% АзНИИ-7 and СБ-3; 4) oil based on mazut deasphaltizate containing 10% АзНИИ-7 and СБ-3; 5) wear for crankshaft necks, μm; 6) rod; 7) crank; 8) wear for upper rod bushing, μm; 9) wear for rod-bearing bushings, from weight loss, mg; 10) for one upper bushing; 11) for one lower bushing; 12) wear for crank-bearing bushings, from weight loss, mg; 13) piston wear (μm), from change in; 14) outer diameter; 15) diameter at bosses; 16) piston-pin wear, μm.

TABLE 87

Ring Mobility and Tar Formation

Состояние деталей после 600 ч работы двигателя 1	Д-11+3% ЦИАТИМ-339 2	Масло на базе деасфальтизата гудрона с 10% АзНИИ-7 и СБ-3 3	Масло на базе деасфальтизата мазута с 10% АзНИИ-7 и СБ-3 4
5 Подвижность поршневых колец			
6 свободные	16	27	29
7 инертные	14	2	2
8 защемленные	1	0	1
9 поломанные	1	3	0
10 Лаковое покрытие на юбках поршней, %			
11 черного цвета	55–70	50	30
12 темно-коричневое	—	5	20
13 светло-коричневое	—	5	8
14 Оценка чистоты поверхности юбки поршня по стандарту 334-Т	6,5—7	5,6	4,7

1) Condition of components after engine operation for 600 h; 2) Д-11 + 3% ЦИАТИМ-339; 3) oil based on petroleum-asphalt deasphaltizate containing 10% АзНИИ-7 and СБ-3; 4) oil based on mazut deasphaltizate containing 10% АзНИИ-7 and СБ-3; 5) piston-ring mobility; 6) free; 7) inert; 8) pinched; 9) broken; 10) tar coating on piston skirts, %; 11) black; 12) dark brown; 13) light brown; 14) evaluation of piston-skirt cleanness by 334-T standard.

TABLE 88

Deposits and Oil Consumption

Показатели 1	Д-11+3% ЦИАТИМ-339 2	Масло на базе деасфальтизата гудрона с 10% АзНИИ-7 и СБ-3 3	Масло на базе деасфальтизата мазута с 10% АзНИИ-7 и СБ-3 4
5 Отложения на фильтрующих элементах очистки масла в среднем за 60-часовой цикл, г	384	400	526
6 Расход масла на угар в среднем за 60-часовой цикл, кг	8	4,120	5,290
7 То же в % к расходу топлива	0,99	0,5	0,6
8 Нагарообразование, г			
9 на поршневых кольцах	2,83	1,72	4,86
10 в канавках поршня	3,42	4,22	6,61
11 Всего нагара, г	6,25	5,94	11,47
12 Отложения с продувочных окон гильз цилиндров, г	13 Не оценено	18,10	30,2

1) Index; 2) Д-11 + 3% ЦИАТИМ-339; 3) oil based on petroleum-asphalt deasphaltizate containing 10% АзНИИ-7 and СБ-3; 4) oil based on mazut deasphaltizate containing 10% АзНИИ-7 and СБ-3; 5) deposits on oil-filter elements, average for 60-h cycle, g; 6) oil burnt, average for 60-h cycle, kg; 7) the same, % of fuel consumption; 8) carbon deposition, g; 9) on piston rings; 10) on piston grooves; 11) total carbon deposits, g; 12) deposits in cylinder-sleeve exhaust ports, g; 13) not determined.

Tables 85 and 86 present data characterizing engine-component wear during operation with the test oils in long-term tests. As can be seen, almost all the wear indices for the specimen produced by deasphaltization of petroleum asphalt were substantially poorer. Engine-component wear for the oil produced by deasphaltization of mazut was similar to that for Д-11 containing 3% ЦИАТИМ-339 additive.

The character and amount of the carbon and tar deposits on the engine components and the state of the piston rings were evaluated by visual inspection and weighing. Tables 87 and 88 present data on piston-ring mobility, deposits on piston components, and oil physicotechnical characteristics.

TABLE 90

Change in Physicochemical Properties of Diesel Oil Obtained by Deasphaltization of Petroleum Asphalt, with 10% АзНИИ-7 and СБ-3 Additives (in ratio of 1:2)

1 Время отбора проб	2 Кинематическая вязкость (*сст*) при 50° С	100° С	Зольность, % 3	Механические примеси, % 4	Кислотное число, *мг* КОН 5	Кокс, % 6	% несгораемых частиц 7
20 *мин* 8	92,87	13,45	0,80	0,019	0,09	1,05	0,015
10 *ч* 9	92,51	13,31	0,71	0,013	0,18	1,21	0,009
20 *ч*	93,91	13,42	0,74	0,015	0,21	1,15	0,008
30 *ч*	97,52	13,47	0,74	0,019	0,16	1,52	0,012
40 *ч*	94,61	13,59	0,76	0,022	0,13	1,86	0,012
50 *ч*	95,11	13,79	0,76	0,023	0,18	1,69	0,012
60 *ч*	98,09	14,72	0,79	0,045	0,28	1,72	0,014
10 Изменение показателя	+5,22	+1,27	−0,01	+0,026	+0,19	+0,67	−0,002

1) Sampling time; 2) kinematic viscosity (cSt) at; 3) ash, %; 4) mechanical impurities, %; 5) acid number, mg KOH; 6) tars, %; 7) % unconsumed particles; 8) min; 9) h; 10) change in index.

It can be seen from the data in these tables that the poorest results were obtained when the engine was run with the mazut deasphaltizate. The piston-skirt cleanness was very low (about 5 points), although it was one point higher than the corresponding index for Д-11 oil containing 3% ЦИАТИМ-339 additive.

Tables 89-91 present the results of an analysis of oil samples taken during engine operation.

The changes in the physicochemical properties of the oils were about the same in both cases. The only difference was that the tar content of the mazut deasphaltizate increased somewhat more rapidly.

Analysis of the results of long-term stand tests on oils produced by deasphaltization of mazut and petroleum asphalt enables us to draw the following conclusions.

TABLE 90

Change in Physicochemical Properties of Diesel Oil Based on Mazut Deasphaltizate, with 10% АзНИИ-7 and СБ-3 Additives (in ratio of 1:2)

1 Время отбора проб	2 Кинематическая вязкость (*ccm*) при		Золь-ность, % 3	Механические примеси, % 4	Кислотное число, *мг* КОН 5	6 Кокс, %
	50°C	100°C				
20 *мин* 7	96,8	14,06	0,76	0,010	Следы	1,23
10 ч 8	101,63	14,33	0,75	0,014	10 „	1,51
20 ч	99,92	14,45	0,76	0,015	„	1,8
30 ч	100	14,77	0,78	0,016	„	2,22
40 ч	102,15	14,87	0,78	0,023	„	2,27
50 ч	107,1	14,93	0,78	0,030	„	2,43
60 ч	102,31	14,95	0,78	0,033	0,13	2,51
Увеличение показателя 9	+5,51	+0,89	+0,02	+0,023	0,13	+1,28

1) Sampling time; 2) kinematic viscosity (cSt) at; 3) ash, %; 4) mechanical impurities, %; 5) acid number, mg KOH; 6) tars, %; 7) min; 8) h; 9) increase in index; 10) traces.

TABLE 91

Change in Physicochemical Properties of Д-11 Diesel Oil Containing 3% ЦИАТИМ-339 Additive

1 Время отбора проб	2 Кинематическая вязкость, при 100°C, *ccm*	3 Зольность, %	4 Механические примеси, %	5 Кислотное число, *мг* КОН	6 Кокс, %
20 *мин* 7	11,41	0,307	0,03	0,055	0,880
10 ч 8	11,50	0,152	0,024	0,142	0,680
20 ч	11,58	0,167	0,028	0,185	0,795
30 ч	11,86	0,172	0,043	0,230	1,200
40 ч	12,29	0,182	0,062	0,307	1,410
50 ч	12,85	0,192	0,043	0,300	1,500
60 ч	12,83	0,221	0,037	0,280	1,680
Изменение показателя 9	+1,42	−0,086	+0,027	+0,225	+0,800

1) Sampling time; 2) kinematic viscosity at 100°C, cSt; 3) ash, %; 4) mechanical impurities, %; 5) acid number, mg KOH; 6) tars, %; 7) min; 8) h; 9) change in index.

1. Engine-component wear is usually substantially greater for the oil produced by deasphaltization of petroleum asphalt.

2. Piston-ring mobility is about the same in both cases.

3. Piston-skirt cleanness is also roughly the same in both cases (4.5-5.5 points).

4. Carbon deposition is substantially greater for the oil based on mazut deasphaltizate.

5. The change in oil physicochemical properties during engine operation and the economic indices of the engine are almost identical in both cases.

Thus, while the oil obtained by deasphaltization of petroleum asphalt yields unsatisfactory results with respect to engine-component wear, the results of the tests on the mazut-deasphaltizate oil are very unsatisfactory with respect to carbon deposition.

Testing of Highly Refined (250% furfurol) Diesel Oil from Prospective Mixture of Baku Crude Oils Containing 6% БФК Additive in КДМ-46 Engine

These tests were comparitive in nature: the engine characteristics of the test oil were compared with those of oil containing 3% ЦИАТИМ-399 additive produced by the Novo-Ufa Plant, which were determined by tests in the same engine at the VNII NP. The purpose of the tests was to establish the feasibility of using selectively refined diesel oil from Bakinskoye crude oils containing 6% БФК-1 additive in КДМ-46 engines operating on GOST 305-42 diesel fuel containing 1% sulfur.

TABLE 92

Physicochemical Indices of Oils Tested

Показатели 1	Масло НУЗ 2	Бакинское масло 3
4 Вязкость кинематическая, *сст* при 50° С	63,4	77,65
100° С	11,1	11,58
5 Отношение вязкостей 50°:100°	5,72	7,02
6 Кислотное число, *мг* КОН	15 отс.	15 отс.
7 Зольность, %	0,25	0,64
8 Коксуемость, %	0,74	0,98
9 Содержание водорастворимых кислот и щелочей	16 Щелочная реакция	15 Отс.
10 Содержание механических примесей, %	0,009	0,029
11 Содержание воды, %	15 отс.	15 Отс.
12 Моющие свойства по методу ПЗВ, баллы	—	1
13 Коррозия по методу НАМИ, *г/м²*	—	0,9
14 Испытания на 4-шариковой машине d_u	—	0,55
$P_к$		83
P_m		22200
$G_к$		14300

1) Index; 2) НУЗ oil; 3) Bakinskoye oil; 4) kinematic viscosity, cSt at; 5) viscosity ratio, 50°:100°; 6) acid number, mg KOH; 7) ash, %; 8) tars, %; 9) content of water-soluble acids and alkalies; 10) mechanical impurities, %; 11) water content, %; 12) detergent properties by PZV method, points; 13) corrosion by NAMI method, g/m²; 14) tests in four-ball machine; 15) none; 16) alkaline reaction.

Table 92 shows the physicochemical indices of the oils.

The tests were conducted by the usual method and consisted in running the КДИ-46 engine for 2000 h. The water and oil temperatures were held at 80 ± 3°C and 75 ± 3°C respectively in the loaded regimes.

In order to monitor engine operation, thermocouples were installed in the exhaust header in order to measure the temperature of the exhaust gases from the cylinders. The tests were carried out in 10-h stages under the following regimes:

об/мин [1]	[2] Мощность, л. с.	[5] Продолжительность
1000	90	1 ч[6]
1000	80	7 ч
1000	[3] Макс.	1 ч 45 мин[7]
600	[4] Холостой ход	15 мин

1) r/min; 2) power, hp; 3) maximum; 4) idle; 5) duration; 6) h; 7) min.

Technical servicing of the engine during the test period was conducted in accordance with the manufacturer's instructions. Oil sampling, micrometric measurement of components, and other observations were carried out in accordance with established test procedures.

The engine operated normally throughout the entire test period. The fuel system also functioned normally: the injectors did not have to be replaced.

Increased oil burning was observed from the 8th cycle on, apparently as a result of loss of mobility in the upper oil rings.

The engine power and economy indices remained unchanged during the tests: the maximum power was 95 hp, the per-hour fuel consumption was 18.9 kg, and the specific fuel consumption was 199 g per hp per h.

TABLE 93

Cylinder-Sleeve Wear for Oil Containing 3% ЦИАТИМ-339 Additive Produced by Novo-Ufa Plant, μ

[1] Поясы и расстояние их от верха гильз, мм	[2] № цилиндра				[3] Средний износ
	1	2	3	4	
1 –30	86	10	4	29	32
2 –150	10	8	0	8	7
3 –220	–12	–14	–20	–35	–20

1) Bands and distance from top of cylinder, mm; 2) cylinder No.; 3) average wear.

TABLE 94

Cylinder-Sleeve Wear for Bakinskoye Oil Containing 6% БФК Additive, μ

[1] Поясы и расстояние их от верха гильз, мм	[2] № цилиндра				[3] Средний износ
	1	2	3	4	
1 –22	27,0	25,0	13,0	25	16,9
2 –35	30,0	5,0	17,5	30	20,5
3 –50	22,5	7,5	15,0	40	21,2
4 –100	22,5	15,0	7,5	23	17,0
5 –190	20,0	17,5	17,5	20	18,7

1) Bands and distance from top of cylinder, mm; 2) cylinder No.; 3) average wear.

TABLE 95

Average Increase in Ring Gap, mm

Кольца [1]	Масло НУЗ [2]	Бакинское масло [3]
I	[4] Сломано	0,40
II	[4] Сломано	0,40
III	0,58	0,39
IV	1,28	0,50
V	—	0,30

1) Ring; 2) НУЗ oil; 3) Bakinskoye oil; 4) broken.

TABLE 96

Average Ring Wear, from Weight, Loss, g

Кольца [1]	Масло НУЗ [2]	Бакинское масло [3]
I	3,635	0,3806
II	1,944	0,4043
III	1,279	0,2345
IV	1,174	0,2734
V	—	0,4940

1) Ring; 2) НУЗ oil; 3) Bakinskoye oil.

The data in Tables 93 and 94 characterize the cylinder-sleeve wear.

As can be seen from the data given in these tables, the average cylinder wear in the maximum-wear zones was substantially less for Bakinskoye oil containing 6% БФК additive than for Novo-Ufa oil containing ЦИАТИМ-339 additive.

Tables 95, 96, and 97 show the indices of piston-ring wear.

It can be seen from the data in Tables 95-97 that all ring-wear indices were far lower for Bakinskoye oil containing БФК additive than for Eastern oil containing ЦИАТИМ-339 additive.

TABLE 97

Piston-Ring Wear, from Thickness and Height, μm

Кольца [1]	[2] По толщине		[5] По высоте	
	[3] Масло НУЗ	Бакинское масло [4]	[3] Масло НУЗ	Бакинское масло [4]
I	192	31,1	32	12,5
II	—	35,9	27	6,5
III	—	66	24	7,5
IV	249	40,5	6	—
V		48	—	6

1) Ring; 2) from thickness; 3) НУЗ oil; 4) Bakinskoye oil; 5) from height.

TABLE 98

Wear for Rod Necks and Bearings

1 Показатели	2 Масло НУЗ	3 Бакинское масло
4 Средний износ шатунных шеек, *мк*	31	3,1
5 Износ вкладышей по толщине, *мк*	15,5	0,0

1) Index; 2) НУЗ oil; 3) Bakinskoye oil; 4) average rod-neck wear, µm; 5) bushing wear, from thickness, µm.

TABLE 99

Wear for Crank Necks and Bearings

1 Показатели	2 Масло НУЗ	3 Бакинское масло
4 Средний износ коренных шеек вала, *мк*	14	2,5
5 Износ вкладышей по потере веса, *г*	0,198	—
6 Износ вкладышей по толщине, *мк*	—	1,5

1) Index; 2) НУЗ oil; 3) Bakinskoye oil; 4) average crank-neck wear, µm; 5) bushing wear, from weight loss, g; 6) bushing wear, from thickness, µm.

TABLE 100

Ring Mobility

1 Подвижность	2 Компрессионные		5 Маслосъемные	
	Масло НУЗ 3	Бакинское масло 4	Масло НУЗ 3	Бакинское масло 4
6 Свободные	1	9	4	4
7 Плотные	—	3	—	—
8 Прихваченные	11	—	—	4
9 Закатанные	—	—	—	

1) Mobility; 2) compression; 3) НУЗ oil; 4) Bakinskoye oil; 5) oil; 6) free; 7) tight; 8) frozen; 9) rolled.

Table 98 shows the wear indices for the rod necks and rod-bearing bushings, while Table 99 shows those for the crank necks and crank-bearing bushings.

As can be seen from the data in these tables, the wearing of both the necks and bearing bushings was substantially lower for the Bakinskoye oil containing БФК additive.

Carbon deposition on the pistons and rings averaged 30.77 g for the Novo-Ufa oil containing 3% ЦИАТИМ-399 and 2.33 g for the Bakinskoye oil (this does not include the deposits on the oil rings and grooves).

The data in Table 100 characterize the piston-ring mobility after the tests. It must be emphasized that the engine used with Д-11 (highly refined) oil containing 6% БФК additive had a piston with two oil rings, while the engine used for the Eastern oil had only one oil ring.

TABLE 101

Oil Consumption and Burning for Д-11 Oil Containing 6% БФК Additive

1 № цикла	2 Расход масла за цикл (120 ч), кг	3 Слито масла в конце цикла с учетом проб, кг	4 Угар масла за цикл, кг
1	37,2	21,6	15,6
2	32,4	21,3	11,1
3	38,8	26,3	12,1
4	35,9	20,7	15,2
5	47,5	22,3	25,2
6	45,1	19,7	25,4
7	48,2	19,9	28,1
8	64,8	16,8	48,0
9	59,5	20,7	28,25
10	63,5	20,0	43,5
11	69,1	19,5	49,6
12	59,2	19,5	39,75
13	69,8	20,4	49,4
14	61,7	18,7	43,05
15	85,3	16,8	68,55
16	68,8	18,7	50,1
5 В среднем за цикл	55,44		34,5

1) Cycle No.; 2) oil consumption over cycle (120 h), kg; 3) oil drained at end of cycle, including samples, kg; 4) oil burnt during cycle, kg; 5) average per cycle.

TABLE 102

Oil Consumption and Burning for НУЗ Oil Containing 3% ЦИАТИМ-339 Additive

1 № цикла	2 Расход масла за цикл (120 ч), кг	3 Слито масла к конце цикла, кг	4 Угар масла за цикл кг
1	23,4	18,1	5,3
2	28,7	18,0	10,7
3	28,5	18,1	10,5
4	28,2	18,6	9,6
5	30,4	18,4	12,0
6	26,7	17,9	8,8
7	25,1	17,6	7,6
8	26,5	14,7	11,8
9	28,7	15,9	12,8
10	28,5	18,2	10,3
11	18,9	18,3	10,6
12	28,5	18,8	9,7
13	28,3	17,0	11,3
14	23,9	18,1	5,8
15	29,5	17,7	11,7
16	31,4	16,5	14,9
5 В среднем за цикл	27,9		10,2

1) Cycle No.; 2) oil consumption during cycle (120 h), kg; 3) oil drained at end of cycle, kg; 4) oil burnt during cycle, kg; 5) average per cycle.

