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Results of Research on Possibility to Use Low-Molecular Polyethylene in Lubricating Compositions

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***Abstract*—The article describes the solution to the problem of reducing the wear of rails and wheels by creating new lubricant compositions for the lubrication of rails based on polymers and other waste products, which allows one to simultaneously solve, to a certain extent, the environmental problem consisting in disposing of some waste professionally. Naturally, it is unlikely that any waste chemical production can be used as a lubricant for the lubrication of rails in the "pure" form. In the course of research, a lubricant containing 85% NMPE, 7% waste oil and 8% graphite was developed and tested. The resulting composition is a homogeneous black grease. It is easily applied to the rails (both stationary and mobile rail lubricators can be used), does not drain from the side surface of the rail head, is well carried by the wheels of the rolling stock, which ensures its uniform distribution on the side surface of the rail head. It is based on production waste, and expensive component-graphite; it contains no more than 10%. The composition has no corrosive effect. It is harmless to humans and the environment. The viscosity of such composition is easily adjusted in accordance with weather conditions by changing the ratio of NMPE: diesel oil. Tests of the obtained compositions were carried out in pilot conditions by applying lubricant to the side surface of the rail manually and by applying it to the rail using a mobile rail lubricator.**

***Keywords*—lubricating composition; modeling; low molecular weight polyethylene.**

I. Introduction

The East Siberian Railway is located in the region, on the territory of which there is a wide network of chemical, petrochemical and allied industries. The waste generated by these enterprises often cannot be professionally recycled, and their emitting, recovery or disposal worsens the already unfavorable ecological situation in the region. As for other wastes of this kind, they are characterized by a certain instability of the composition, and, consequently, of some physical and chemical properties.

The paper presents a solution to the problem of reducing the wear of rails and wheels by creating new lubricant compositions for lubricating rails based on polymers and other production wastes, which allows us to simultaneously solve, to a certain extent, the environmental problem and to recycle certain wastes professionally.

Naturally, it is unlikely that any waste of chemical production can be used as a lubricant for lubricating the rails in its "pure" form. However, as already noted, lubricants are, as a rule, complex compositions, so some wastes, as such or after a little processing, can act as components of lubricating compositions.

Analysis of literature data and the range of waste generated in the region allowed us to select the following wastes and products as components:

1. Used diesel locomotive oil. For diesel locomotive engines, motor oils M-14-G_2 and others are used [1, 2]. During operation, contaminants accumulate mainly in oil from wear products of rubbing parts. This leads to a further increase and acceleration of wear. Therefore, for normal operation of

locomotive diesel engines, periodic oil change is required, which results in the accumulation of spent diesel oil in locomotive depots. Shipping it to refineries is often complicated by a number of technical difficulties. At the same time, given there are tribotechnical characteristics of this production waste, it can be considered quite suitable as a component for compositions that reduce wear in the wheel-rail system.

2. Low molecular polyethylene (LMPE) is a waste from the production of a multi-tonnage product – high-pressure polyethylene. When ethylene is polymerized, a by-product is formed that has a substantially lower molecular weight than commercial polyethylene. It is a viscous oily product of white or light brown color. Oily properties and high chemical inertness prompted us to use this waste as a component for the lubrication of rails. The literature describes the use of this substance for lubricating rubber gaskets in the food industry [3], which indicates its absolute safety.

3. Coke breeze. In the production of petroleum electrode coke in delayed coking units, sometimes a fraction of a coke with a particle size of less than 8 mm does not find a qualified market. Since coke is a raw material for the production of graphite – the most important antifriction material, including the rail sector – we also used it as a component for the preparation of lubricant compositions.

4. Organochlorine waste production of epichlorohydrin. Organic chlorine compounds pose a great danger to the environment, since they are foreign to the biosphere and very slowly decompose under the action of light, oxygen, etc. [4]. In the production of epichlorohydrin, the most important monomer for the production of epoxy resins, more than 0.5 tons of organochlorine waste are produced per ton of the target product [5]. They are fluid liquids boiling in the range of 70 ÷ 150 ° C. Although it is known in the literature that chlorine-containing products are used as extreme-pressure additives for lubricating oils [6–8], substances that are part of this type of waste, due to their high volatility, cannot be used for these purposes. However, it is easy to get polymers with a high content of sulfur or residual chlorine from them by polycondensation with sodium polysulfide [9]. We have obtained solid and liquid polymers from waste of this type, which can be introduced into lubricating compositions. The sulfur and chlorine atoms contained in the polymer can give the lubricant high anti-scuff and anti-wear properties.