We have introduced the term "rolled ring" in connection with the fact that the loss of mobility for all the top oil rings during use of Bakinskoye oil containing БФК additive was due to covering of these rings with the piston metal. This phenomenon cannot have been associated with operation of the engine with the test oil, but resulted from unsatisfactory machining of the pistons. Confirmation is provided by the fact that the piston-skirt diameter increased by the following average amounts (in the planes of maximum increment) over 2000 h of operation: 143 μm for piston I, 140 μm for piston II, 143 μm for piston III, and 143 μm for piston IV. Thus, the expansion slits in the piston skirts were halved in size, which could not help but lead to extreme tightness of the pistons in the sleeves and to large frictional forces, which caused rolling of metal onto the oil-ring grooves.

Secondly, examination of the pistons showed that the bevel of 0.5 × 45° that should have been made in the lower edge of the upper oil-ring groove, in accordance with the blueprints, was actually lacking, which also promoted metal buildup.

TABLE 103

Average Data on Oil Consumption and Burning

1 Показатели	2 Масло НУ3	3 Бакинское масло	2 Масло НУ3	3 Бакинское масло
4 В среднем за цикл, *кг*	27,8	55,4	10,2	34,4
5 % к расходу топлива	1,54	2,93	0,55	1,82

1) Index; 2) НУ3 oil; 3) Bakinskoye oil; 4) average per cycle, kg; 5) % of fuel consumption.

TABLE 104

Change in Engine Power and Economy Indices

1 Показатели	2 Масло НУ3		5 Бакинское масло	
	3 до испыт.	4 после испыт.	3 до испыт.	4 после испыт.
6 Максимальная мощность	94	94	95	95
7 Часовой расход, *кг/ч*	19,0	19,0	19,0	19,0
8 Удельный расход *г/э.л.с.ч.*	202	202	200	200

1) Index; 2) НУ3 oil; 3) before test; 4) after test; 5) Bakinskoye oil; 6) maximum power; 7) hourly fuel consumption, kg/h; 8) specific fuel consumption, g per effective hp per h.

As can be seen from Tables 101-103, oil consumption and burning were substantially greater for the Д-11 oil containing 6% БФК, which resulted from the loss of upper oil-ring mobility caused by rolling.

Table 104 presents data on the change in engine power and economy indices during the tests. As can be seen, these indices

TABLE 105

Change in Physicochemical Properties of Oil from Novo-Ufa Plant

1 Период работы	2 Вязкость кинематическая при 50° C, *сст*	3 Кислотное число, *мг* KOH	4 Коксуемость, %	5 Зольность, %
6 Свежее масло	63,4	11 Щелочное	0,74	0,25
7 Через 20 *мин* 8	64,2	0,11	0,75	0,17
30 ч 9	66,2	0,48	0,70	0,10
60 ч	68,0	0,52	0,79	0,04
120 ч	69,7	0,60	0,91	0,05
10 Изменение за цикл	+6,3	+0,60	+0,17	−0,20

1) Operating time; 2) kinematic viscosity at 50°C, cSt; 3) acid nu ber, mg KOH; 4) tars, %; 5) ash, %; 6) fresh oil; 7) after; 8) min; 9) h; 10) change over cycle; 11) alkaline.

remained almost constant in both cases.

Table 105 shows the change in the physicochemical indices of the Novo-Ufa oil containing 3% ЦИАТИМ-339 additive during engine operation, while Table 106 shows that for the Д-11 oil containing 6% БФК additive.

As can be seen from the data in these tables, the physicochemical indices underwent a smaller change for the Д-11 oil containing 6% БФК additive. Specifically, while the ash content of the Novo-Ufa oil containing ЦИАТИМ-339 additive was greatly reduced or almost zero after 30 h of engine operation, that of the Bakinskoye oil remained constant to the end of the cycle.

Comparative tests in a КДМ-46 engine thus established the following facts.

TABLE 106

Change in Physicochemical Indices of Bakinskoye Oil

1 Период работы	2 Вязкость кинематическая при 50° C, *сст*	3 Кислотное число, *мг* KOH	4 Коксуемость, %	5 Зольность, %
6 Свежее масло	77,65	11 Отсут.	0,98	0,64
7 Через 20 *мин* 8	80,77	0,040	0,98	0,675
30 ч 9	88,54	0,126	1,094	0,735
60 ч	91,83	0,150	1,128	0,763
120 ч	92,21	0,183	1,156	0,777
10 Изменение за цикл	+14,56	+0,183	+0,176	+0,137

1) Operating period; 2) kinematic viscosity at 50°C, cSt; 3) acid number, mg KOH; 4) tars, %; 5) ash, %; 6) fresh oil; 7) after; 8) min; 9) h; 10) change during cycle; 11) none.

1. Both engines operated normally, without any apparent defects, during the tests. Increased oil consumption was observed after operation for 1000 h with the Д-11 oil containing БФК additive.

2. The engine power and economy indices remained almost unchanged.

3. The wear for the main engine components (cylinder sleeves, piston rings, crank necks, and crank bearing bushings) was substantially for the Д-11 oil containing 6% БФК-1 additive and was actually negligible.

4. The amount of carbon deposited on the piston components during operation with the oil containing БФК additive was less by a factor of 10 than that observed during operation with the oil containing ЦИАТИМ-339 additive.

5. The physicochemical properties of the Д-11 oil containing 6% БФК additive changed less during engine operation.

6. Loss of upper oil-ring mobility resulting from covering with the piston metal was noted for the Д-11 oil containing 6% БФК additive; this was due to deficiencies in piston qualities. All the compression rings except one lost their mobility during operation with the Novo-Ufa oil containing 3% ЦИАТИМ-339 additive.

7. Д-11 (Bakinskoye) oil containing 6% БФК additive can provide normal operation of the КДМ-46 engine on high-sulfur fuels.

Investigation of Engine Characteristics of Thickened Automobile Oils

Thickened or "all-weather" oils produced by thickening low-viscosity base oils with high-molecular polymer additives are receiving ever greater recognition in modern transport. Such oils, which exhibit high viscosity indices, permit easy engine starting at low temperatures, reduce losses due to friction during urban winter driving, and have a number of other advantages.

АСЗ-10 oil is produced by thickening a base that has been refined with furfurol, acid, and gumbrin and has a viscosity of 4.5-7 cSt at 100°C. The polyisobutylene consumption for thickening is 0.5-1%. АСЗ-6 oil is produced by adding about 1% polyisobutylene to a light-duty distillate refined with 100% furfurol and then further refining the thickened product with acid and gumbrin.

Long-term stand tests were conducted in order to evaluate the engine properties of thickened automobile oils in comparison with commercial oils. The test specimens provided complete piston-ring mobility throughout the test period in all cases.

The data in Table 107 characterize carbon deposition on the piston-ring assemblies and high-quality oil filter, as well as the amount of oil burnt.

TABLE 107

Deposits on Engine Components

1 Образец	2 Нагар на поршнях с кольцами, г	3 В т. ч. с колец канавок, г	4 Отложения на Ф. Т. О. масла, г	5 Угар масла, г/ч	6 Угар масла, % к расходу топлива
АСЗ-10% с[7] 10% СБ-3	11,0	0,96	123,0	57,0	0,48
АС-10 с 10% СБ-3	10,1	1,55	110,3	45,0	0,37
АСЗ-10 с 5% АзНИИ-8 (АзНИИ-5)	10,65	2,13	120,0	47,0	0,39
АС-10 с 3% АзНИИ-8 (АзНИИ-5)	20,8	—	—	—	—
АСЗ-10 с 5% АзНИИ-8 (СБ-3)	7,81	2,09	48,0	47,0	0,39
АС-10 с 5% АзНИИ-8 СБ-3	8,65	0,89	57,0	36,5	0,3
АСЗ-6 с 10% (СБ-3)	12,24	1,73	47,0	87,0	0,71
АС-6 с 10% СБ-3	5,2	0,39	76,0	56,0	0,46

1) Specimen; 2) carbon deposits on pistons and rings, g; 3) including ring grooves, g; 4) deposits on high-quality oil filter, g; 5) oil burnt, g/h; 6) oil burnt, % of fuel consumption; 7) with.

TABLE 108

Cylinder Wear, μm

1 Образцы	2 Плоскость оси вала		5 Приведенный износ цилиндров
	3 параллельной	4 перпендикулярной	
АСЗ-10% с[6] 10% СБ-3	4,5	5,5	5,0
АС-10 с 10% СБ-3	2,56	5,2	3,93
АСЗ-10 с 5% АзНИИ-8 (АзНИИ-5)	12,0	13,0	12,5
АС-10 с 3% АзНИИ-8 (АзНИИ-5)	—	—	5,9
АСЗ-10 с 5% АзНИИ-8 (СБ-3)	12	13	12,5
АС-10 с 5% АзНИИ-8 (СБ-3)	3,3	3,5	3,4
АСЗ-6 с 10% СБ-3	1,0	3,5	2,25
АС-6 с 10% СБ-3	0,2	0,6	0,4

1) Specimen; 2) crankshaft-axis plane; 3) parallel; 4) perpendicular; 5) reduced cylinder wear; 6) with.

These data indicate that the amount of carbon deposited on the rings and grooves were somewhat greater for the AC3-10 oil containing 5% АзНИИ-8 additive based on СБ-3 additive and the AC3-6 oil containing 10% СБ-3 additive than for the commercial AC-10 and AC-6 oils containing the same additives.

The amount of carbon deposited on the high-quality oil filter was roughly the same for the thickened and commercial oils containing the same additives.

Oil burning was of the same order (very slight) in all cases, except for the AC3-6 oil containing 10% СБ-3, where it amounted to 0.71% of the fuel consumption.

The cleanest piston surfaces were obtained for the AC3-10 and AC3-6 oils containing 10% СБ-3 additive. Roughly the same results were obtained for the AC3-10 oil containing АзНИИ-8 additive based on both АзНИИ-5 and СБ-3 additives, but these were poorer than for the oils containing СБ-3 additive. Use of АзНИИ-8 additive based on СБ-3 additive with АС-10 commercial oil provided substantially better results for this index.

Component Wear

Table 108 presents data on engine-cylinder wear.

As can be seen, the reduced cylinder wear for all the test and standard specimens was of roughly the same order (about 2-6 μm), the only exception being the АСЗ-10 oil containing АзНИИ-8 additive based on АзНИИ-5 or СБ-3 additive, where it was somewhat higher (12.5 μm). Table 109 shows the piston-ring wear.

As can be seen from the data in Table 109, piston-ring wear for all the thickened automobile oils tested was either close to or lower than that for the commercial automobile oils containing the same additives. The АСЗ-6 oil containing 10% СБ-3 was an exception, producing almost twice as much average piston-ring wear with respect both to increase in ring gap and to weight loss as the commercial АС-6 oil containing 10% СБ-3.

Table 110 shows the wear for certain main engine components.

It can be seen from the data in this table that the thickened АСЗ-10 oil was equivalent in these indices to commercial АС-10 automobile oil (with the same additives). Greater piston-boss and upper rod-bushing wear was observed with the АСЗ-6 oil.

The data in Table 111 characterized the average per-cycle (51 h) change in crankcase-oil physicochemical properties.

As can be seen, the changes in these indices were normal in all cases.

We thus established the following facts:

1. АСЗ-10 oil containing 10% СБ-3 additive, 5% АзНИИ-8 additive based on АзНИИ-5 additive, or 5% АзНИИ-8 additive based on СБ-3 additive provides normal engine operation for 600 h under stand conditions; component-surface cleanness and carbon deposition are either equivalent to or better than those obtained for commercial АС-10 automobile oil. АСЗ-6 oil containing 10% СБ-3 additive causes greater carbon deposition on the rings and grooves and greater burning than АС-6 oil with the same additive.

2. Piston-ring mobility is maintained throughout the entire test period in all cases.

§3. ENGINE CHARACTERISTICS OF OIL ADDITIVES

The purposes and functions of the various types of additives used in oils are not always properly evaluated. In the opinion of some authors, additives are of greater importance for service than the oil itself.

Pritzker [9] gives the following explanation of additive use: "it is important to keep in mind that most oil additives serve only to improve definite properties and increase oil serviceability. Oils suitable for specific lubrication purposes are the basic and decisive factor in compounding any lubricant. Improvers added to an oil do not achieve their goal if the oil itself is poorly refined or unsuitable for the job at hand. The oil should be of the appropriate type, stable, and as chemically pure as can be achieved by modern technological methods. These qualities, in conjunction with various improvers, make it possible to produce a more efficient and stable lubricating mixture."

It can be stated that the purpose of motor-oil additives is to improve the properties of highly refined high-quality mineral oils; additives cannot compensate for poor oil quality or poor refining.

Heavy-duty oils are most widely used in diesel engines. Introduction of detergent additives into such oils is very effective for holding soot and resins in a dispersed state in the oil and for preventing coagulation and deposition.

TABLE 109

Piston-ring Wear

Образец (1)	Увеличение зазора, мк (2)				Потеря веса, мг (6)				Износ по высоте, мк (7)				Износ по толщине, мк (8)			
	Компрессионные (3)		Маслосъемные (4)	В среднем на одно кольцо (5)	Компрессионные (3)		Маслосъемные (4)	В среднем на одно кольцо (5)	Компрессионные (3)		Маслосъемные (4)	В среднем на одно кольцо (5)	Компрессионные (3)		Маслосъемные (4)	В среднем на одно кольцо (5)
	I	II			I	II			I	II			I	II		
АСЗ-10 с (9) 10% СБ-3	30	[illegible]	150	90,0	48,5	54,0	[illegible]	[illegible]	6,0	5,0	0	4,4	14,0	19,0	26,8	19,0
АС-10 с 10% СБ-3	50	7,5	120	101,0	44,0	30,5	54,0	44,5	0	0	0	[illegible]	9,4	11,7	17,0	13,0
АСЗ-10 с 5% АзНИИ-8 (АзНИИ-5)	40	63	210	111,0	42,3	30,0	[illegible]	64,5	2,0	7,0	4	4,7	70,0	31,5	39,3	50,4
АС-10 с 3% АзНИИ-8 (АзНИИ-8)	—	—	—	177,0	—	—	—	81,0	—	—	—	2,7	—	—	—	22,5
АСЗ-10 с 5% АзНИИ-8 (СБ-3)	75	40	132	80,0	32,0	37,4	60,1	30,1	0	0	[illegible]	0,3	2,0	9,0	17,0	9,0
АС-10 с 5% АзНИИ-8 (СБ-3)	17	35	130	87,2	42,7	43,0	[illegible]	50,0	0	0	[illegible]	0	8,0	6,7	12,13	9,0
АСЗ-6 с 10% СБ-3	75	105	460	236,3	30,0	64,7	204,0	110,0	1,0	0	3	1,3	16,0	27,0	80,0	48,0
АС-6 с 10% СБ-3	15	70	150	78,3	40,0	72,0	70,0	54,0	0	1,0	1	0,7	—	—	—	—

1) Specimen; 2) increase in gap, μm; 3) compression; 4) oil; 5) average per ring; 6) weight loss, mg; 7) wear from height, μm; 8) wear from thickness, μm; 9) with.

The Institute of Additive Chemistry, Academy of Sciences of the Azerbaydzhan SSR, has recently conducted a great deal of research on the engine characteristics of multipurpose additives. The additives designated as БФК and СБ-3 have come into the widest use.

As many tests of БФК in various automobile and tractor engines have shown, use of this additive in pure form greatly reduces the corrosiveness of the oil, has a material stabilizing effect, and

TABLE 110

Engine-Component Wear

1 Детали	АСЗ-10 с 10% СБ-3	АС 10 с 10% С.-3	АС-10 с 5% АзНИИ-8 (АЗ-5)	АС-10 с 3% АзНИИ-8 (АЗ-5)	АСЗ-10 с 5% А.НИИ-8 (СБ-3)	АС-10 с 5% АзНИИ-8 (СБ-3)	АСЗ-6 с 10% СБ-3	АС-6 с 10% СБ-3
3 Поршень, мк								
4 Бобышки	0,0	6,9	—	10,0	4,0	4,0	9,4	0.7
5 Юбка	—	3,9	2,0	6,0	2,0	0,0	5,7	4,0
6 Втулка верхней головки шатуна	4,8	3,0	5,6	3,5	5,5	5,8	7,5	0,6
7 Поршневой палец	0,0	5,6	0,0	—	0,0	0,0	0,1	0,0
8 Коленчатый вал								
9 Шатунная шейка	4,5	1,7	0,0	—	0,0	0,0	1,2	1,0
10 Коренная шейка	6,5	1,7	0,0	—	0,0	0,0	0,0	0,6
11 Вкладыши, мг								
12 шатунные	64,0	78,5	75,0	—	75,0	65,0	129,5	117,5
13 коренные	64,0	105,2	79,0	—	79,0	75,0	96,5	110,0

1) Components; 2) with; 3) piston, μm; 4) bosses; 5) skirt; 6) upper rod bushing; 7) piston pin; 8) crankshaft; 9) rod neck; 10) crank neck; 11) bushings, mg; 12) rod; 13) crank.

consequently promotes maintenance of piston-ring mobility. The effectiveness of БФК additive in reducing wear and carbon deposition and ensuring ring mobility is greater than that of ЦИАТИМ-339 additive. According to the results of tests conducted in a УИМ-3 apparatus, the detergent properties of БФК additive are almost twice as good as those of ЦИАТИМ-339 additive.

The results of tests conducted with БФК additive mixed with ДС-11 НКЗ oil in single-cylinder 1Ч and УИМ-3 engines are given in Table 112.

Table 113 presents the results of short-term tests of БФК additive mixed with Bakinskoye and Eastern oils in a ЯАЗ-204 engine.

As can be seen from the data in Table 113, the БФК additive yielded less wear, less carbon deposition, and almost complete ring mobility. It must be emphasized that, in testing oils in a ЯАЗ-204 engine under the regime specified by the long-term test instructions, maintenance of piston-ring mobility during operation with high-sulfur fuels is a rare phenomenon even for 140-h tests with effective oil additives. For example, partial ring welding occurs after engine operation for 140 h with oil containing ВНИИ-360 additive. This fact also indicates the good engine characteristics of БФК additive.

Long-term Stand Tests of Д-11 Oil Containing 5% БФК Additive in ЯАЗ-204 Engine

Tables 114 and 115 present data characterizing the wear for the main engine components during operation with standard and

TABLE 111

Change in Physicochemical Properties of Worked-out Oils

[1] Показатели	АСЗ-10 с[2] 10% СБ-3	АС-10 с[2] 10% СБ-3	АСЗ-10[2]с 5% АзНИИ-8 (АзНИИ-5)	АС 10 с[2] 3% АзНИИ-8 (АзНИИ-5)	АСЗ-10[2]с 5% АзНИИ-8 (СБ-3)	АС-10 с[2] 5% АзНИИ-8 (СБ-3)	АСЗ-6 с[2] 10% СБ-3	АС-6 с[2] 10% СБ-3
[3] Вязкость кинематическая при 50° С, *сст*								
20 *мин*[4]	63,66	57,9	64,70	63,07	54,00	34,60	31,70	40,22
51 *ч*[5]	72,06	68,2	72,23	90,60	57,33	75,04	34,73	41,97
[6] Вязкость кинематическая при 100° С, *сст*								
20 *мин*[4]	11,25	9,7	10,63	9,71	9,99	10,26	7,13	7,34
51 *ч*[5]	11,79	9,9	11,26	12,53	10,15	11,12	7,57	7,65
[7] Кислотное число, *мг* КОН								
20 *мин*[4]	0,02	0,077	0,07	0,046	0,02	0,08	0,03	0,07
51 *ч*[5]	0,23	0,308	0,17	0,180	0,33	0,183	0,37	0,20
[8] Зольность, %								
20 *мин*[4]	0,59	0,57	0,57	0,266	0,25	0,465	0,63	0,60
51 *ч*[5]	0,85	0,56	0,53	0,296	0,26	0,523	0,75	0,69
[9] Коксуемость, %								
20 *мин*[4]	0,83	0,71	0,64	0,48	0,48	0,63	0,87	0,74
51 *ч*[5]	1,22	0,84	0,91	0,80	0,58	0,87	1,33	0,97

1) Index; 2) with; 3) kinematic viscosity at 50°C, cSt; 4) min; 5) h; 6) kinematic viscosity at 100°C, cSt; 7) acid number, mg KOH; 8) ash, %; 9) tars, %.

TABLE 112

Results of Tests in 1Ч Apparatus

[1] Показатели	ДСП-11	ДС-11 НКЗ с[2] 6% БФК	ДС-11 НКЗ с[2] 8% БФК
[3] Износ I и II колец, *мг*	155,8	101,4	104,3
[4] Средний износ колец, *мг*	35,0	23,9	24,3
[5] Нагар с колец, *г*	0,22	0,19	0,15
[6] Нагар с канавок, *г*	0,27	0,24	0,19
[7] Подвижность колец			
[8] свободные	1	5	4
[9] плотные	5	1	2
[10] прихваченные	—	—	—

1) Index; 2) with; 3)wear for 1st and 2nd rings, mg; 4) average ring wear, mg; 5) carbon deposits on rings, g; 6) carbon deposits on grooves, g; 7) ring mobility; 8) free; 9) tight; 10) frozen.

TABLE 113

Short-term Tests in ЯАЗ-204 Engine

1 Показатели	ДСП-11 (НКЗ)	ДС-11 (НКЗ)+5% БФК	ДС-11 (НКЗ)+6% БФК	Д-11 2(бак.)+8% БФК	ДС-11 (НКЗ)+8% БФК
3 Износ компрессионных колец по потере веса, *мг*					
I	111,0	80,0	63,5	76,7	72,3
II	231,0	149,0	110,8	110,4	133,8
III	146,0	109,0	117,4	115,5	135,8
IV	126,0	161,0	149,9	116,0	154,5
4 В среднем на кольцо	154,0	125,0	110,4	104,5	124,1
5 То же маслосъемных колец					
I	15,7	51	9,2	17,3	10,6
II	11,0	47	4,5	11,5	10,6
III	19,0	27	6,1	19,4	9,7
IV	14,0	87	9,7	19,5	14,8
4 В среднем на кольцо	17,0	40	7,4	17,0	11,4
6 Износ компрессионных колец по увеличению зазора, *мк*					
I	83	75	50	20	37,5
II	250	50	112,5	80	87,5
III	125	25	75	50	50,0
IV	100	133	37,5	30	83,0
4 В среднем на кольцо	139	71	68,1	45	64,5
5 То же маслосъемных					
I	25	50	50	30	25
II	16	100	25	30	50
III	25	87	62,5	60	25
IV	37,5	75	75	60	50
4 В среднем на кольцо	25,8	78	53	45	37,5
7 Нагар, *г*					
8 с колец	2,82	2,30	2,02	2,35	2,43
9 с канавок	6,43	1,92	4,97	4,85	3,34
10 с днища	1,48	0,84	1,60	2,05	0,71
11 Суммарный	10,73	5,06	8,59	9,25	6,48
12 Средний износ вкладышей по потере веса (*мг*) на один					
13 верхний	29,3	65	7,0	27,3	27,0
14 нижний	21,7	57	1,7	15,2	20,7
15 Подвижность колец					
16 свободные	11	16	14	14	15
17 плотные	4	—	2	2	1
18 прихваченные	1	—	—	—	—

1) Index; 2) Bakinskoye; 3) compression-ring wear, from weight loss, mg; 4) average per ring; 5) the same, for oil rings; 6) compression-ring wear, from increase in gap, μm; 7) carbon deposits, g; 8) on rings; 9) on grooves; 10) on piston faces; 11) total; 12) average bushing wear, from weight loss (mg), per bushing; 13) upper; 14) lower; 15) ring mobility; 16) free; 17) tight; 18) frozen.

TABLE 114

Wear for Cylinder-Piston Components

1 Показатели износа	2 Д-11(товарное) +3% ЦИАТИМ-339	2 Д-11 (товарное) +5% БФК
3 Износ гильз цилиндров (мк) в поясе на расстоянии 22 мм	43	31
25 мм	45	30
95 мм	46	26
140 мм	38	15
170 мм	30	15
273 мм	3	14
4 Приведенный износ гильз, мк	34	22
5 Износ поршней (мк) по изменению наружного диаметра,	4	5
6 диаметра бобышек	9	1,2
7 Износ поршневых колец		
8 по потере веса в среднем на одно кольцо, мг	259	325
9 по изменению зазора в стыке колец, мм	0,145	0,15
10 Износ поршневого пальца, мм	0,002	0

1) Wear index; 2) (commercial); 3) cylinder-sleeve wear (μm) in bands at distance of; 4) reduced sleeve wear, μm; 5) piston wear (μm), from change in outside diameter; 6) boss diameter; 7) piston-ring wear; 8) from loss of weight, average per ring, mg; 9) from change in ring gap, mm; 10) piston-pin wear, mm.

TABLE 115

Wear for Crankshaft-Rod Components

1 Показатели износа	Д-11+3% ЦИАТИМ-339	Д-11+5% БФК
2 Износ шеек коленчатого вала, мм		
3 шатунных	0	0,0075
4 коренных	0	0,0036
5 Износ верхней втулки шатуна, мк	3	11
6 Износ вкладышей шатунных подшипников по потере веса (мг) в среднем		
7 на один верхний	44	94
8 на один нижний	12	27
9 Износ вкладышей коренных подшипников по потере веса (мг) в среднем		
7 на один верхний	44	30
8 на один нижний	196	115

1) Wear index; 2) crankshaft-neck wear, mm; 3) rod necks; 4) crank necks; 5) upper rod-bushing wear, μm; 6) rod bearing-bushing wear, from weight loss (mg), average for; 7) one upper bushing; 8) one lower bushing; 9) crank bearing-bushing wear, from weight loss (mg), average for.

test oils.

The cylinder sleeves exhibited less wear for Д-11 oil containing БФК additive than for standard Д-11 oil containing ЦИАТИМ-339 oil.

The piston and piston-pin wear was slight for the specimens tested and can be regarded as almost equivalent in both cases. The piston-ring wear was somewhat greater than for the standard oil. Thus, the average per-ring wear was 259 mg for the Д-11 oil containing 3% ЦИАТИМ-399 additive and 325 mg for the Д-11 oil containing 5% БФК additive.

The character and amount of the carbon and tar deposits on the pistons and of the resin deposits on the oil-filter elements were evaluated by visual inspection and weighing. Table 116 gives the results of the inspection.

TABLE 116

Comparative Evaluation of Ring Mobility and Tar Deposits

1 Состояние деталей после 60 ч работы двигателя	Д-11+3% ЦИАТИМ-339	Д-11+5% БФК
2 Подвижность поршневых колец		
3 свободных	16	32
4 плотных	14	—
5 прихваченных полностью	1	—
6 прихваченных частично	—	—
7 сломанных	1	—
8 Лаковые покрытия на юбках поршней	9 Лак черного цвета на 65—70% поверхности	10 Лак темно-серого цвета на 30% поверхности

1) Condition of components after engine operation for 60 h; 2) piston-ring mobility; 3) free; 4) tight; 5) completely frozen; 6) partially frozen; 7) broken; 8) tar deposits on piston skirts; 9) black tars over 65-70% of surface; 10) dark gray tars over 30% of surface.

TABLE 117

Deposits and Oil Consumption

1 Показатели	Д-11+3% ЦИАТИМ-339	Д-11+5% БФК
2 Отложения на фильтрующих элементах тонкой очистки масла в среднем за 60-часовый цикл, г	384	501
3 Расход масла на угар в среднем на 60-часовой цикл, кг	8	6,15
4 То же в % к расходу топлива	0,99	0,77
5 Нагарообразование на основных деталях поршневой группы, г		
6 поршневые кольца	2,83	2,36
7 канавки поршня	3,42	2,3
8 Всего нагара, г	6,25	4,66

1) Index; 2) deposits on high-quality oil-filter element, average over 60-h cycle, g; 3) oil burnt, average over 60-h cycle, kg; 4) the same, % of fuel consumption; 5) carbon deposition on main piston components, g; 6) piston rings; 7) piston grooves; 8) total carbon deposits, g.

TABLE 118

Change in Physicochemical Properties of Д-11 Diesel Oil Containing 3% ЦИАТИМ-339

1 Время отбора проб	2 Кинематическая вязкость, сст	3 Зольность %	4 Механические примеси, %	5 Кислотное число, мг КОН	6 Коксуемость, %	7 Коррозия, г/м²	8 Железо, мг
20 мин 9	11,41	0,307	0,03	0,055	0,880	0,57	14,0
10 ч 10	11,50	0,152	0,024	0,142	0,680	0,78	13,0
20 ч	11,58	0,167	0,028	0,185	0,795	1,10	26,0
30 ч	11,83	0,172	0,043	0,230	1,200	1,13	31,5
40 ч	12,29	0,182	0,062	0,307	1,410	0,96	37,5
50 ч	12,85	0,192	0,043	0,300	1,500	1,05	35,7
60 ч	12,83	0,221	0,057	0,280	1,680	0,85	37,5
11 Изменение показателей	+1,42	−0,086	+0,027	+0,225	+0,800	+0,28	+23,5

1) Sampling time; 2) kinematic viscosity, cSt; 3) ash, %; 4) mechanical impurities, %; 5) acid number, mg KOH; 6) tars, %; 7) corrosion, g/m²; 8) iron, mg; 9) min; 10) h; 11) change in index.

As can be seen, the data in this table indicate that БФК additive has a clear advantage with respect to piston-ring mobility.

Table 117 gives data on oil-filter deposits and carbon deposits.

As can be seen from the data in Table 117, carbon deposition on the engine components was less when the engine was run with the oil containing БФК additive.

TABLE 119

Change in Physicochemical Properties of Д-11 Diesel Oil Containing 5% БФК

1 Время отбора проб	2 Кинематическая вязкость, сст	3 Зольность, %	4 Механические примеси, %	5 Кислотное число, мг КОН	6 Коксуемость, %	7 Коррозия, г/м	8 Железо, мг
20 мин 9	12,6	0,611	0,035	0,095	1,60	0,44	16,0
10 ч 10	12,8	0,567	0,033	0,125	1,82	0,20	16,0
20 ч	13,0	0,600	0,025	0,130	1,91	0,45	34,0
30 ч	13,3	0,600	0,020	0,120	2,30	0,25	25,0
40 ч	14,0	0,610	0,018	0,122	2,31	0,40	25,0
50 ч	14,3	0,602	0,020	0,150	2,66	0,44	30,0
60 ч	15,0	0,606	0,020	0,150	2,91	0,53	33,0
11 Изменение показателей	+ 2,4	−0,005	−0,015	+0,055	+1,31	+0,09	+17,0

1) Sampling time; 2) kinematic viscosity, cSt; 3) ash, %; 4) mechanical impurities, %; 5) acid number, mg KOH; 6) tars, %; 7) corrosion, g/m²; 8) iron, mg; 9) min; 10) h; 11) change in index.

Tables 118 and 119 present the results of an analysis of the worked-out standard and test oils.

The change in main physicochemical properties during engine operation was smaller for the Д-11 oil containing 5% БФК additive than for the standard specimen.

On the average, the ash content of the oil containing the new test additive remained constant over a 60-h engine-operation cycle, while that of the oil containing ЦИАТИМ-339 additive decreased by more than 20%.

Long-Term Stand Tests of ДС-11 НКЗ Oil containing 6%БФК Additive in Д-40 Engine

Tables 120-122 present data characterizing the wear for the main engine components during operation with the standard and test oils.

As can be seen from Table 120, the cylinder-sleeve wear (particularly in the maximum-wear zone) was very small and identical in both cases.

As can be seen from the data in Table 121, all piston-ring wear indices were substantially lower for the oil containing БФК additive.

The data in Table 122 indicate that the wear for both the rod- and crank-bearing bushings was less when the engine was run with the oil containing БФК additive.

TABLE 120

Wear for Cylinder-Piston Components

1 Показатель износа	ДС-11 НКЗ+3% ЦИАТИМ-339	ДС-11 НКЗ +6% БФК
2 Износ гильз цилиндров (мк) в поясе на расстоянии		
22 мм	38	40
48 мм	15	27
65 мм	11	20
170 мм	4	20
230 мм	5	14
3 Приведенный	15	24
4 в поясе максимального износа	38	40
5 Износ поршней (мк) по изменению		
6 наружного диаметра	0	6,8
7 бобышек	11,2	15,8

1) Wear index; 2) cylinder-sleeve wear (μm) in band at distance of; 3) reduced; 4) in maximum-wear zone; 5) piston wear (μm), from change in; 6) outside diameter; 7) boss diameter.

Tables 123 and 124 show the amount of carbon deposits on the pistons and of deposits on the oil filters.

Analyzing the data in Tables 123 and 124, it can be seen that

TABLE 121

Piston-Ring Wear and Mobility

1 Показатели	2 Масла ДС-11 НКЗ | 3% ЦИАТИМ-339	2 Масло ДС-11 НКЗ-| 6% БФК
3 Износ компрессионных колец по потере веса, *мг*		
I	791	73,2
II	424,7	50,8
III	170	20,9
IV	163	20
4 В среднем на кольцо	387	42,0
5 То же маслосъемных		
I	21,3	1,6
II	96,0	8,8
4 В среднем на кольцо	108	5,2
6 Износ компрессионных колец по увеличению зазора в замке, *мк*		
I	237	50
II	175	37
III	187	37
IV	87	87
4 В среднем на кольцо	172	53
5 То же маслосъемных		
I	162	87
II	112	100
4 В среднем на кольцо	137	94
7 Износ по радиальной толщине компрессионных колец, *мк*		
I	50,0	5,5
II	28,0	5,5
III	23,6	4,0
IV	23,0	4,5
4 В среднем на кольцо	31,1	4,9
5 То же маслосъемных		
I	28,0	8,0
II	39,8	4,5
4 В среднем на кольцо	33,9	6,3
8 Износ по высоте компрессионных колец, *мк*		
I	5,5	5,5
II	3,5	6,5
III	2,3	3,6
IV	2,6	3,5
4 В среднем на кольцо	16,0	4,8
5 То же маслосъемных		
I	1,6	3
II	3,0	4,5
4 В среднем на кольцо	2,3	3,7
9 Подвижность колец		
10 свободные	24	24
11 плотные	0	0
12 прихваченные	0	0

1) Index; 2) oil; 3) compression-ring wear, from weight loss, mg; 4) average per ring; 5) the same, for oil rings; 6) compression-ring wear, from increase in ring gap, μm; 7) compression-ring wear, from radial thickness, μm; 8) compression-ring wear, from height, μm; 9) ring mobility; 10) free; 11) tight; 12) frozen.

the ДС-11 НК3 oil containing 6% БФК yielded substantially better results with respect to filter deposits, carbon deposits on piston components, and piston-surface cleanness.

TABLE 122

Wear for Crank-rod Components

1 Показатели	Масло ДС-11 НК3 с 3% ЦИАТИМ-339 2	Масло ДС-11 НК3 + 6% БФК 3
4 Износ шеек коленчатого вала, мк		
5 шатунных	4,4	1,4
6 коренных	4,25	1,25
7 Износ верхней втулки шатуна, мк	0	11,25
8 Средний износ вкладышей шатунных подшипников по потере веса (мг) на один		
9 верхний	388	111
10 нижний	266	84
11 Износ вкладышей коренных подшипников по потере веса (мг) в среднем на один		
верхний	296	70
нижний	422	85

1) Index; 2) ДС-11 НК3 oil containing 3%ЦИАТИМ-339; 3) ДС-11 НК3 oil containing 6% БФК; 4) crankshaft-neck wear, μm; 5) rod necks; 6) crank necks; 7) upper rod-bushing wear, μm; 8) average rod-bearing bushing wear, from weight loss (mg), per; 9) upper bushing; 10) lower bushing; 11) crank bearing-bushing wear, from weight loss (mg); average per.

TABLE 123

Deposits on Filters

1 Цикл	2 Отложения на Ф. Г. О., г		5 Отложения на Ф. Т. О., г (центрифуга)	
	Масло ДС-11 НК3+3% ЦИАТИМ-339 3	Масло ДС-11 НК3 с 6% БФК 4	Масло ДС-11 НК3 с 3% ЦИАТИМ-339	ДС-11 НК3 с 6% БФК
I	30		65	—
II	25	40	90	55
III	65	40	40	30
IV	55	—	55	25
V	95	45	65	30
VI	—	30	85	25
VII	30	—	—	30
VIII	40	—	—	25
IX	—	—	—	—
6 В среднем на цикл	48,5	39,0	57,0	31,5

1) Cycle; 2) deposits on low-quality filter, g; 3) ДС-11 НК3 oil containing 3% ЦИАТИМ-339; 4) ДС-11 НК3 oil containing 6% БФК; 5) deposits on high-quality filter, g (centrifuge); 6) average per cycle.

TABLE 124

Carbon Deposition, g

1 Нагар	2 Масло ДС-11 НК3 с 3% ЦИАТИМ-339	3 Масло ДС-11 НК3 с 6% БФК
4 С днища	1,36	0,77
5 С канавок	6,28	1,49
6 С колец	1,83	0,32
7 Всего	9,47	2,58

1) Carbon deposits; 2) ДС-11 НК3 oil containing 3% ЦИАТИМ-339; 3) ДС-11 НК3 oil containing 6% БФК; 4) piston face; 5) grooves; 6) rings; 7) total.