Table I shows the characteristics of used diesel oil in the locomotive depot of the Irkutsk-Sortirovochny station (according to measurements of the chemical and technical laboratory of the East Siberian Railway).

TABLE I. CHARACTERISTICS OF USED DIESEL OIL

Indicator	Value
1. Flash point in an open cup, °C	205 ÷ 210
2. Kinematic viscosity at 40 °C, cSt	110 ÷ 115
3. Kinematic viscosity at 100 °C, sSt	8 ÷ 12
4. Ash content, % wt	0.90 ÷ 0.95

Since July 1997, the waste diesel oil, both in pure form and with the addition of graphite [10], has become widely used in the East Siberian Railway instead of certified lubricants RS-6 and RP-1. Since March 1998, rail- lubricating locomotives have been used to move bread cars, store cars, and other traction vehicles. Wheel pairs of attached cars contribute to rubbing graphite and oil onto the side surface of the rail head immediately after applying the grease to the rail, preventing it from running off.

Fig. 1 shows the specific lateral wear of the rails (for 1 million tons of cargo) in the East Siberian Railway segment in 2016-2017. From the graph it can be seen that during the indicated period the specific wear has been exceeding the standard practically all the time.

Analysis of these data shows that, despite the high anti-friction properties of waste diesel oil (especially in combination with graphite), lubrication of rails with its help is ineffective. Most likely, this is due to the rapid run-off of grease from the rail due to insufficient viscosity and adhesion. In addition, the suspension of finely disintegrated graphite in oil is not stable, since graphite quickly settles to the bottom of the tank. Obviously due to these reasons, as well as some other ones (for example, weather conditions), the graph in Fig. 1 reflects the nonstationarity of wear in the wheel-rail system.

Therefore, the task of the study included the improvement of lubricant performance on the basis of the waste diesel oil and graphite. It was possible to achieve this, first of all, by introducing LMPE into the lubricant.

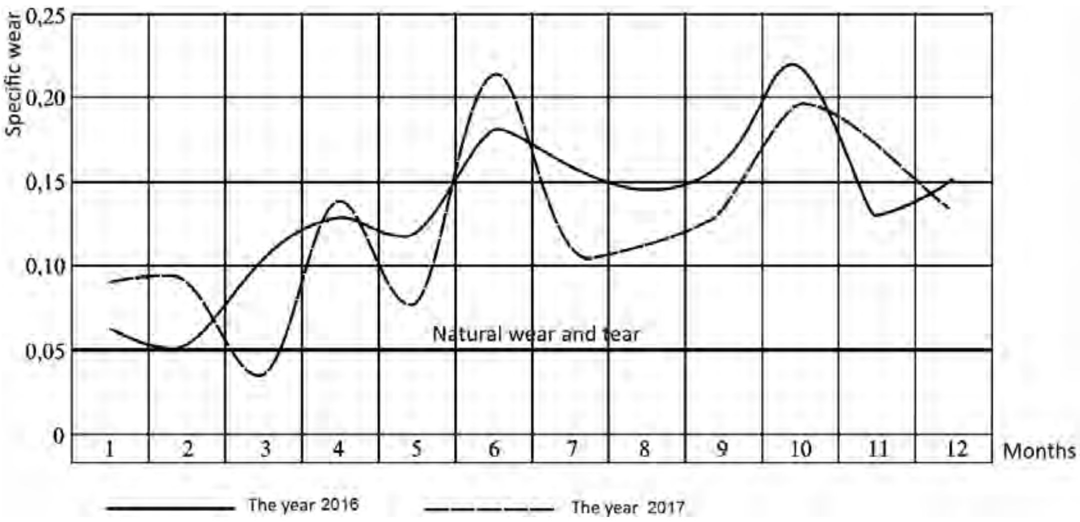

Fig. 1. Specific lateral wear of rails in the experimental area of the East Siberian Railway

II. THE USE OF LOW MOLECULAR POLYETHYLENE IN LUBRICATING COMPOSITIONS

To create lubricant compositions, we used LMPE produced at the plant for the production of high-pressure polyethylene of OAO Angarsk Petrochemical Company. In the company, this production waste has found practically no market, and it produces ≈ 40 tons/year. Such performance can fully meet the needs of the ESR and other nearby roads.