The average amount of oil burnt per cycle was 12.4 kg for the ДС-11 НК3 oil containing 3% ЦИАТИМ-339 additive and 6.25 kg for the ДС-11 НК3 oil containing 6% БФК additive.

Tables 125 and 126 present the results of an analysis of the worked-out standard and test oils.

TABLE 125

Change in Physicochemical Properties of ДС-11 НК3 Oil Containing 3% ЦИАТИМ-339 Additive

1 Время отбора	2 Вязкость кинематическая при 100° С сст	3 Зольность, %	4 Механические примеси, %	5 Кислотное число, мг КОН	6 Коксуемость, %	7 Коррозия, г/м²	8 Железо, г
9 Исходное	10,59	0,55	—	—	—	—	—
20 мин 10	11,68	0,30	0,024	0,17	0,62	0,92	20
20 ч 11	11,06	0,33	0,031	0,19	—	1,05	17
60 ч	11,31	0,31	0,025	0,115	—	0,916	19
100 ч	11,50	0,27	0,047	0,195	1.01	0,88	27
12 Изменение показателей	+1,09	—0,28	+0,023	+0,025	+0,39	—0,04	+ 7

1) Sampling time; 2) kinematic viscosity at 100°C, cSt; 3) ash, %; 4) mechanical impurities, %; 5) acid number, mg KOH; 6) tars, %; 7) corrosion, g/m²; 8) iron, g; 9) initial; 10) min; 11) h; 12) change in index.

It can be seen from the data in Tables 125 and 126 that the ash content of the oil containing БФК additive remained almost unchanged during operation for 60 h, while that of the oil containing ЦИАТИМ-399 additive was halved, which indicates that this additive is rapidly worked out.

The acid number and mechanical-impurity content of the two oils over 100 h of operation were of the same order, while the corrosiveness of the oil containing БФК was only half that of the oil containing ЦИАТИМ-399.

TABLE 126

Change in Physicochemical Properties of ДС-11 НКЗ Oil Containing 6% БФК

Время[1] отбора	Вязкость[2] кинематическая при 100° С, *сст*	Зольность, %[3]	Механические примеси, %[4]	Кислотное число, *мг* КОН[5]	Коксуемость, %[6]	Коррозия, *г/м²*[7]	Железо, *г*[8]
9 Исходное	11,21	[illegible]	0,04	0,03	0,90	—	—
20 *мин* 10	11,44	0,67	0,22	0,05	0,90	0,26	5,6
20 ч 11	14,39	0,36	0,10	0,09	0,97	0,24	4,5
60 ч	12,24	0,73	0,09	0,10	1,1	0,23	7,6
100 ч	12,38	0,66	0,09	0,20	1,11	0,45	10,2
12 Изменение показателей	+1,17	+0,03	+0,05	+0,17	+0,21	+0,19	+ 4,6

1) Sampling time; 2) kinematic viscosity at 100°C, cSt; 3) ash, %; 4) mechanical impurities, %; 5) acid number, mg KOH; 6) tars, %; 7) corrosion, g/m²; 8) iron, g; 9) initial; 10) min; 11) h; 12) change in index.

The iron and tar contents of the oil containing БФК were substantially lower after service for 100 h.

Analysis of the test results enables us to draw the following conclusions.

1. Oils containing БФК additive produce substantially less engine-component wear than a standard specimen in a Д-40 engine.

2. БФК additive ensures piston-ring mobility throughout the entire test period, while tests with the standard specimen result in tight or frozen rings.

3. The amount of carbon deposited on the piston components is several times less for operation with an oil containing БФК additive.

4. Considerably less tars are formed on the piston surfaces when the engine is operated with oil containing БФК additive.

5. The average change in physicochemical properties for oil containing БФК additive over a single test cycle is less than that for oil containing ЦИАТИМ-339 additive.

Investigation of Engine Characteristics of C5-3 Additive Mixed with Oils

The automobile oils produced by Soviet industry require a substantial improvement in engine characteristics in order to ensure reliable long-term service of modern spark-ignition automobile engines.

As recent experience has shown, one way to improve oil characteristics is use of multipurpose additives. Preliminary engine and nonengine tests conducted by the INKhP, Academy of Sciences

TABLE 127

Ring Mobility

1 Испытуемое масло	2 Количество колец			
	3 полностью закоксованных	4 частично закоксованных (суммарная дуга)	5 плотных	6 свободных
АС-9,5 НКЗ (без присадки) [7]	1	2/650°	2	19
АС-9,5 НКЗ+3% ЦИАТИМ-339	0	0	0	24
АС-9,5 НКЗ+10% СБ-3	0	0	0	24
СУ	1	3/590°	2	18
АС-10 (бак.) [8] +3% АзНИИ-8 (Ва)	0	0	0	24
АС-10 (бак.)+10% СБ-3	0	0	0	24
АК-10+10% СБ-3	0	0	0	18*

*Piston with 3 rings.

1) Oil tested; 2) number of rings; 3) completely frozen; 4) partially frozen (total arc); 5) tight; 6) free; 7) without additives; 8) Bakinskoye.

TABLE 128

Amount of Deposits on Engine Components and Oil Burning

1 Испытуемое масло	2 На поршнях с кольцами, г	3 На Ф. Т. О., г	4 Угар масла, г/ч
АС-9,5 НКЗ (без присадки) [5]	8,4	87	67
АС-9,5 НКЗ+3% ЦИАТИМ-339	6,3	20	63
АС-9,5 НКЗ+10% СБ-3	4,1	114	42
СУ	20,9	173	57
АС-10 (бак.) [6] +3% АзНИИ-8 (Ва)	20,6	—	—
АС-10 (бак.)+10% СБ-3	10,1	110,5	45
АК-10+10% СБ-3	2,31	91	35

1) Oil tested; 2) on pistons and rings, g; 3) on high-quality oil filter, g; 4) oil burnt, g/h; 5) without additives; 6) Bakinskoye.

o[f] the Azerbaydzhan SSR, have shown that the new СБ-3 additive is highly efficient. Its addition to both Bakinskoye and Eastern automobile oils provided high oil engine characteristics in carbureted engines.

In order to determine the effectiveness of СБ-3 additive mixed with automobile oils produced from Bakinskoye crude oils, the test results were compared with those obtained for operation of a ГАЗ-51 engine with СУ oil and with АС-10 (Bakinskoye) oil containing 3% АзНИИ-8 additive (barium type).

The data in Table 127 characterize piston-ring mobility after these tests.

As can be seen from the data in Table 127, АС-9.5 НКЗ oil containing 3% ЦИАТИМ-339 additive and 10% СБ-3 additive and АС-10 oil containing 3% АзНИИ-8 (Ba) additive and 10% СБ-3 additive provided full piston-ring mobility throughout the entire test.

Table 128 presents data characterizing the amount of deposits on the engine components during operation with different oils.

TABLE 129

Component Wear

1 Показатели	2 Масло АС-9,5 НКЗ		
	3 без присадки	3% ЦИАТИМ-339	10% СБ-3
4 Средний износ цилиндров, *мк*	29	9	4
5 Износ поршневых колец по потере веса (*мг*) на одно кольцо	475	87,5	83
6 Износ компрессионных колец по увеличению зазора в замке, *мк*	800	165	115
7 Износ коленчатого вала, *мк*			
8 шатунные шейки	8	5	2
9 коренные шейки	4	6	2
10 Износ вкладышей подшипников			
11 шатунные	—	—	6
12 коренные	—	—	1,4
13 Подвижность поршневых колец			
14 свободные	18	24	24
15 плотные	2	0	0
16 пригоревшие	4	0	0
17 Нагар (всего), *г*	8,4	6,3	4,1
18 в том числе с колец и канавок	—	0,13	—

1) Index; 2) oil; 3) without additives; 4) average cylinder wear, µm; 5) piston-ring wear, from weight loss (mg), per ring; 6) compression-ring wear, from increase in gap, µm; 7) crankshaft wear, µm; 8) rod necks; 9) crank necks; 10) bearing-bushing wear; 11) rod bearings; 12) crank bearings; 13) piston-ring mobility; 14) free; 15) tight; 16) welded; 17) carbon deposits (total), g; 18) including rings and grooves.

As can be seen from the data in this table, AC-9.5 НКЗ oil containing 10% СБ-3 additive produced substantially less carbon deposits on the pistons and rings than did the oil containing 3% ЦИАТИМ-339 additive. The same effect was observed when СБ-3 additive was mixed with AC-10 Bakinskoye oil. This can be seen from a comparison of AC-10 (Bakinskoye) oil containing 10% СБ-3 oil with AC-10 (Bakinskoye) oil containing 3% АзНИИ-8 (Ba) additive.

While mixing of AC-10 oil with 3% АзНИИ-8 (Ba) additive reduces carbon deposits to the level observed for operation with СУ oil, use of СБ-3 additive with the same oil reduces carbon deposits by a factor of 2.

Comparison of AC-10 (Bakinskoye) oil containing 10% СБ-3 additive with AC-9.5 НКЗ oil containing 3% ЦИАТИМ-339 additive shows that a somewhat smaller amount of carbon deposit was produced in the former case. This is attributable to the qualitative difference in the base oils.

Both the Eastern and Bakinskoye oils containing СБ-3 additive yielded substantially better results from the standpoint of tar deposition on the pistons. Thus, the tar deposits on the piston skirts amounted to 2.0-3 points on the color scale for AC-9.5 oil containing 3% ЦИАТИМ-339 additive and to no more than 0.5 point for both Eastern and Bakinskoye oils containing СБ-3 additive. The oil-ring gaps were absolutely clean in the latter case.

Tables 129-131 present data characterizing engine-component wear for Eastern and Bakinskoye oils containing СБ-3 additive.

The fuel consumption and spark-advance angle of the engine were adjusted in accordance with the manufacturer's instructions before the tests. Table 132 shows the initial power and economy indices of the engine at full throttle and 2000 rpm, which was taken as the control regime for checking engine operation. The fuel consumption under these conditions should be 13.5-13.8 kg/h and the spark-advance angle should be 18-20°.

Table 133 presents data characterizing the change in power and economy indices.

The change in the physicochemical indices of the test oils proceeded almost uniformly over the surface period (see Table 134).

TABLE 130

Component Wear

1 Показатели	2 АК-10 с 10% СБ-3	3 Машинное СУ	4 Масло АС-10 (бак.) 3% АзНИИ-8	10% СБ-3
5 Средний износ цилиндров, *мк*	7,1	23,7	5,9	3,93
6 Износ поршневых колец по потере веса (*мг*) на одно кольцо	67,0	187	81	93
7 Износ колец по увеличению зазора в замке (*мк*) на одно кольцо	10[illegible]	296	177	50
8 Износ коленчатого вала, *мк*				
9 шатунные шейки	2	7	8	1,7
10 коренные шейки	2	2	8	1,4
11 Износ вкладышей подшипников, *мг*				
12 шатунные	—	235	131	3,8
13 коренные	—	105	131	5,0
14 Подвижность поршневых колец				
15 свободные	18*	21	24	24
16 плотные	0	0	0	0
17 пригоревшие (полностью или частично)	0	3	0	0
18 Нагар				
19 с колец и канавок	1,33	17.0	14,0	1,55
20 с днища поршня	0,98	3,9	5,8	8.56

*Piston with 3 rings.

1) Index; 2) АК-10 containing 10% СБ-3; 3) СУ machine oil; 4) АС-10 (Bakinskoye) oil; 5) average cylinder wear, μm; 6) piston-ring wear, from weight loss (mg), per ring; 7) ring wear, from increase in gap (μm), per ring; 8) crankshaft wear, μm; 9) rod necks; 10) crank necks; 11) bearing-bushing wear, mg; 12) rod bushings; 13) crank bushings; 14) piston-ring mobility; 15) free; 16) tight; 17) welded (completely or partially); 18) carbon deposits; 19) on rings and grooves; 20) on piston faces.

TABLE 131

Engine-Component Wear, μm

Деталь [1]	Масло [2] АС-9,5 НКЗ			Машинное СУ [4]	Масло [2] АС-10 (бак.)		
	без присадки [3]	3% ЦИАТИМ-339	10% СБ-3		АзНИИ-8	СБ-3	АК-10 с [6] 10% СБ-3
[7] Поршень							
[8] Канавка кольца							
I	11	10	0	9	10	0	0
II	6	4	0	3	5	0	0
III	6	3	8,3	3	8	0	0
IV	6	2	8,3	5	5	0	0
[9] Бобышки	4	3	0	4	10	6,9	2,4
[10] Юбка	10	2	2,5	20	—	3.9	6,6
[11] Втулка шатуна	7	1	1	2	3,5	3	3,5
[12] Поршневой палец	1	2	0	2		5.6	0,3

1) Component; 2) oil; 3) without additives; 4) СУ machine oil; 5) Bakinskoye; 6) with; 7) piston; 8) ring grooves; 9) bosses; 10) skirt; 11) rod bushing; 12) piston pin.

TABLE 132

Operating Characteristics of ГАЗ-51 Engine Under Control Regime at 2000 r/min

Масло [1]	Мощность [2], л. с.	Расход топлива [3], кг/ч	Уд. расход топлива [4], г/э. л. с. ч.	Угол опережения зажигания, [5] град.
АС-9,5 НКЗ (без присадки [6])	51,3	13,63	265	20
АС-9,5 НКЗ+3% ЦИАТИМ-339	51,0	13,4	263	20
АС-9,5 НКЗ+10% СБ-3	50,5	13,6	269	20
СУ	51,5	13,6	264	20
АС-10 (бак. [7])+3% АзНИИ-8	50,5	13,6	269	20
АС-10 (бак.)+10% СБ-3	49,4	13,6	274	20
АК-10 с [8] 10% СБ-3	53,0	13,6	250	20

1) Oil; 2) power, hp; 3) fuel consumption, kg/h; 4) specific fuel consumption, g per effective hp per h; 5) spark-advance angle, degrees; 6) without additives; 7) Bakinskoye; 8) with.

TABLE 133

Power and Economy Characteristics of Engine at Full Throttle and 2800 r/min

1 Масло		2 Мощность при полном дросселе, л/с	3 Часовой расход топлива, кг/ч	4 Удельный расход топлива, г/э. л. с. ч.
АС-9,5 НКЗ (без[5] присадки)	до испыт.	63,4	18,0	284
	после испыт.	59,3	17,92	303
АС-9,5 НКЗ+3% ЦИАТИМ-339	8 до испыт.	64,5	18,55	287
	9 после испыт.	61,5	18,75	282.
АС-9,5 НКЗ+10% СБ-3	8 до испыт.	67,6	18,4	273,0
	9 после испыт.	67,0	17,6	263,5
6 Машинное СУ	8 до испыт.	—	—	—
	9 после испыт.	—	—	—
АС-10 (бак.[7])+3% АзНИИ-8	8 до испыт.	65	18,5	295
	9 после испыт.	63,5	18,0	275
АС-10 (бак.[7])+10% СБ-3	8 до испыт.	67,2	18,2	271
	9 после испыт.	66,6	18,2	272
АК-10 +10% СБ-3	8 до испыт	65	17,1	262
	9 после испыт.	65	17,0	261,5

1) Oil; 2) power at full throttle, hp; 3) fuel consumption, kg/h; 4) specific fuel consumption, g per effective hp per h; 5) without additives; 6) СУ machine oil; 7) Bakinskoye; 8) before test; 9) after test.

TABLE 134

Change in Oil Physicochemical Properties

1 Масло	2 Вязкость при 50° С, сст			6 Коксуемость, %			7 Зольность, %			8 Кислотное число, мг КОН		
	3 исх.	4 20 мин	5 51 ч	исх.	20 мин	51 ч	исх.	20 мин	51 ч	исх.	20 мин	51 ч
АС-9,5 НКЗ (без[9] присадки)	50,47	49,58	59,94	0,15	0,20	0,47	—	—	—	0,13	0,17	0,41
АС-9,5 НКЗ+3% ЦИАТИМ-339	55,63	54,9	65,10	0,45	0,45	0,65	0,25	0,26	0,22	10 отсут.	0,04	0,32
АС-9,5 НКЗ+10% СБ-3	53,78	56,8	58,8	0,75	0,83	0,93	0,58	0,54	0,56	0,02	0,073	0,28
СУ	—	49,38	64,06	—	1,109	0,389	0,003	0,005	0,011	0,13	0,23	0,258
АС-10+ 3% АзНИИ-8	—	66,07	90,60	—	0,48	0,80	—	0,266	0,285	—	0,046	0,18
АС-10+10% СБ-3	64,74	51,9	48,2	0,66	0,71	0,84	0,62	0,57	0,56	10 отс.	0,077	0,308
АК-10+10% СБ-3	72,64	71	70,37	0,91	0,94	1,18	0,65	0,64	0,57	10 отс.	0,07	0,32

1) Oil; 2) viscosity at 50°C, cSt; 3) initial; 4) min; 5) h; 6) tars, %; 7) ash, %; 8) acid number, mg KOH; 9)without additives; 10) absent.

Long-term stand tests of automobiles produced from a prospective mixture of Baku crude oils, subjected to a high degree of refining (200% furfurol) and containing АзНИИ-8 (Ba) and СБ-3 additives, and testing of СБ-3 additive mixed with AC-9 НКЗ oils produced from Vostok crude oils enable us to draw the following conclusions.

1. Bakinskoye oils containing АзНИИ-8 (Ba) additive and particularly СБ-3 additive ensure normal, reliable operation of ГАЗ-51 carbureted engines and have better operating properties (wear, carbon deposition, tar formation, and piston-ring mobility) than AC-9.5 НКЗ oil containing 3% ЦИАТИМ-339 additive for СУ machine oil.

2. The most effective of the additives tested was СБ-3, which provided complete piston-ring mobility, high piston cleanness, and minimum wear and carbon deposition on engine components in comparison with the other specimens tested when mixed with selectively purified automobile oils produced from Baku and Vostok crude oils.

Testing of Engine Characteristics of АзНИИ-8 Additives (Based on СБ-3 and СК-3 Additives) Mixed with Automobile Oils

When the СБ-3 additive appeared, work was begun to develop new versions of the АзНИИ-8 additive, whose detergent component (АзНИИ-5 additive) was replaced by СБ-3 or СК-3. This substitution was made in an attempt to improve the detergent properties and, possibly, other engine characteristics of АзНИИ-8 additive. The following specimens were tested:

AC-10 oil from Bakinskoye crude oil mixed with 5% АзНИИ-8 additive based on СК-3 (2.5% АзНИИ-7 + 2.5% СК-3);

AK-10 oil from Bakinskoye crude oil mixed with 5% АзНИИ-8 additive based on СБ-3 (2.5% АзНИИ-7 + 2.5% СБ-3);

AC-9.5 oil from Vostok crude oil containing 5% АзНИИ-8 additive based on СК-3 (2.5% АзНИИ-7 + 2.5% СК-3).

TABLE 135

Ring Mobility

1 Образец	2 Свободные
АС-10 3 с 3% АзНИИ-5	24
АС-10 с 10% СБ-3	24
АС-10 с 5% АзНИИ-8 (СК-3)	18
АС-10 с 5% АзНИИ-8 (СК-3)	18
АК-10 с 10% СБ-3	18
АК-10 с 5% АзНИИ-8 (СБ-3)	18
АС-9,5 (НКЗ) с 3% ЦИАТИМ-339	24
АС-9,5 (НКЗ) с 10% СК-3	18
АС-9,5 (НКЗ) с 5% АзНИИ-8 (СК-3)	18

Note. There were no tight or frozen rings.

1) Specimen; 2) free; 3) with.

The test results were compared with the results of analogous tests:

first series: AC-10 oil containing 3% АзНИИ-8 additive based on АзНИИ-5 additive, 10% СБ-3 additive, or 5% АзНИИ-8 additive based on СБ-3;

second series: AK-10 oil containing 10% СБ-3;

third series: AC-9.5 НКЗ oil containing 3% ЦИАТИМ-339 additive and 10% СК-3.

Table 135 presents the results of an evaluation of piston-ring mobility.

As can be seen, all the specimens tested provided complete piston-ring mobility.

As was to be expected from the results of the preliminary tests, the detergent properties of the AK-10 oil containing 5% АзНИИ-8 (СБ-3) additive were poor, apparently as a result of the low susceptibility of this oil to the additive used. The best results were obtained for АзНИИ-8 (СБ-3) additive mixed with AC-10 oil. The АзНИИ-8 (СК-3) additive occupied an intermediate position with respect to piston-skirt condition when mixed with AC-10 oil or, particularly, with AC-9.5 НКЗ oil.

TABLE 136

Deposits on Components and Oil Burning

1 Образец	Нагар на поршнях с кольцами, г 2	Нагар с колец и канавок, г 3	Отложения на Ф.Т.О. масла, г 4	Угар масла, г/ч 5	Угар масла в % к расходу топлива 6
АС-10 с[7] 3% АзНИИ-8 (АзНИИ-5)	20,8	—	—	—	—
АС-10 с 10% СБ-3	10,1	1,55	110,5	45,0	0,37
АС-10 с 5% АзНИИ-8 (СБ-3)	8,65	0,89	57	36,5	0,3
АС-10 с 5% АзНИИ-8 (СК-3)	6,72	2,06	110,0	47,0	0,39
АК-10 с 10% СБ-3	2,31	—	91	35,0	0,29
АК-10 с 5% АзНИИ-8 (СБ-3)	8,55	3,33	36,0	56,5	0,46
АС-9,5 (НКЗ) с 3% ЦИАТИМ-339	6,3	—	20,0	53,0	0,53
АС-9,5 (НКЗ) с 10% СК-3	6,33	0,29	73,0	30,8	0,25
АС-9,5 (НКЗ) с 5% АзНИИ-8 (СК-3)	12,74	2,97	77,0	70,0	0,57

1) Specimen; 2) deposits on pistons and rings, g; 3) deposits on rings and grooves, g; 4) deposits on high-quality oil filter, g; 5) oil burnt, g/h; 6) oil burnt, % of fuel consumption; 7) with.

TABLE 137

Cylinder Wear, μm

1 Образец	2 Плоскость оси коленчатого вала		5 Средний износ цилиндра
	3 параллельной	4 перпендикулярной	
АС-10 6 с 3% АзНИИ-8 (АзНИИ-5)	—	—	5,9
АС-10 с 10% СБ-3	2,66	5,2	3,93
АС-10 с 5% АзНИИ-8 (СБ-3)	3,3	3,5	3,4
АС-10 с 5% АзНИИ-8 (СК-8)	4,0	4,6	4,3
АС-10 с 10% СБ-3	—	—	7,1
АС-10 с 5% АзНИИ-8 (СБ-3)	10,0	15,7	12,8
АС-9,5 (НКЗ) с 3% ЦИАТИМ-339	5,0	13,0	9,0
АС-9,5 (НКЗ) с 10% СК-3	13,2	15,0	11,5
АС-9,5 (НКЗ) с 5% АзНИИ-9 (СК-3)	2,2	7,6	4,9

1) Specimen; 2) plane of crankshaft axis; 3) parallel; 4) perpendicular; 5) average cylinder wear; 6) with.

Table 136 presents data on carbon deposits on the pistons and rings, deposits on the high-quality oil filter, and amount of oil burnt.

Use of АзНИИ-8 (СБ-3) additive with AK-10 oil increased the amount of carbon deposited on the pistons and rings in comparison with that yielded by 10% СБ-3, but somewhat reduced the amount of deposits on the high-quality oil filter. More carbon was deposited on the rings and grooves. The amount of deposits on the high-quality oil filter after engine operation for 51 h was 75-100 g in all cases, except for the AC-10 oil containing АзНИИ-8 (СБ-3) additive and AK-10 oil containing АзНИИ-8 (СБ-3) additive, where it was somewhat lower.

The amount of oil burnt did not exceed 0.5-0.6% of the fuel consumption in any case.

Table 137 presents data on cylinder wear.

As can be seen, cylinder wear was very small for all tests with the new versions of АзНИИ-8 additive, being close to the amount obtained for 10% СБ-3 and less than that obtained for АзНИИ-8 (АзНИИ-5) or 10% СК-3.

Table 138 presents data on piston-ring wear.

Less wear than with 1k0% СБ-3, 10% СК-3, 3% ЦИАТИМ-339, or 3% АзНИИ-8 (АзНИИ-5) was obtained in all cases. Only for AC-10 oil containing 5% АзНИИ-8 (СК-3) were the results somewhat poorer than for 10% (СБ-3), but they were still substantially better than those obtained for AC-10 oil containing 3% (АзНИИ-5).

However, the average per-ring wear determined from the weight loss was 45-60 mg in all cases; it amounted to 81 mg for the AC-10 oil containing 3% (АзНИИ-5) and to 87 mg for the AC-9.5 НКЗ oil

TABLE 138

Piston-ring Wear

1 Образец	2 Увеличение зазора, мк				6 Потеря веса, мг				7 Износ по высоте, мк				8 Износ по толщине, мк			
	3 Компрессионные		4	5	3 Компрессионные		4	5	3 Компрессионные		4	5	3 Компрессионные		4	5
	I	II	Маслосъемное	В среднем на кольцо	I	II	Маслосъемное	В среднем на кольцо	I	II	Маслосъемное	В среднем на одно кольцо	I	II	Маслосъемное	В среднем на одно кольцо
АС-10 с[9] 3% АзНИИ-8 (АзНИИ-5)	—	—	—	177,0	—	—	—	81,0	—	—	—	2,7	—	—	—	32,6
АС-10 с[9] 10% СБ-3	58	125	120	101	44,0	39,5	56,0	43,5	0	0	0	0	9,4	11,7	17,8	13,0
АС-10 с[9] 5% АзНИИ-8 (СБ-3)	17	25	130	57,2	43,7	43,0	71,7	58,0	0	0	0	0	8,0	6,7	12,3	9,0
АС-10 с[9] 5% АзНИИ-8 (СК-3)	50	91	184	110	46,4	48,5	85,0	60,0	3,0	1,5	2,0	2,1	13,0	13,5	36,0	21,0
АК-10 с[9] 10% СБ-3	—	—	—	105	—	—	—	67,0	3,0	4,3	3,0	3,5	7,0	8,0	17,0	—
АК-10 с[9] 5% АзНИИ-8 (СБ-3)	33	67,0	142,0	81	38,4	44,1	61,6	48,5	17,0	8,0	9,0	9,3	—	—	—	—
АС-9,5 (НК3) с[9] 3% ЦИАТИМ-339	110	120	210	146	90,0	80,0	90,0	87,0	1,0	2,0	4,0	2,2	3,0	5,0	9,0	6,0
АС-9,5 (НК3) с[9] 10% СК-3	8	80	310	132	48,4	80,0	143,5	91,5	1,0	2,0	2,5	1,8	2,0	3,8	7,0	4,3
АС-9,5 (НК3) с[9] 5% АзНИИ-8 (СК-3)	57	67	125	86,0	42,0	58,0	74,0	58,0	—	—	—	—	—	—	—	—

1) Specimen; 2) increase in gap, μm; 3) compression; 4) oil; 5) average per ring; 6) weight loss, mg; 7) wear, from height, μm; 8) wear, from thickness, μm; 9) with.

TABLE 139

Engine-Component Wear

1 Деталь	АС-10 с 3% АзНИИ-8 (АзНИИ-5)	АС-10 [2] с 10% СБ-3	АС-10 [2] с 5% АзНИИ-8 (СБ-3)	АС-10 [2] с 5% АзНИИ-8 (СК-3)	АК-10 [2] с 10 СБ-3	АК-10 [2] с 5% АзНИИ-8 (СБ-3)	АС-9,5 (НКЗ) с 3% ЦИАТИМ-339	АС-9,5 (НКЗ) с 10% СК-3	АС-9,5 [2] с 5% АзНИИ-8 (СК-3)
3 Поршень, мк									
4 Бобышки	10	6,9	4,0	0,0	?4	4,4	3,0	4,0	11,5
5 Юбка	6	3,9	0,0	1,0	,6	7,5	2,0	5,0	6,6
6 Втулка верхней головки шатуна, мк	3,5	3,0	5,8	0,0	3,5	3,0	1,0	5,0	2,7
7 Поршневой палец, мк	—	5,3	0,0	0,0	0,8	0,0	2,0	0,0	0,0
8 Коленчатый вал, мк									
9 Коренные шейки	—	1,7	0,0	2,0	2,0	2,0	5,0	2,0	5,2
10 Шатунные шейки	—	1,4	0,0	2,0	2,0	2,0	6,0	0,2	5,6
11 Вкладыши, мг									
12 шатунные	—	78,5	65,0	55,2	—	53,0	—	132,0	100,0
13 коренные	—	105,2	75,0	75,2	—	47,0	—	107,5	76,0

1) Component; 2) with; 3) piston, µm; 4) bosses; 5) skirt; 6) upper rod bushing, µm; 7) piston pin, µm; 8) crankshaft, µm; 9) crank necks; 10) rod necks; 11) bushings, mg; 12) rod; 13) crank.

TABLE 140

Change in Oil Physicochemical Properties

1 Показатели	АС-10 с 3% АзНИИ-8 (АзНИИ-5)	АС-10 [2] с 10% СБ-3	АС-10 [2] с 5% АзНИИ-8 (СБ-3)	АС-10 [2] с 5% АзНИИ-8 (СК-3)	АК-10 с [2] 10% СБ-3	АК-10 [2] с 5% АзНИИ-8 (СБ-3)	АС-9,5 НКЗ [2] с 3% ЦИАТИМ-339	АС-9,5 НКЗ с [2] 10% СК-3	АС-9,5 НКЗ [2] с 5% АзНИИ-8 (СК-3)
3 Вязкость кинематическая при 50° С, сст									
20 мин 4	56,07	57,9	64,60	69,2	71,0	59,04	54,9	57,06	52,86
51 ч 5	90,60	68,2	75,04	84,3	70,37	67,08	65,10	58,81	53,03
6 Вязкость кинематическая при 100° С, сст									
20 мин 4	9,71	9,7	10,26	11,45	—	9,43	—	—	9,65
51 ч 5	12,53	9,9	11,12	11,65	—	10,35	—	—	10,85
7 Кислотное число, мг КОН на 1 г масла									
20 мин 4	0,046	0,077	0,08	0,105	0,07	0,01	0,04	0,14	0,01
51 ч 5	0,18	0,308	0,183	0,135	0,32	0,23	0,32	0,30	0,37
8 Зольность, %									
20 мин 4	0,26	0,57	0,435	0,37	0,64	0,33	0,26	0,30	0,27
51 ч 5	0,29	0,56	0,523	0,40	0,57	0,35	0,22	0,30	0,27
9 Коксуемость, %									
20 мин 4	0,48	0,71	0,63	0,60	0,94	0,52	0,45	1,56	0,41
51 ч 5	0,80	0,84	0,87	0,93	1,18	0,85	0,65	0,72	0,71
10 Содержание общих примесей, %									
20 мин 4	—	—	—	—	—	0,15	—	—	0,34
51 ч 5	—	—	—	—	—	0,82	—	—	0,99
11 Содержание железа, мг/кг масла									
20 мин 4	—	—	—	—	—	25	—	—	28
51 ч 5	—	—	—	—	—	31	—	—	57

1) Index; 2) with; 3) kinematic viscosity at 50°C, cSt; 4) min; 5) h; 6) kinematic viscosity at 100°C, cSt; 7) acid number, mg KOH per g of oil; 8) ash, %; 9) tars, %; 10) total impurities, %; 11) iron content, mg per kg of oil;

containing 3% ЦИАТИМ-339.

Table 139 presents data on the wear for certain engine components.

Very slight wear was produced in all cases; none of the specimens tested were inferior to the standards in this respect.

The average change in oil physicochemical characteristics over a single engine-operation cycle (51 h) is characterized by the data in Table 140.

It can be seen from the data in this table that the specimens underwent changes smaller than or equivalent to those in the standards. The only exceptions were the acid number of the АС-9.5 НКЗ oil containing 5% АзНИИ-8 (СК-3) and the tar contents of all the specimens, which underwent a somewhat greater change than for the standards.

The test results enable us to draw the following conclusions:

1. АС-10 oil containing 5% АзНИИ-8 (СК-3) provided a cleaner piston surface than for АзНИИ-8 (АзНИИ-5) additive, but this index was somewhat poorer for oil containing 10% СБ-3 or 5% АзНИИ-8 (СБ-3). The degrees of piston cleanness obtained for АК-10 oil containing 5% АзНИИ-8 (СБ-3) and АС-9.5 oil containing 5% АзНИИ (СК-3) were respectively equivalent to those obtained for АС-10 oil containing АзНИИ-8 (АзНИИ-5) and АС-9.5 oil containing 3% ЦИАТИМ-399.

2. The indices for cylinder, piston-ring, and other engine-component wear were lower than or equivalent to those for the standard specimens.

3. Piston-ring mobility was maintained throughout all the tests.

4. The changes in engine power and economy indices were slight.

5. The average per-cycle change in the physicochemical characteristics of the crankcase oil was also slight.

Testing of СК-3 Additive Mixed with АС-9.5 НКЗ Oil

Replacement of dehydrated barium oxide used to produce СБ-3 additive by hydrated calcium oxide yields an additive whose active component consists of calcium salts of the sulfur-containing acids present in the crude oil. An additive of this type, designated as СК-3 (calcium sulfonate), was synthesized and subjected to stand tests in an ГАЗ-51 engine in mixtures with АС-9.5 НКЗ oil. The test results were compared with data obtained in similar tests on АС-9.5 НКЗ oil containing СБ-3 and ЦИАТИМ-339 additives.

Inspection of the engine after the tests established that all the piston rings move freely in their grooves. The piston-skirt surfaces were clean. The piston condensers were covered with different amounts of tar, ranging from completely clean to light-brown in color. The bottoms of the piston grooves for the second and third rings were clean, while the rings themselves were covered with brown tar; the groove lands were clean.

The oil-ring grooves, crankcase-valve housing, and filter housings contained no greasy deposits. The piston surfaces appeared to be as clean as in tests with oil containing СБ-3 additive.

Complete piston-ring mobility was maintained in all the tests: all the rings remained free.

Table 141 presents data on carbon deposits on the pistons and rings, deposits on the high-quality oil filter, and amount of oil burnt.

TABLE 141

Amount of Deposits on Engine Components and Amount of Oil Burnt

1 Масло	2 На поршне с кольцами, г	3 На Ф. Т. О., г	4 Угар масла г/ч
АС-9,5 НКЗ+10% СК-3	6,33	73	30,8
АС-9,5 НКЗ + 10% СБ-3	4,1	14	42,0
АС-9,5 НКЗ+3% ЦИАТИМ 339	6,3	20	63,0

1) Oil; 2) on pistons and rings, g; 3) on high-quality oil filter, g; 4) oil burnt, g/h.

TABLE 142

Cylinder Wear, μm

1 Масло	2 Плоскость оси коленчатого вала		5 Средний по двум плоскостям
	3 параллельной	4 перпендикулярной	
АС-9,5 НКЗ+10% СК-3	11,5	15	13,2
АС-9,5 НКЗ + 10% СБ-3	3	6	4,5
АС-9,5 НКЗ+3% ЦИАТИМ-339	5	13	9

1) Oil; 2) plane of crankshaft axis; 3) parallel; 4) perpendicular; 5) average for two planes.

As can be seen, the amount of carbon deposited on the pistons and rings by the oil containing СК-3 additive appear to be somewhat greater than for the oil containing СБ-3 additive and equivalent to that for the oil containing 3% ЦИАТИМ-339 additive.

Table 142 shows the average maximum cylinder wear.

Use of the oil containing СК-3 additive resulted in somewhat greater wear than use of the oil containing СБ-3 additive and roughly the same wear as use of the oil containing ЦИАТИМ-339.

TABLE 143

Piston-ring Wear

1 Масло	2 Увеличение зазора в замке, мм			5 Потеря веса, г			6 Износ по высоте, мк		
	3 Компрессионные		4 Маслосъемные	3 Компрессионные		4 Маслосъемные	3 Компрессионные		4 Маслосъемные
	I	II		I	II		I	II	
АС-9,5 НКЗ+10% СК-3	0,08	0,08	0,310	0,048	0,080	0,143	1,3	2,4	4
АС-9,5 НКЗ+10% СБ-3	0,067	0,067	0,165	0,032	0,082	0,114	3	2,5	3
АС-9,5 НКЗ+3% ЦИАТИМ-339	0,11	0,12	0,21	0,09	0,08	0,09	11	8	9

1) Oil; 2) increase in gap, mm; 3) compression; 4) oil; 5) weight loss, g; 6) wear, from height, μm.

TABLE 144

Engine Component Wear, μm

1 Деталь	АС-9,5 НКЗ 2 с 3% ЦИАТИМ-339	АС 9,5 НКЗ+ 10% СБ-3	АС-9,5 НКЗ+ 10% СК-3
3 Поршень			
4 Канавка кольца			
I	10	0	0
II	4	0	0
III	3	8,3	3
IV	2	8,3	—
5 Бобышки	3	0	4
6 Юбки	2	2,5	5
7 Втулка шатуна	1	1	5
8 Поршневой палец	2	0	0
9 Шейки коленчатого вала			
10 Шатунные	5	1,7	2
11 Коренные	6	1,4	0,2

1) Component; 2) with; 3) piston; 4) ring grooves; 5) bosses; 6) skirt; 7) rod bushing; 8) piston pin; 9) crankshaft necks; 10) rod; 11) crank.