The characteristics of the used NMPA are given in Table II. For a more accurate determination of the structure of LMPE molecules, the IR spectrum of a polymer sample in a thin layer was obtained using an IFS25 instrument (Fig. 2). Analysis of the spectrum in the range of 2750 ÷ 3000 cm^{-1} allows us to conclude that there are no tertiary carbon atoms (> CH) in the structure of molecules [11], that is, the molecules are linear and have no branching. A slight absorption of 1645 cm^{-1} and 3080 cm^{-1} indicates the presence of double bonds in the molecule. Given the average molecular weight of 1500 units (Table II), it can be said that the molecules of LMPE contain more than 100 CH_2 fragments (molecular weight 1400). The presence of a double bond in such a large molecule should give a very weak absorption in the IR spectrum [11], which corresponds to reality. The weak absorption of 1730 cm^{-1} characterizes the presence of a small amount of carbonyl groups in the substance. A broad band of low intensity 3448.5 cm^{-1} indicates the presence of traces of water.

Thus, the analysis of the IR spectrum allows us to conclude that the LMPE molecules are linear and contain a small number of –CH = CH2 and> C = O groups. The linear structure suggests the presence of a structuring ability in LMPE, and these groups should facilitate the adsorption of molecules on the metal surface.

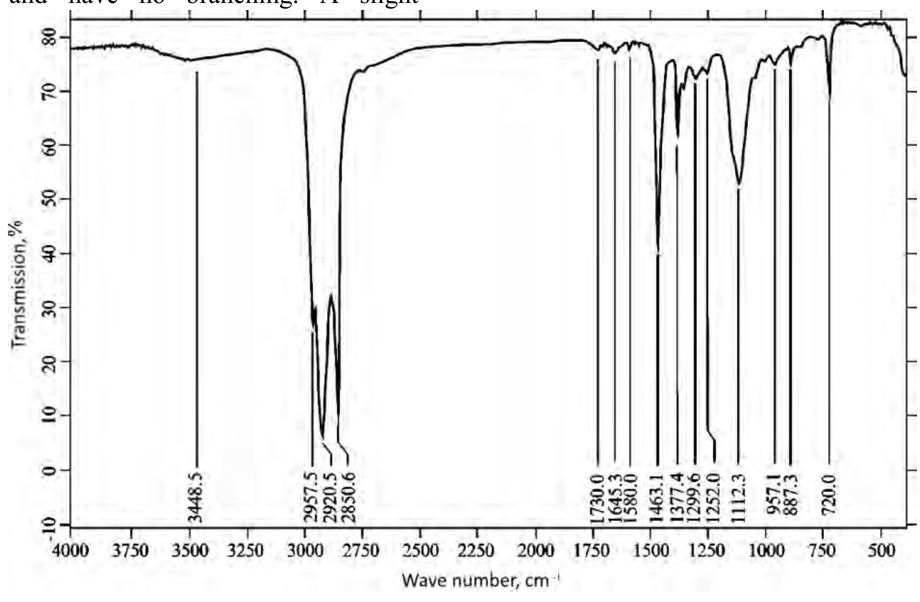

Fig. 2. Infrared spectrum of LMPE

TABLE II. PROPERTIES OF LMPE

Indicator	Value	Testing Method
1. Melting point, ^{0}C	in the range of 70 – 95	GOST 18995.4
2. Drop point, ^{0}C	78	GOST 6793
3. Dynamic viscosity at 140 ^{0}C Pa×s×10^{-3}	73	TU 6-05-1837
4. Flash point in an open cup, ^{0}C	257	GOST 4333
5. Molecular weight	≈1500	TU 6-05-1837
6. Ash content, mass %	<0.1	GOST 15973
7. Acid number, mg KOH/g of a product	<1	GOST 5734

LMPE is difficult to mix with used diesel oil at normal temperature (20 °C). For the preparation of lubricant compositions, LMPE was heated to 90 °C and poured into diesel oil heated to 70 - 80 °C. After cooling, the mixtures remained homogeneous, that is, no LMPE and diesel oil separation was observed at any of their ratios.