TABLE 145

Change in Oil Physicochemical Properties

1 Масло	2 Вязкость кинематическая при 50° С, сст			6 Коксуемость, %			7 Зольность %			8 Кислотное число, мг КОН на 1 г масла		
	3 исх.	4 20 мин	5 51 ч	3 исх.	4 20 мин	5 51 ч	3 исх.	4 20 мин	5 51 ч	3 исх.	4 20 мин	5 51 ч
АС-9,5 9 с 10% СК-3	57,60	57,06	58,81	0,56	1,56	0,72	0,30	0,80	0,30	0,07	0,14	0,30
АС-9,5 с 10% СБ-3	53,18	55,8	58,8	0,75	0,83	0,93	0,58	0,54	0,56	0,02	0,07	0,28
АС-9,5 с 3% ЦИАТИМ-339	55,63	54,9	65,10	0,45	0,45	0,65	0,26	0,36	0,22	Отс.	0,04	0,32

1) Oil; 2) kinematic viscosity at 50°C, cSt; 3) initial: 4) min; 5) h; 6) tars, %; 7) ash, %; 8) acid number, mg KOH of oil; 9) with.

However, the absolute cylinder wear was very small in all cases.

Table 143 presents data on piston-ring wear. Compression-ring wear was of the same order for the CK-3 and CБ-3 additives, being substantially less than that for the ЦИАТИМ-339 additive.

The wear for the remaining engine components (Table 144) was of the same order and was very small in terms of absolute magnitude.

Table 145 presents data on the change in oil physicochemical properties over 51 h of engine operation. These data indicate that the changes proceeded uniformly for the CБ-3 and CK-3 additives.

Long-term stand tests of CK-3 additive enables us to draw the following conclusions.

1. The results obtained in testing oil containing CK-3 additive were similar to those of analogous tests conducted with oil containing CБ-3 additive.

2. AC-9.5 oil containing 10% CK-10 additive ensured complete piston-ring mobility.

3. Engine-component wear was small in absolute magnitude and far less than for use of ЦИАТИМ-339 additive.

4. Use of CK-3 additive with AC-9.5 oil provided exceptional piston-surface cleanness.

5. Engine power and economy indices remained unchanged during operation with oil containing CK-3 additive.

6. The change in the physicochemical properties of oil containing CK-3 additive was small and proceeded in roughly the same fashion as for CБ-3 additive.

Long-term Stand Tests of AC-6 HK3 and AC-6 (Bakinskoye) Oils Containing 10% CБ-3 Additive in ГАЗ-51 Engine

In addition to testing CБ-3 additive mixed with AC-9.5 HK3, AC-10, and AK-10 summer oils, we also tested AC-6 HK3 and AC-6 winter oils (produced from Bakinskoye crude oil) containing 10% CБ-3 additive. These mixtures were also subjected to long-term 600-h tests in a ГАЗ-51 engine.

Examination of the engine after the tests established that all the piston rings moved freely in their grooves when the engine was run with AC-6 (Bakinskoye) oils containing 10% CБ-3 additive. When AC-6 oil containing ЦИАТИМ-339 additive was tested in two engines, all the rings in one engine were free but a slight force was required to move the rings in the other.

Engines operated with AC-6 HK3 and AC-6 (Bakinskoye) oils containing CБ-3 additive exhibited roughly the same tar- and carbon-deposition indices. The lateral piston surface was clean in both cases. Small areas of the piston surface adjoining the con-

TABLE 146

Deposits and Oil Burning

1 Образец	2 Нагар на поршне с кольцами, г	3 Отложения на фильтре тонкой очистки, г	4 Угар масла, г/ч
АС-6+3% присадки ЦИАТИМ-339 и 1% АзНИИ ЦИАТИМ-1, двигатель 1	4,72	20	55
То же, двигатель 2	3,80	10	92
АС-6 НК3+10% присадки СБ-3	0,56	58	52
АС-6 (бак.)+10% присадки СБ-3	0,39	76	56

1) Specimen; 2) deposits on piston and rings, g; 3) deposits on high-quality oil filter, g; 4) oil burnt, g/h; 5) additive; 6) engine; 7) the same; 8) Bakinskoye; 9) and.

TABLE 147

Cylinder and Crankshaft Wear

1 Образец	2 Плоскость оси коленчатого вала, мк		5 Средний износ цилиндра, мг
	3 параллельной	4 перпендикулярной	
АС-6+3% присадки ЦИАТИМ-339 и 1% АзНИИ ЦИАТИМ-1, двигатель 1	8	10	9
То же, двигатель 2	4	6	5
АС-6 НК3+10% присадки СБ-3	8	16	12
АС-6 (бак.)+10% присадки СБ-3	0,2	0,6	0,4

1) Specimen; 2) plane of crankshaft axis, μm; 3) parallel; 4) perpendicular; 5) average cylinder wear, mg; 6) -6 + 3% ЦИАТИМ-339 additive and 1% АзНИИ ЦИАТИМ-1 additive, engine 1; 7) the same, engine 2; 8) additive; 9) Bakinskoye.

densers were coated with tar, which was light brown for the AC-6 HK3 oil and yellow for the AC-6 (Bakinskoye oil). The tar deposited on the condensers ranged in color from light to dark brown. The inner surface of the piston skirt was coated with light-yellow tar.

There were no deposits in the oil-ring slits or the piston drain ports. Light-brown tar covered from 45 to 55% of the piston surfaces in the engine operated with AC-6 HK3 oil containing 3% ЦИАТИМ-339 additive. A thin layer of soft deposits was formed in the oil-ring grooves and on the rings themselves.

The amount of oil burnt was about the same in all cases (Table 146).

The cylinder wear in the maximum-wear zone for the AC-6 HK3 oil containing CБ-3 additive was roughly the same as for the AC-6 oil containing ЦИАТИМ-339 additive.

The cylinder wear in the maximum-wear zone was about the same for the AC-6 HK3 oils containing CБ-3 and ЦИАТИМ-339 additives. Slightly less wear was observed for the Bakinskoye oil. The absolute cylinder wear was very small in all tests (see Table 147).

TABLE 148

Piston-ring Wear

1 Масло	2 Увеличение зазора, мк			5 Потеря веса, мг			6 Износ по высоте, мк		
	3 Компрессионные		4 Маслосъемные	3 Компрессионные		4 Маслосъемные	3 Компрессионные		4 Маслосъемные
	I	II		I	II		I	II	
АС-6 НК3+10% СБ-3	8	67	170	27	61	80	4	18	15
АС-6 (бак.)[7]+10% СБ-3	15	70	150	40	52	70	0	1	1
АС-6 НК3+3% ЦИАТИМ-339, двигатель 1 [8]	120	90	140	110	70	50	12	15	8
9 То же, двигатель 2	20	70	140	80	50	52	2	1	1

1) Oil; 2) increase in gap, μm; 3) compression; 4) oil; 5) weight loss, mg; 6) wear, from height, μm; 7) Bakinskoye; 8) engine; 9) the same, engine 2.

The wearing of the first piston rings was substantially less for the oils containing CБ-3 additive than for the AC-6 oil containing ЦИАТИМ-339 additive (see Table 148).

The wear for the remaining engine components, shown in Table 149, was of the same order.

Table 150 shows the change in engine power and economy indices. As can be seen, the engine operated with AC-6 HK3 oil containing 10% CБ-3 additive retained the same indices throughout the

TABLE 149

Engine-Component Wear, μm

1 Деталь	2 АС-6+3% ЦИАТИМ-339 и 1% АзНИИ-ЦИАТИМ-1		4 АС-6 НКЗ++10% присадки СБ-3	5 АС-6 (бак.)+10% присадки СБ-3
	3 двигатель 1	3 двигатель 2		
6 Поршень, мк				
7 Канавка кольца				
I	15	7	15	0
II	10	2	9	0
III	3	1	3	0
IV	5	1	—	—
8 Бобышки	8	5	7	0,7
9 Юбка	2	1	11	4
10 Втулка шатуна	4	9	7	0,6
11 Поршневой палец	2	2	0,0	0,0
12 Коленчатый вал				
13 шатунные шейки	6	2*	3	1
14 коренные шейки	[illegible]	1*	3	0,6

*Data for 500 h of engine operation.

1) Component; 2) and; 3) engine; 4) АС-6 НКЗ + 10% СБ-3 additive; 5) АС-6 (Bakinskoye) + 10% СБ-3 additive; 6) piston, μm; 7) ring grooves; 8) bosses; 9) skirt; 10) rod bushing; 11) piston pin; 12) crankshaft; 13) rod necks; 14) crank necks.

TABLE 150

Change in Power and Economy Indices

1 Показатели	АС-6+3% ЦИАТИМ-339 2 и 1% АзНИИ-ЦИАТИМ-1				6 АС-6 НКЗ с 10% присадки СБ-3		7 АС-6 (бак.) с 10% присадки СБ-3	
	3 Двигатель 1		3 Двигатель 2					
	4 до испыт.	5 после испыт.	4 до испыт.	5 после испыт.	4 до испыт.	5 после испыт.	4 до испыт.	5 после испыт.
8 Мощность при полном дросселе, л.с.	65,0	66,0	68,0	66,5	70,2	69,5	66,1	63,5
9 Часовой расход топлива, кг/ч	18,5	17,9	18,2	18,0	18,2	18,2	18,2	18,2
10 Удельный расход топлива, г/э. л. с. ч.	283	272	268	270	260	262	274	266

1) Index; 2) and; 3) engine; 4) before test; 5) after test; 6) АС-6 НКЗ containing 10% СБ-3 additive; 7) АС-6 (Bakinskoye) containing 10% СБ-3 additive; 8) power at full throttle, hp; 9) hourly fuel consumption, kg/h; 10) specific fuel consumption, g per effective hp per h.

experiment, while that operated with AC-6 (Bakinskoye) oil containing the same additive exhibited a slight improvement in indices.

The average change in oil physicochemical properties proceeded in roughly the same fashion in all cases (Table 151).

The test results enable us to draw the following conclusions.

1. Cylinder and first-compression-ring wear was less for AC-6 НКЗ and AC-6 (Bakinskoye) oils containing СБ-3 additive than for AC-6 oil containing 3% ЦИАТИМ-339 additive.

TABLE 151

Change in Oil Physicochemical Properties

1 Показатели	АС 6 НКЗ с 3% 2 присадки ЦИАТИМ-339+ 1% АзНИИ-ЦИАТИМ-1	3 АС-6 НКЗ с 10% присадки СБ-3	4 АС-6 (бак.) с 10% присадки СБ-3
5 Вязкость кинематическая (*сст*) при 50° С			
20 *мин* 6	38,05	34,60	40,22
51 *ч* 7	38,18	34,56	41,97
8 Вязкость кинематическая (*сст*) при 100° С			
20 *мин* 6	—	7,26	7,34
51 *ч* 7	—	6,81	7,65
9 Кислотное число, *мг* КОН на 1 *г* масла			
20 *мин* 6	0,13	0,07	0,07
51 *ч* 7	0,29	0,25	0,20
10 Зольность, %			
20 *мин* 6	0,31	0,69	0,60
51 *ч* 7	0,25	0,75	0,69
11 Коксуемость, %			
20 *мин* 6	0,51	0,84	0,74
51 *ч* 7	0,61	1,08	0,97
12 Органическая часть механических примесей, %			
20 *мин* 6	—	0,011	0,014
51 *ч* 7	—	0,024	0,010
13 Неорганическая часть механических примесей, %			
20 *мин* 6	—	0,022	0,022
51 *ч* 7	—	0,025	0,028
14 Несгораемые, %			
20 *мин* 6	—	0,022	0,022
51 *ч* 7	—	0,025	0,028

1) Index; 2) AC-6 НКЗ containing 3% ЦИАТИМ-339 + 1% АзНИИ-ЦИАТИМ-1 additive; 3) AC-6 НКЗ containing 10% СБ-3 additive; 4) AC-6 (Bakinskoye) containing 10% СБ-3 additive; 5) kinematic viscosity (cSt) at 50°C; 6) min; 7) h; 8) kinematic viscosity (cSt) at 100°C; 9) acid number, mg KOH per g of fuel; 10) ash, %; 11) tars, %; 12) organic mechanical impurities; 13) inorganic mechanical impurities; 14) unconsumed material, %.

The wearing of the remaining components during operation with the oils containing СБ-3 additive was either less than or equivalent to that obtained in tests with AC-6 oil containing ЦИАТИМ-339 additive.

2. The amount of tars deposited on the pistons and other engine components was less for the oils containing СБ-3 additives.

3. Full piston-ring mobility was maintained throughout the test period.

4. The engine power and economy indices remained constant.

5. The change in oil physicochemical properties proceeded normally, as when the engine was run with oil containing ЦИАТИМ-339 additive.

§4. ENGINE CHARACTERISTICS OF COMPOUND ADDITIVES

As the results of many tests have shown, use of БФК-1 additive in various tractor engines in pure form greatly reduces oil corrosiveness, as a material stabilizing effect, and consequently promotes maintenance of piston-ring mobility. However, there is a slight increase in compression-ring wear (by weight). Use of СБ-3 additive, which does not have antioxidant properties, in pure form does not provide piston-ring mobility in various diesels, but minimum piston-ring wear is obtained.

We conducted separate and joint engine tests of different concentrations of БФК-1 and СБ-3 additives mixed with Baku and Vostok oils. Numerous tests confirmed the effectiveness of using a mixture of these additives, since there is a substantial mutual reinforcement of properties (synergistic effect) [10].

Engine Tests of ДС-11 НКЗ Oil Containing 15% of Mixture of БФК and СБ-3 Additives in Ratio of 8:7

On the basis of an analysis of the data obtained in laboratory and nonengine tests, we decided to subject an oil containing 15% of a mixture of БФК-1 and СБ-3 additives in a ratio of 8:7 to engine tests in a УИМ-3 apparatus (ЯАЗ-204 engine) for 100 h in order to determine the detergent, antiwear, and antioxidant properties of the specimen under engine conditions.

Table 152 gives the data obtained in a 100-h test of the speci-

TABLE 152

Results of Tests in УИМ-3 Apparatus

1 Масло	2 Результат, баллы
ДС-11 НКЗ+3% ЦИАТИМ-339	13,3
Д-11+10% СБ-3	9,8
Д-11+10% СБ-3	7,26
Д-11+8% БФК	10,5
3 Д-11+10% с БФК и СБ-3 в соотношении 2:1	3,54
4 ДС-11 НКЗ+15% БФК с СБ-3 соотношении 8:7 (100-часовое испытание)	3,65

1) Oil; 2) result, points; 3) Д-11 + 10% БФК and СБ-3 in ratio of 2:1; 4) ДС-11 НКЗ + 15% БФК СБ-3 in ratio of 8:7 (100-h test).

TABLE 153

Results of Short-term Tests in ЯАЗ-204 Engine

1 Показатели	АС-11 НКЗ 2 с 3% ЦИАТИМ-339	ДС-11 НКЗ 2 с 5% БФК 3 и 10% СБ-3	2 ДС-11 НКЗ с 8% БФК 3 и 7% СБ-3
4 Износ компрессионных колец по весу, *мг*			
I	502	302	380
II	294	174,2	235
III	121	80,7	32,4
IV	105	58,4	34,4
5 В среднем на кольцо	255	154	170,4
6 То же маслосъемных колец			
I	25,0	21,0	10,7
II	22,5	22,1	9,0
III	19,7	15,9	8,4
IV	20,2	15,0	10,3
5 В среднем на кольцо	21,8	18,5	9,6
7 Износ компрессионных колец по увеличению зазора в замке, *мк*			
I	300	216,6	300
II	262	175,0	100
III	62,6	112,5	12,5
IV	15	100	12,5
5 В среднем на кольцо	174,8	126,0	106,3
6 То же маслосъемных колец			
I	50	87,5	37,5
II	62,5	50,0	37,5
III	62,5	62,5	0,0
IV	62,5	62,5	37,5
5 В среднем на кольцо	59,3	65,6	28,1
8 Нагар, *мг*			
9 с колец	2,98	2,54	1,70
10 с канавок	4,55	5,09	4,55
11 Всего	7,53	7,63	6,25
12 Износ вкладышей (*мг*) на один			
13 верхний	39,9	35,3	10,0
14 нижний	17,2	18,3	2,0
15 Подвижность колец			
16 свободные	10	15	16
17 плотные	5	—	—
18 прихваченные	1	1	—
19 Средний износ цилиндров по методу вырезанных лунок, *мк*	17,2	10,16	2,58

1) Index; 2) containing; 3) and; 4) compression-ring wear, from weight loss, mg; 5) average per ring; 6) the same, for oil rings; 7) compression-ring wear, from increase in gap, μm; 8) carbon deposits, mg; 9) on rings; 10) on grooves; 11) total; 12) wear for single bushings (mg); 13) upper; 14) lower; 15) ring mobility; 16) free; 17) tight; 18) frozen; 19) average cylinder wear, by hole method, μm.

men in the УИМ-3 apparatus. The test time was increased to 100 h, rather than the 50 h customarily employed, because the piston was completely clean and no evaluation on the point scale could be made after 50 h.

For purposes of comparison, we use data obtained in testing ДС-11 oil containing 3% ЦИАТИМ-339 additive and Д-11 oil containing different concentrations of БФК and С5-3 additives in pure form and in mixtures over 50 h of engine operation.

As can be seen, the results obtained for tests on the 15% mixture of БФК and С5-3 additives in a ratio of 8:7 were substantially better for 100 h of engine operation than the results for the other specimens over 50 h of engine operation. The absence of tars on the piston with the УИМ-3 engine operating under a high-temperature regime indicates that the combination of СБ-3 and БФК additives substantially improves oil thermostability.

Table 153 presents data obtained in testing the specimen in a ЯАЗ-204 engine, as well as data obtained in the same engine for ДС-11 НКЗ oil containing 3% ЦИАТИМ-339 additive and ДС-11 НКЗ oil containing 15% БФК and СБ-3 in a ratio of 2:1.

It can be seen from an analysis of the data in the table that the oil containing 15% БФК and СБ-3 in a ratio of 8:7 yielded better results for all the indices evaluated (piston cleanness, carbon deposits in grooves and on rings, cylinder wear, bushing wear, ring wear from increase in gap, and ring mobility). The fact that the wear for the first two compression rings (by weight) was somewhat greater than that obtained at a ratio of 1:2 can be attributed to the higher sulfur content of the fuel for the 8:7 ratio (1%, as against 0.83%).

ДС-11 НКЗ oil containing 15% БФК and СБ-3 additives in a ratio of 8:7 thus has sufficiently good antioxidant, antiwear, and detergent properties, which, in a 140-h test in a supercharged ЯАЗ-204 diesel, resulted in good piston-surface cleanness, complete piston-ring mobility, minimum carbon deposition on the rings and grooves, minimum wearing of the cylinder-piston components, and absolutely clean exhaust ports.

Long-term Stand Tests of ДС-11 НКЗ Oil Containing 10% БФК and СБ-3 Additives in Ratio of 2:1 in ЯАЗ-204 Engine

Tables 154 and 155 characterize the wear for the main engine components during operation with the test and standard oil.

As can be seen, substantially less wear for all the main components was obtained with the mixture of БФК and СБ-3 additives.

The character and amount of the carbon and tar deposits on the pistons and of the resin deposits on the oil-filter elements were evaluated by visual examination and weighing (Table 156).

Since the NAMI list does not include data on the amount of carbon deposited on the pistons and rings, we used the carbon deposition obtained in operating a ЯАЗ-204 engine with СУ oil con-

TABLE 154

Wear for Cylinder-Piston Components

1 Показатели	2 ДС-11 НК3 с 3% ЦИАТИМ-339	3 ДС-11 НК3 + 10% БФК и СБ-3 в соотношении 2:1
4 Максимальный износ гильзы в верхнем поясе в плоскости оси вала, мк		
5 параллельной	37	0
6 перпендикулярной	78	10
7 в среднем	55	5
8 Износ поршней по изменению диаметра, мк		
9 наружного	21	1,0
10 бобышек	25	9
11 Износ кольцевых канавок по высоте, мк		
I	24	40
II	11	2,5
III	11	2,5
IV	10	5
12 маслосъемных колец	10	2,5
13 Износ поршневого пальца, мк	4	0,5
14 Износ компрессионных колец по потере веса, мг		
I	526	264,2
II	570	349,6
III	385	358,0
IV	350	305,0
15 В среднем на кольцо	457,5	319,2
16 То же по изменению зазора, мк		
I	317	100
II	355	350
III	305	212
IV	270	237
15 В среднем на кольцо	310	224
17 То же по высоте, мк		
I	32	32,7
II	15	17,9
III	14	18,0
IV	13	12,6
15 В среднем на кольцо	18,5	20,0

1) I dex; 2) ДС-11 НК3 containing 3% ЦИАТИМ-339; 3) ДС-11 НК3 + + 10% БФК and СБ-3 in ratio of 2:1; 4) maximum cylinder-sleeve wear, upper zone, in shaft-axis plane, μm; 5) parallel; 6) perpendicular; 7) average; 8) piston wear, from change in diameter, μm; 9) outside; 10) boss; 11) ring-groove wear, from height, μm; 12) oil rings; 13) piston-pin wear, μm; 14) compression-ring wear, from weight loss, mg; 15) average per ring; 16) the same, from change in gap, μm; 17) the same, from height, μm.

taining 3% ЦИАТИМ-339 additive and high-sulfur fuel (VNII NP).

The clear advantage of the mixture of БФК and СБ-3 additives can be seen from the data in the table.

TABLE 155

Wear for Crankshaft-Rod Components

1 Показатели износа	2 ДС-11 НК3 с 3% ЦИАТИМ-339	3 ДС-11 НК3 с 10% БФК и СБ-3 в соотношении 2:1
4 Износ шеек коленчатого вала, мк		
5 шатунных	2	1,0
6 коренных	3	1,3
7 Износ вкладышей подшипников по потере веса, мг		
8 шатунных верхних	—	75,9
9 нижних	—	34,4
10 коренных верхних	—	32,7
9 нижних	—	71,8
11 Износ вкладышей подшипников по толщине, мк		
5 шатунных	13	0,5
6 коренных	10	1,8
12 Износ втулки верхней головки шатуна, мк	13	12

1) Wear index; 2) ДС-11 НК3 containing 3% ЦИАТИМ-339; 3) ДС-11 НК3 containing 10% БФК and СБ-3 in ratio of 2:1; 4) crankshaft-neck wear, µm; 5) rod necks; 6) crank necks; 7) bearing-bushing wear, from weight loss, mg; 8) upper rod bushings; 9) lower bushings; 10) upper crank bushings; 11) bearing-bushing wear, from thickness, µm; 12) upper rod-bushing wear, µm.

TABLE 156

Piston-Ring Mobility, Deposits on Filter Elements, Carbon Deposits, and Oil Burning

1 Состояние деталей после 600 ч работы двигателей	2 ДС-11 НК3 с 3% ЦИАТИМ-339	3 ДС-11 НК3 с 10% БФК и СБ-3 (2:1)
4 Подвижность поршневых колец		
5 свободные	27	30
6 плотные	4	2
7 прихваченные	1	—
8 сломанные	—	—
9 Лаковые покрытия на юбке поршней	18 Лак черного цвета на 60—70% поверхности	19 Лак темно-серого цвета на 15—20% поверхности
10 Отложения на фильтрующих элементах грубой очистки масла в среднем за 60-часовой цикл, г	29	46
11 То же на элементах тонкой очистки	36	155
12 Расход масла на угар в среднем за 60-часовой цикл, кг	—	3,2
13 в % к расходу топлива	1,35	0,40
14 Нагары на деталях поршневой группы, г		
15 В том числе	20,95	11,06
16 на кольцах	—	2,99
17 в канавках	—	6,77

1) Engine condition after operation for 600 h; 2) ДС-11 НК3 containing 3% ЦИАТИМ-339; 3) ДС-11 НК3 containing 10% БФК and СБ-3 (2:1); 4) piston-ring mobility; 5) free; 6) tight; 7) frozen; 8)

broken; 9) tar deposits on piston skirt; 10) deposits on low-quality oil-filter elements, average for 60-h cycle, g; 11) the same, for high-quality filter elements; 12) amount of oil burnt, average for 60-h cycle, kg; 13) % of fuel consumption; 14) carbon deposits on piston components, g; 15) inclusive; 16) rings; 17) grooves; 18) black tar on 60-70% of surface; 19) dark gray tar on 15-20% of surface.

TABLE 157

Change in Physicochemical Properties of ДС-11 НКЗ Oil Containing 10% БФК and СБ-3 in Ratio of 2:1

1 Время отбора проб	2 Вязкость сст при 50° C	100° C	3 Коксуемость, %	4 Зольность, %	5 Кислотное число, мг КОН	6 Железо, мг/кг	7 Механические примеси, %
20 мин 8	73,62	12,33	1,85	0,96	0,08	15,8	0,074
10 ч 9	75,46	12,16	2,08	0,90	0,09	16,2	0,036
20 ч	76,09	12,59	2,41	0,93	0,03	25	0,030
30 ч	76,37	13,17	2,93	0,90	0,09	35	0,027
40 ч	77,83	13,79	3,34	0,91	0,08	43	0,023
50 ч	80,[illegible]	—	—	0,96	0,07	56	0,027
60 ч	81,56	13,35	3,42	0,91	0,10	58	0,027
10 Изменение за 60 ч	+7,94	+1,02	+1,57	−0,02	+0,02	+42,2	−0,047

1) Sampling time; 2) viscosity, cSt, at; 3) tars, %; 4) ash, %; 5) acid number, mg KOH; 6) iron, mg/kg; 7) mechanical impurities, %; 8) min; 9) h; 10) change over.

Table 157 presents data on the change in oil physicochemical properties during engine operation.

According to the NAMI data, operation of a ЯАЗ-204 engine with high-sulfur diesel fuel (GOST 305-62) and ДСП-11 oil yields the following average per-cycle indices for change in oil physicochemical properties: viscosity at 100°C – +1.9 cSt, tars – +12.79%, ash – +0.15%, and acidity – +0.25 mg KOH.

The oil containing БФК and СБ-3 additives thus underwent substantially smaller changes during engine operation for 60 h.

Long-term Tests of Bakinskoye Diesel Oil Containing 10% БФК and СБ-3 Additives in Ratio of 2:1 in КДМ-46 engine

These tests were conducted by the usual method and consisted in operating a КДМ-46 engine for 2000 h.

It can be seen from the data in Table 158 that cylinder-sleeve wear was very small for the test specimen, being far less than for the oils used as comparison standards.

Table 159 shows piston-ring wear, as determined from weight loss, increase in gap, and change in thickness and height.

As can be seen, the average indices for both compression-

TABLE 158

Average Cylinder-Sleeve Wear in Maximum-Wear Zone

1 Масло	2 Износ, мк
ДС-11 НКЗ с[3] 3% ЦИАТИМ-339	32
4 Д-11 (бак.) +6% БФК	21,2
5 Д-11 (бак.) + 10% БФК и СБ-3 в соотношении 2:1	2

1) Oil; 2) wear, μm; 3) containing; 4) ДС-11 (Bakinskoye) + 6% БФК; 5) Д-11 (Bakinskoye) + 10% БФК and СБ-3 in ratio of 2:1.

and oil-ring wear were very low, being substantially less than for the other oils tested.

Table 160 presents data on the wear for other engine components.

As can be seen, the least component wear was also obtained for the oil containing the combined additive.

Table 161 shows the data obtained in the wear zones and in the directions of maximum piston-skirt-diameter increase for each piston.

The amount and character of the deposits on the engine components were evaluated visually and by weighing.

Weighing of the carbon deposits removed from the pistons and rings showed that they amounted to 7.0 g for the test specimen, 123.1 g for НКЗ oil containing 3% ЦИАТИМ-339 additive, and 9.33 g for Д-11 (Bakinskoye) oil containing 6% БФК additive.

The amount of deposits produced on the low- and high-quality oil filters per cycle (120 h) was 40 and 126 g respectively for the test oil and 51 and 149 g for НУЗ oil containing 3% ЦИАТИМ-339 additive.

As can be seen from the data in Tables 162-164, the average increase in oil tar content over 120 h of operation was the same in all cases. The acid number of the oil containing the combined БФК and СБ-3 additives rose substantially more slowly. The ash content of the test oil remained constant, while that of НКЗ oil containing 3% ЦИАТИМ-339 additive fell sharply.

The long-term tests with 10% of the combined additive enable us to draw the following conclusions.

1. Engine-component wear was least for the oil containing 10% of the combined additive.

2. Less carbon was deposited on the pistons and rings when the engine was run with the test oil. Better results were also obtained for piston cleanness and piston-ring mobility.

TABLE 159

Piston-Ring Wear

Показатели износа [1]	Масло[2] ДС-11 с 3% ЦИАТИМ-339	Масло[3] Д-11 (бак.) с 6% БФК	Масло[4] Д-11 (бак.) с 10% БФК и СБ-3
[5] Износ компрессионных колец по потере веса, *мг*			
I	3635	380	310
II	1944	404	263
III	1279	234	206
[6] В среднем на кольцо	2260	340	260
[7] То же маслосъемных колец			
I	1174	273,4	190
II	—	494	220
[6] В среднем на кольцо	1174	382	205
[8] Износ компрессионных колец по увеличению зазора, *мк*			
I	[11] Сломано	400	50
II	[11] Сломано	400	64
III	580	390	87
[6] В среднем на кольцо	580	397	66
[7] То же маслосъемных колец			
I	1280	500	220
II	—	300	113
[6] В среднем на кольцо	1280	400	165
[9] Износ компрессионных колец по высоте, *мк*			
I	32	12,5	7,3
II	27	6,5	6,5
III	24	7,5	4,25
[6] В среднем на кольцо	27,7	8,6	6,0
[7] То же маслосъемных колец			
I	6	—	2,25
II	—	6	6,0
[6] В среднем на кольцо	6	6	4,06
[10] Износ компрессионных колец по толщине, *мк*			
I	192	31,1	10,5
II	—	35,9	9,5
III	—	66	11,5
[6] В среднем на кольцо	192	44	),3
[7] То же маслосъемных колец			
I	249	40,5	11,5
II	—	48	5,7
[6] В среднем на кольцо	249	44,2	8,5

1) Wear index; 2) ДС-11 oil containing 3% ЦИАТИМ-339; 3) Д-11 (Bakinskoye) oil containing 6% БФК; 4) Д-11 oil (Bakinskoye) containing 10% БФК and СБ-3; 5) compression-ring wear, from weight loss, mg; 6) average per ring; 7) the same, for oil rings; 8) compression-ring wear, from increase in gap, μm; 9) compression-ring wear, from height, μm; 10) compression-ring wear, from thickness, μm; 11) broken.

TABLE 160

Engine-Component Wear

[1] Показатели	[2] ДС-11 НКЗ 3% ЦИАТИМ-339	[3] Д-11 (бак.) с 6% БФК	[4] Д-11 (бак.) с 10% БФК и СБ-3
[5] Износ шеек коленчатого вала, *мк*			
[6] шатунных	1	3,1	0,0
[7] коренных	24	2,5	0,0
[8] Износ вкладышей подшипников по потере веса, *мг*			
[6] шатунных	—	—	110
[7] коренных	198	—	67
[9] То же по толщине, *мк*			
[6] шатунных	15,5	0,0	1,5
[7] коренных	—	1,5	1,0
[10] Износ поршневого пальца, *мк*	—	6,2	0,0
[11] Износ втулки верхней головки шатуна, *мк*	—	0	1,0
[12] Износ поршня по изменению диаметра в бобышках, *мк*	—	72	35,0

1) Index; 2) ДС-11 НКЗ containing 3% ЦИАТИМ-339; 3) Д-11 (Bakinskoye) containing 6% БФК; 4) Д-11 (Bakinskoye) containing 10% БФК and СБ-3; 5) crankshaft-neck wear, μm; 6) rod necks; 7) crank necks; 8) bearing-bushing wear, from weight loss, mg; 9) the same, from thickness, μm; 10) piston-pin wear, μm; 11) upper rod-bushing wear, μm; 12) piston wear, from change in diameter at bosses, μm.

TABLE 161

Change in Piston-Skirt Diameter After Operation for 2000 h, mm

I поршень[1]		II поршень[1]		III поршень[1]		IV поршень[1]	
[2] до испыт.	[3] после испыт.	[2] до испыт.	[3] после испыт.	[2] до испыт.	[3] после испыт.	[2] до испыт.	[3] после испыт.
144,69	144,83	144,69	144,83	144,58	144,57	144,71	144,83
[4] Увеличение	+0,14	[4] Увеличение	+0,14	[4] Увеличение	—0,01	[4] Увеличение	+0,12

1) Piston; 2) before test; 3) after test; 4) increase.

TABLE 162

Change in Physicochemical Properties of Д-11 Oil Containing 10% БФК and СБ-3

[1] Время отбора проб	[2] Вязкость при 50° С, *сст*	[3] Коксуемость, %	[4] Кислотное число, *мг* КОН	[5] Зольность, %	[6] Железо, %
20 *мин*[7]	93,7	1,55	0,05	1,08	13,4
30 ч [8]	104,81	1,56	0,05	1,14	9
60 ч	106,46	1,66	0,08	1,16	10,9
120 ч	110,86	1,75	0,10	1,25	16,7
[9] Увеличение показателя	+17,29	+0,20	+0,05	+9,15	+ 3,3

1) Sampling time; 2) viscosity at 50°C, cSt; 3) tars, %; 4) acid number, mg KOH; 5) ash, %; 6) iron, %; 7) min; 8) h; 9) increase in index.

TABLE 163

Change in Physicochemical Properties of Д-11 (Bakinskoye) Oil Containing 6% БФК

1 Время отбора проб	2 Вязкость, при 50°C, сст	3 Коксуемость, %	4 Кислотное число, мг КОН	5 Зольность, %
20 мин 6	80,77	0,98	0,04	0,675
30 ч 7	88,54	1,094	0,126	0,736
60 ч	91,83	1,128	0,150	0,763
120 ч	92,21	1,153	0,183	0,777
8 Увеличение показателя	+11,44	+0,176	+0,143	0,103

1) Sampling time; 2) viscosity at 50°C, cSt; 3) tars, %; 4) acid number, mg KOH; 5) ash, %; 6) min; 7) h; 8) increase in index.

TABLE 164

Change in Physicochemical Properties of ДС-11 НКЗ Oil Containing 3% ЦИАТИМ-339

1 Время отбора проб	2 Вязкость, при 50° C, сст	3 Кислотное число, мг КОН	4 Коксуемость, %	5 Зольность, %
20 мин 6	64,2	0,11	0,76	0,17
30 ч 7	66,2	0,48	0,70	0,10
60 ч	68,0	0,52	0,79	0,04
120 ч	69,7	0,60	0,91	0,05
8 Увеличение показателя	+5,5	+0,49	+0,15	—0,12

1) Sampling time; 2) viscosity at 50°C, cSt; 3) acid number, mg KOH; 4) tars, %; 5) ash, %; 6) min; 7) h; 8) increase in index.

TABLE 165

Results of Tests in УИМ-3 Apparatus

1 Масло	2 Результат, баллы
ДС-11 НКЗ+3% ЦИАТИМ-339	13,3
ДС-11+10% СБ-3	9,8
ДС-11+15% СБ-3	7,26
ДС-11+8% БФК	10,5
ДС-11+10% БФК 3 с СБ-3 (2:1)	3,54
ДС-11 + 15% БФК с СБ-3 (8 и 4 7)	3,65 (100ч 5)

1) Oil; 2) result, points; 3) containing; 4) and; 5) h.

3. The physicochemical properties of ДС-11 oil containing 10% of the compound additive changed less in the ЯАЗ-204 engine than did those of ДСП-11 oil. When a КДМ-46 engine was run with Д-11 Bakinskoye oil containing the same additive, the change in oil properties was roughly equivalent to that observed for pure БФК.

Testing of Additives Mixed with ДС-11 Oil Produced From Vostok Crude Oil

In order to make a preliminary evaluation of the characteristics of oils containing БФК-1 and СБ-3 additives in pure form and in combination, we conducted preliminary tests on ДС-11 НКЗ oil containing 15% БФК-1, 15% СБ-3, and 15% of a mixture composed of 8 parts БФК-1 and 7 parts СБ-3.

Data obtained in similar tests on ДС-11 НКЗ oil containing 3% ЦИАТИМ-339 additive were used for comparison in all cases.

Table 165 presents data obtained in a 100-h test of the specimen in a УИМ-3 apparatus.

The test time was increased to 100 h from the usual 50 h because the piston was absolutely clean and evaluation in points was difficult after operation for 50 h.

For purposes of comparison, the table gives data in tests conducted with ДС-11 oil containing ЦИАТИМ-339 additive and Д-11 oil containing different concentrations of БФК and СБ-3 additives, both in pure form and in combination, over 50 h of engine operation, using the same procedure and apparatus.

As can be seen, the results obtained in the 100-h test of the 15% mixture of БФК and СБ-3 additives in a ratio of 8:7 were substantially better in point terms than for 50-h tests with the other specimens. The absence of tars on the piston with the УИМ-3 engine operating at high temperatures indicates that the combination of СБ-3 and БФК additives substantially improved oil thermostability.

140-hour Tests in ЯАЗ-204 Engine

Table 166 presents data obtained in testing the specimen in a ЯАЗ-204 engine.