Fig. 3 (curve a) shows the dependence of the rate of runoff of diesel oil and its mixtures with LMPE on a rail steel vertical plate. Such simple experiment makes it possible to evaluate the ability of a lubricant to be held on a rail, taking into account both its viscosity and adhesive ability. The viscosity index alone cannot serve as a criterion for the retention of the colloidal lubrication system on the rail, since the characteristics of oils change under high loads [12], especially with regard to viscosity, which changes dramatically with the destruction of the colloidal structure [13]. For comparison, Fig. 3 (curve b) shows the dependence of the kinematic viscosity of mixtures on the composition. It can be seen from the figure that curve a) goes significantly steeper than curve b), that is, even small additives of LMPE significantly reduce the run-off of grease from the rail. This indicates that LMPE does indeed have structuring properties and increases adhesion of the lubricant to the metal. The introduction of finely divided graphite into the mixture of LMPE and waste diesel oil (WDO) allowed us to develop a new grease lubricant composition for lubrication of rails [14, 15].

The developed composition is characterized by the following formulation:

- graphite 5 ÷ 10% (weights);
- WDO 5 ÷ 15%;
- LMPE
- the rest up to 100%.

Tests of the compositions were carried out under semi-commercial conditions by manually applying lubricant to the side surface of the rail.

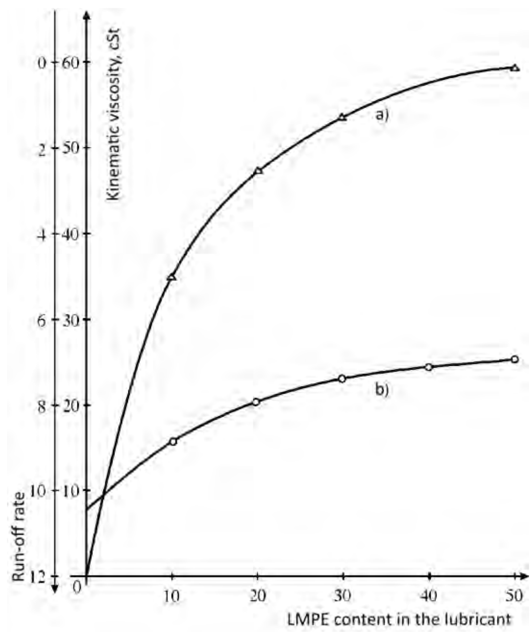

Fig. 3. Rate of grease run-off from the steel plate (a) and viscosity of the lubricant compositions (b)

Table III shows the state of the rail for the third lubricated picket using compositions of different formulation. When the trains were moving, the lubricant was spread to 4 and 5 non-lubricated pickets of the curve, and their inspection indicated a protective effect on these sections.

Lubrication tests were also carried out by applying it to the rail with a mobile rail lubricator. A lubricant containing 85% of LMPE, 7% of waste oil and 8% of graphite was used. Visual monitoring of the rail condition showed that the lubricant effectively protects the side surface of the rail from wear.

Fig. 4 presents a chart of observations of the rail state when a single lubricant is applied to one picket after 12 hours (≅ 3×10^3 wheels). The presented picture clearly shows the protective effect of the lubricant and its transfer by the wheels of the rolling stock.

TABLE III. THE TEST RESULTS OF THE LUBRICANT COMPOSITION OF DIFFERENT FORMULATION WHEN APPLIED TO THE RAIL MANUALLY WITH A BRUSH

No. of experiment	Composition formulation, % wt			Condition of rail after day (passage of 5×103 wheels)
	LMPE	*Waste Oil*	*Graphite*	
1	85	7	8	The rails are polished, with a black stripe on the side, no scuffing
2	90	5	5	–″–
3	80	10	10	–″–
4	90	4	6	The rails are polished, with a black stripe, small scuffings in some places. Lubrication was applied unevenly on the rail.
5	80	16	4	The black stripe is pale. Small scuffings
6	85	10	5	Rails are polished, with a black stripe, no scuffing

Lubrication tests were also carried out by applying it to the rail with a mobile rail lubricator. A lubricant containing 85% of LMPE, 7% of waste oil and 8% of graphite was used. Visual monitoring of the rail condition showed that the lubricant effectively protects the side surface of the rail from wear.