As can be seen, all the indices evaluated after 140-h tests were better for the oil containing 15% БФК and СБ-3 additives in a ratio of 8:7. The fact that the wear for the first two compression rings was somewhat greater in this case than when the additive ratio was 1:2 can be attributed to the higher sulfur content of the fuel employed for the 8:7 ratio.

ДС-11 НКЗ oil containing 15% БФК and СБ-3 additives in a ratio of 8:7 thus has sufficiently good antioxidant, antiwear, and detergent properties, which resulted in high piston-surface cleanness, good piston-ring mobility, minimum carbon deposition on the rings and grooves, minimum wear for the cylinder-piston components, and absolutely clean exhaust ports during 140-h tests in a supercharged ЯАЗ-204 diesel.

TABLE 166

Results of Short-term Tests in ЯАЗ-204 Engine

1 Показатели	2 ДС-11 НКЗ с 3% ЦИАТИМ-339	3 ДС-11 НКЗ с 5% БКФ+ 10% СБ-3	4 ДС-11 НКЗ с 3% БФК+7% СБ-3
5 Износ компрессионных колец по потере веса, мг			
I	502	302	380
II	294	174,2	235
III	121	80,7	32,4
IV	105	58,4	34,4
6 В среднем на кольцо	255	154	170,4
7 То же маслосъемных колец			
I	25,0	21,0	10,7
II	22,5	22,1	9,0
III	19,7	15,0	8,4
IV	20,2	15,0	10,3
6 В среднем на кольцо	21,8	18,5	9,6
8 Износ компрессионных колец по увеличению зазора в замке, мк			
I	300	216,6	300
II	262	175,0	100
III	625	112,5	12,5
IV	15.0	100,0	12,5
6 В среднем на кольцо	174,3	125,0	106,2
7 То же маслосъемных колец			
I	50	87,6	37,5
II	62,5	50,0	37,5
III	62,6	62,5	
IV	52,5	62,5	37,5
6 В среднем на кольцо	59,3	65,6	29,1
9 Нагары, г			
10 с колец	2,98	2,54	1,70
11 с канавок	4,55	5.09	4,55
12 с колец и канавок	7,53	7,63	6,25
13 Износ вкладышей (мг) на один			
14 верхний	39,9	35,3	10.0
15 нижний	17,2	13,3	2,0
16 Подвижность колец			
17 свободные	10	15	16
18 плотные	5	—	—
19 прихваченные	1	1	—
20 Средний износ цилиндров по методу вырезанных лунок, мк	17,2	10,15	2,58

1) Index; 2) ДС-11 НКЗ containing 3% ЦИАТИМ-339; 3) ДС-11 НКЗ containing 5% БФК + 10% СБ-3; 4) ДС-11 НКЗ containing 3% БФК + 7% СБ-3; 5) compression-ring wear, from weight loss, mg; 6) average per ring; 7) the same, for oil rings; 8) compression-ring wear, from increase in gap, μm; 9) carbon deposits, g; 10) on rings; 11) on grooves; 12) on rings and grooves; 13) bushing wear (mg), for single; 14) upper bushing; 15) lower bushing; 16) ring mobility; 17) free; 18) tight; 19) frozen; 20) average cylinder wear, by hole method, μm.

In selecting the proper compositions, the БФК concentration was taken as a constant 8% in all cases, since this concentration yielded the best results with respect to ring mobility and piston-surface cleanness. Different amounts (4, 8, and 12%) of the СБ-3 additive were used.

Results of 140-hour Stand Tests in ЯАЗ-204 Engine

Table 167 presents the results of 140-h stand tests of Д-11 (Bakinskoye) oil containing 8% pure БФК additive and 3 mixtures БФК and СБ-3 additives in a ЯАЗ-204 engine.

TABLE 167

Results of Tests in ЯАЗ-204 Engine

1 Показатели	2 Д-11 (бак.) с 8% БФК	Д-11 (бак.) с 8% БФК и 4% СБ-3 (3)	Д-11 (бак.) с 8% БФК и 8% СБ-3	Д-11 (бак.) с 8% БФК и 12% СБ-3
4 Износ компрессионных колец по потере веса, *мг*				
I	349,2	354,9	320,4	331,6
II	218,3	99,7	206,0	127,0
III	115,1	36,6	35,2	50,0
IV	105,9	38,9	46,3	52,0
5 В среднем на кольцо	197,1	131,0	151,5	141,0
6 То же маслосъемных колец				
I	15,4	24,3	25,0	16,8
II	13,5	29,0	25,4	12,0
III	16,4	27,4	32,9	15,7
IV	13,5	24,8	27,4	17,7
5 В среднем на кольцо	14,7	26,4	30,2	15,5
7 Износ компрессионных колец по увеличению зазора, *мк*				
I	200,0	125	50	100
II	62,5	116	83	75
III	50,0	33,3	50	25
IV	16,0	50	33	25
5 В среднем на кольцо	82,1	108	54	53
6 То же маслосъемных колец				
I	37,5	100	83	87,5
II	25	100	83	33
III	50	87,5	83	50
IV	0	83,3	83	60
5 В среднем на кольцо	28,1	92,7	83	59,1
8 Нагар, *г*				
9 с колец	2,49	1,85	2,35	1,48
10 с днища	2,28	1,30	4,20	1,80
11 с канавок	3,20	3,55	3,05	3,47
12 с колец и канавок	5,69	5,40	5,40	4,95
13 Отложения на окнах, *г*	1,0	2,45	1,70	3,10
14 Износ вкладышей (*мг*) на один				
15 верхний	53,6	37,4	43,1	21,5
16 нижний	28,4	28,0	43,2	3,9
17 Подвижность колец				
18 свободные	15	15	15	—
19 плотные	1	1	—	—
20 прихваченные	—	—	—	—

1) Index; 2) Д-11 (Bakinskoye) containing; 3) and; 4) compression-ring wear, from weight loss, mg; 5) average per ring; 6) the same, for oil rings; 7) compression-ring wear, from increase in gap, μm; 8) carbon deposits, g; 9) on rings; 10) on piston faces; 11) on grooves; 12) on rings and grooves; 13) deposits on ports, g; 14) bushing wear (mg), for single; 15) upper bushing; 16) lower bushing; 17) ring mobility; 18) free; 19) tight; 20) frozen.

Mixture of 4% СБ-3 additive with Д-11 oil containing 8% БФК additive reduced average compression-ring wear by 30% in comparison with 8% pure БФК. Increasing the СБ-3 concentration had almost no effect on ring wear. However, when the СБ-3 concentration was raised to 8% and then to 12%, the piston-skirt surface became markedly cleaner, ring mobility improved, and there was a slight decrease in the amount of carbon deposited on the rings and grooves.

Use of additive combinations is now the most common procedure in compounding lubricants for Soviet ICE's. Most of the motor oils of Series, A, B, C, and D in the new oil classification [11] recommended for mass-produced automobile, tractor, marine, and other ICE's are combinations based on additives produced by alkylphenol-formaldehyde condensation and sulfonate additives. New additive compounds for all groups of oils produced from Apsheron crude oils have been developed and put into production, their main component being БФК and СБ-3 additives [12].

TABLE 168

Results of Comparative Tests in ГАЗ-51 Engine

1 Показатели	2 Д-11 с 3% СБ-3 и 2% ДФ-11	3 Д-11 с 3% СБ-3 и 2% ИНХП-21
4 Износ комплекта поршневых колец, мг	59,0	62,0
5 Износ вкладышей шатунных подшипников, мг	56,0	70,0
6 Отложения нагара на кольцах и в канавках, г	4,3	3,9
7 Лак на юбке поршня, баллы	4,9	3,7
8 Подвижность колец	2,7	2,3

1) Index; 2) Д-11 containing 3% СБ-3 and 2% ДФ-11; 3) Д-11 containing 3% СБ-3 and 2% ИНХП-21; 4) piston-ring wear, per set, mg; 5) rod-bearing bushing wear, mg; 6) carbon deposits on rings and grooves, g; 7) tar on piston skirt, points; 8) ring mobility.

TABLE 169

Results of 600-hour Stand Tests in ЯМЗ-236 Engine

1 Показатели	2 Д-11 (бак.) с 5% БФК, 2% СБ-3 0,005% ПМС-200А	3 ДС-11+6% ВНИИ НП-370
4 Нагар на поршневых кольцах и в канавках, г	3,17	6,55
5 Средний износ комплекта поршневых колец, г	0,72	1,36
6 Средний износ гильз цилиндров, мк	6,5	11,6
7 Средний износ вкладышей шатунных подшипников, мг	85	150
8 Подвижность поршневых колец, баллы	0	0,25

1) Index; 2) Д-11 (Bakinskoye) containing 5% БФК, 2% СБ-3, and 0.005% ПМС-200А; 3) ДС-11 + 6% ВНИИ НП-370; 4) carbon deposit on piston rings and grooves, g; 5) average piston-ring wear, per set, g; 6) average cylinder-sleeve wear, μm; 7) average rod-bearing bushing wear, mg; 8) piston-ring mobility, points.

TABLE 170

Results of 140-h Tests in ЯАЗ-204 Engine (per-cylinder averages)

1 Показатели	2 Масло Д-11 + 9% Монто-613 + 0,7% Сантолюб-493	3 Масло Д-11(бак.) + +11% БФК + 4% СБ-3 + 1% ИНХП-30 + 0,005% ПМС-200А
4 Износ компрессионных колец по потере веса комплектом, мг	876,9	400
5 То же маслосъемных колец	33,4	54,2
6 В среднем	50	56,7
7 Подвижность колец, баллы	0.75	0,75
8 Перемещение от большого усилия	0	0
9 То же от легкого усилия	2	3
10 Свободные	12	13
11 Защемленные	2	0
12 Нагары, г		
13 с колец	1,15	0,83
14 с канавок	0,839	1,56
15 с днищ	0,522	0,22
16 с боковых поверхностей	0,29	0,30
17 Отложения в продувочных окнах	1,5	1,25
18 Отложения на элементах Ф.Т.О. масла, г	505	345
19 Расход масла в среднем на цикл работы, кг	5,7	5,6

1) Index; 2) Д-11 oil + 9% Monto-613 + 0.7% Santolyub-493; 3) Д-11 (Bakinskoye) oil + 11% БФК + 4% СБ-3 + 1% ИНХП-30 + 0.005% ПМС-200А; 4) compression-ring wear, from weight loss, per set, mg; 5) the same, for oil rings; 6) average; 7) ring mobility, points; 8) large force required for movement; 9) small force required for movement; 10) free; 11) pinched; 12) carbon deposits, g; 13) on rings; 14) on grooves; 15) on piston faces; 16) on lateral surfaces; 17) deposits in exhaust ports; 18) deposits on high-quality oil-filter elements, g; 19) oil consumption, average per operating cycle, kg.

TABLE 171

Results of 600-hour Stand Tests of Д-11 Diesel Oil Containing Group D Compound Additives in ЯАЗ-204 Engine

1 Показатели	2 Эталон группы Г ДС-11 + 0,7% Сантолюб-493 + 9% монто-613	3 Д-11 + 11% БФК + 4% СБ-3 + 1% ИНХП-30 + 0,005% ПМС-200А
4 Износ гильз цилиндров, *мк*	22,0	20,0
5 Износ комплекта компрессионных колец по потере веса, *мг*	1210	880
6 То же маслосъемных колец	110	101,7
7 Износ компрессионных колец по высоте (в среднем на кольцо), *мк*	16	3,1
8 Износ компрессионных колец по увеличению зазора в стыке колец, (в среднем на кольцо), *мк*	0,18	0,18
9 Подвижность компрессионных колец (отнесенная к одному поршню)		
10 закоксованные и перемещающиеся под большим усилием	0	0
11 перемещающиеся под легким усилием	1,3	0,5
12 Суммарная оценка подвижности компрессионных колец, отнесенная к одному поршню (оценка в баллах по методу 344-Т)	0,7	0,25
13 Отложения лаков и нагара на деталях двигателя, отнесенные к одному цилиндру, *г*		
14 на поршневых кольцах	1,01	1,10
15 на головке и перемычках поршня	0,55	0,58
16 на днищах поршней	0,17	0,15
17 в канавках компрессионных колец	2,24	1,90
18 в продувочных окнах гильз цилиндров	0,94	0,64
19 поверхность юбки поршня, покрытая лаком, %	36	33

1) Index; 2) Group D standard: ДС-11 + 0.7% Santolyub-493 + 9% Monto-613; 3) Д-11 + 11% БФК + 4% СБ-3 + 1% ИНХП-30 + 0.005% ПМС-200А; 4) cylinder-sleeve wear, μm; 5) compression-ring wear, from weight loss, per set, mg; 6) the same, for oil rings; 7) compression-ring wear, from height, average per ring, μm; 8) compression-ring wear, from increase in gap, average per ring, μm; 9) compression-ring mobility, for one piston; 10) frozen rings and rings requiring large force for movement; 11) rings requiring slight force for movement; 12) overall estimate of compression-ring mobility, for one piston (in points, by 344-T method); 13) tar and carbon deposits on engine components, for one cylinder, g; 14) on piston rings; 15) on piston head and braces; 16) on piston face; 17) in compression-ring grooves; 18) in cylinder-sleeve exhaust ports; 19) tar-coating of piston-skirt surface, %.

Oils for carbureted engines (groups A and B). As was pointed out above, these groups of oils are intended for gasoline engines with different degrees of supercharging. An example is the oil produced by mixing a selectively refined automobile oil with barium sulfonate (no less than 3% СБ-3) and zinc dialkyldithiophosphate (no more than 2% ДФ-11) [13].

Oil containing 3% СБ-3 and 2% ДФ-11 is recommended for use in supercharged V-block ЗИЛ-130 engines produced by the Automobile Plant imeni Likhachev.

The Institute of Additive Chemistry, Academy of Sciences Azerbaydzhan SSR, has now recommended that the ДФ-11 additive in this combination be replaced by the more effective ИНХП-21 additive.

Table 168 presents the results of comparative 150-h tests of both oils in a ГАЗ-51 engine. The engine was operated without an oil change and with the high-quality oil filter disconnected.

Replacement of ДФ-11 by ИНХП-21 permits a slight improvement in the detergent properties of the oil and reduces its tendency toward formation of carbon and tar deposits.

Oils for compressive-ignition engines without fuel injection (group C). A combination of alkylphenol and sulfonate additives designated as АзНИИ-8 (a mixture of АзНИИ-7 and АзНИИ-5) was first tested in diesel engines at the АзНИИ НП in 1955 [12]. It was subsequently shown that combination of alkylphenol and sulfonate additives is a very effective means for improving the properties of diesel oils. Compounds whose effectiveness was far greater than that of the individual components were produced on the basis of the БФК and СБ-3 additives synthesized at the INKhP. One such combination (5% БФК, 2% СБ-3, and 0.005% ПМС-200А foam depressant) mixed with Д-11 oil from Apsheron crude oil was tested under the designation М-12В in the new ЯМЗ-236 automobile diesel produced by the Yaroslavsk Plant. Table 169 presents the results of the 600-h stand tests, as well as data obtained when the engine was operated under similar conditions with the plant-recommended Д-11 oil containing 6% ВНИИ НП-360 additive. Diesel fuel with a sulfur content of about 1% was used in both cases. The substantially greater detergent and antiwear efficiency of the oil containing the compound additive was obvious, so that М-12В oil from Bakinskoye crude oil was accepted for commercial use.

Oil for supercharged compressive-ignition engines (group D). Fast-stroke two-cycle diesel engines and engines employing medium- and high-pressure fuel injection and using fuels with high sulfur contents should operate with group-D oils, in accordance with the new motor-oil classification.

The INKhP recommends the following as a combination for production of group D oils from Д-11 (Bakinskoye) oil: 11% БФК, 4% СБ-3, 1% ИНХП-30, and 0.005% ПМС-200А [14]. This compound was checked in a ЯАЗ-204 engine under stand conditions, in both 140-h and 600-h tests (see Tables 170 and 171). These tables also show the results of tests conducted with a standard oil containing Monsanto additives.

The recommended combination satisfies the requirements for group D oils, having higher antiwear efficiency than the corresponding standard and being equivalent to it with respect to detergent properties.

It is thus possible to recommend combinations of INKhP additives for production of oils in groups A, B, C, and D; when properly used, these ensure reliable long-term operation of the overwhelming majority of vehicle engines currently being produced in the Soviet Union.

REFERENCES

1. Dzhordzhi, K.V., Motornyye masla i smazka dvigateley [Motor Oils and Engine Lubrication]. Moscow, 1959.

2. Mougey, H.C., Nat. Petr. News. Techn. Ed., 1945, 3, I.

3. Penfold, N.C., Petry, H.C., Lubr. End., June 1945, 7-II.

4. Willey, A.O., Nat. Petr. News. Techn. Eng., 1943, 3, XI.

5. Filippop, V., Trudy VNII NP. Metody analiza nefti i nefteproduktov [Transactions of the All-Union Scientific Research Institute for the Processing of Petroleum and Gas and for the Production of Synthetic Liquid Fuel. Methods of Analyzing Petroleum and Petroleum Products]. Moscow, 1955.

6. Papok, K.K., Zarubin, A.P., Zakharov, G.V., "Khimiya i tekhnologiya topliv i masel," 1959, No. 2.

7. Firsanova, Ye.N., Arabyan, S.G., "Traktory i sel'khozmashiny," 1960, No. 1.

8. Federal Standard Methods, No. 791. Washington D.C., 1959.

9. Pritzker, G., a) Nat. Petr. News, 37, No. 40, R-793-800, 3 October 1945; b) ibid, 37, No. 45, 871-882, 7 November 1945; c) ibid, 27, No. 49, 1001-1010, 5 December 1945.

10. Kuliyev, A.M. et al., Collection entitled "Prisadki k smazochnym maslam" [Additives to Lubrication Oils]. Moscow, 1961.

11. Blagovidov, I.F., Deryabin, A.A., Puchkov, N.G., "Khimiya i tekhnologiya topliv i masel," 1963, No. 2.

12. Kuliyev, A.M., Prisadki k smazochnym maslam. Moscow, 1964.

13. Semenido, Ye.G., Obleukhova, O.S., Shchegolev, N.V., Sanin, P.I., Kuliyev, A.M., et al., Sposob polucheniya motornogo masla [A Method of Producing Motor Oil]. USSR Patent No. 158369, class C10m; 23c 1o1; "Byull. izobreteniy i tovarnykh znakov," 1963, No. 21.

14. Kuliyev, A.M., Suleymanova, F.G., El'ovich, I.I., Zeynalov, G.A. and Mushaylov, A.Ye., Sposob polucheniya motornykh masel. USSR Patent No. 172446, class 23c; "Byull. izobreteniy i tovarnykh znakov," 1965, No. 13.

Manuscript Page No.	Transliterated Symbols
133	н = n = nominal'niy = nominal
139	вых = vykh = vykhodnoy = outlet
139	вход = vkhod = vkhodnoy = inlet
145	макс = maks = maksimal'nyy = maximum
145	т = t = toplivo = fuel