Fig. 4 presents a chart of observations of the rail state when a single lubricant is applied to one picket after 12 hours ($\cong 3\times10^3$ wheels). The presented picture clearly shows the protective effect of the lubricant and its transfer by the wheels of the rolling stock.

A more detailed study of this lubricating composition was not performed, because it contains an expensive component – graphite – in its composition. Therefore, further studies were carried out to replace graphite with a cheaper material – petroleum coke.

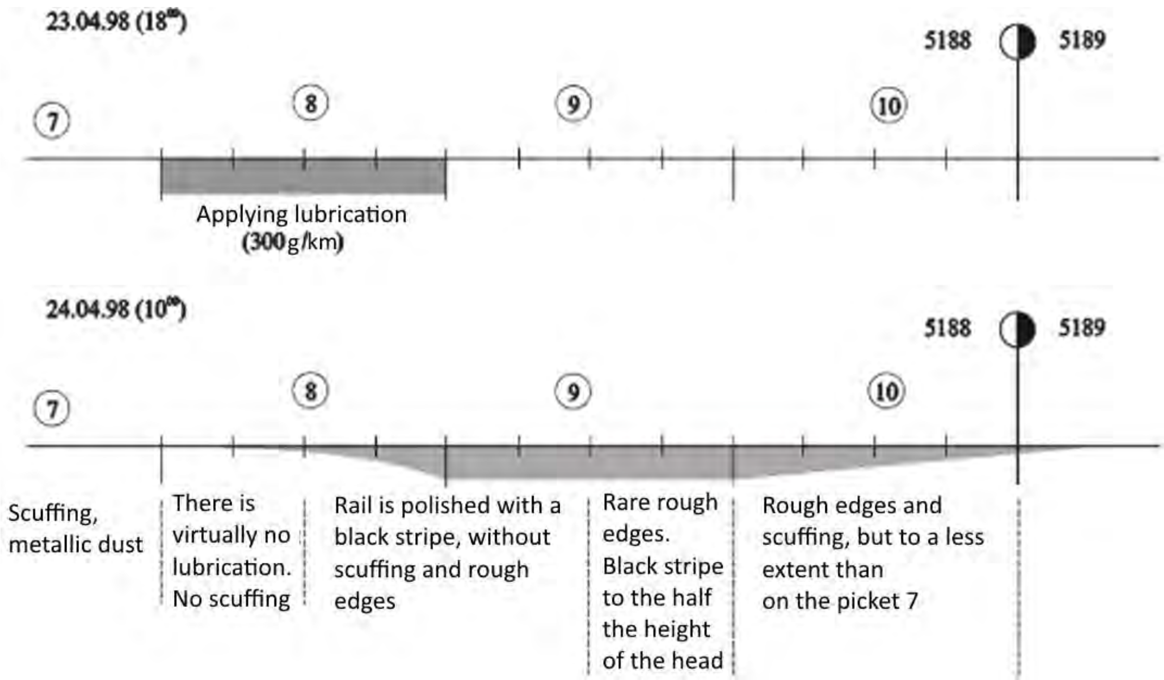

Fig. 4. Observation chart. The curvilinear section begins with the 6th picket.

III. CONCLUSION

The resulting composition is a uniform black grease. It is easily applied to the rails (both stationary and mobile rail lubricators can be used here), does not flow from the side surface of the rail head, is well spread by the wheels of the rolling stock, which ensures its uniform distribution along the side surface of the rail head. As already mentioned, it is based on production waste, and the expensive component, graphite, contains no more than 10%. According to the data of [10], over 15% of graphite was added to the testing of diesel oil, although in many cases this did not take the desired effect (see Fig. 1).

This composition is not corrosive by nature. It is harmless to humans and the environment. The viscosity of such composition is easily adjusted according to weather conditions by changing the ratio of LMPE and diesel oil. Tests of the compositions were carried out in semi-commercial conditions by manually applying lubricant to the side surface of the rail.

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