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Determination of the Optimal Concentration of Polymer Thickener for Production of Plastic Lubricants Based on Secondary Raw Materials

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Abstract

The article substantiates the effect of the concentration of polymer thickener on such basic properties of the plastic lubricant as dripping temperature ($t_{d.p.}$, °C) and adhesive properties (ADG). It was defined that, unlike ($t_{d.p.}$, °C), the ADG indicator is more informative for defining the optimal concentration of the polymer thickener in plastic lubricants produced from secondary raw materials. Determination of the ADG indicator was performed in a laboratory centrifuge, based on the amount of plastic lubricant that remained on the metal plate after the study. This amount should be at the level of 50 % of the initial value. Experimental studies have shown that the optimal concentration in the composition of the lubricant is: in the case of HDPE, 5.0 % for SAE15W-40 oil, 4.3 % for SAE 75W-90 oil, 6.3 % for BP Energol CS68 and HLP-46 oil ; in the case of LDPE, this concentration is equal to 7.0 % for SAE15W-40 oil, 5.2 % for SAE 75W-90 oil, 7.4 % for BP Energol CS68 and HLP-46 oil; in the case of PP, this concentration is equal to 7.5 % for SAE15W-40 oil, 6.2 % for SAE 75W-90 oil, 8.0 % for BP Energol CS68 and HLP-46 oil.

Keywords: *Plastic lubricant; Thickener; Polymer; Optimal concentration; Secondary raw materials; Base oil; Adhesive properties; Centrifuge.*

1. Introduction

Plastic lubricants are petroleum products able to perform their functions (lubrication, accumulation of impurities, removal of excess heat, protection against corrosion) under complex (specific) operating conditions. These conditions include: adhesion to vertical metal surfaces, extremely high temperatures and pressures, resistance to external forces. Specific properties of lubricants are provided by their structure and composition. Plastic lubricants contain base oil (at least 70 % mass, thickener (5.0-15.0 %), filler (up to 10 %) and additives (0.1-5.0 %). Besides, thickener plays a very important role in the composition of plastic lubricants as it forms the spatial structure of the lubricant which determines its consistency and affordable temperature ranges. The thickener is also able to increase the water resistance of the lubricant and its resistance to the aggressive environment. The concentration of the thickener defines the value of these quality indicators and, as a result, terms of exploitation of lubricants. It should also be noted that the duration of technological operations and energy consumption in the production of plastic lubricants depends on the concentration of the thickener which ultimately affects the cost price of plastic lubricant as a final product. Therefore, choosing the optimal concentration of the thickener is an important task that must be solved at the stage of developing formulations of plastic lubricants and taken into account during production design.

2. Aim and scope of the research

Determining of the optimal concentration of thickener in the composition of plastic lubricants is based on "optimization criterion" - the value of a quantitative indicator or ratio that characterizes the extremum of the target function of the system [1].

Using the information given in the technical literature, it has been noted that with an increase of the concentration of polymer thickener (k, % mass) improves some properties of the plastic lubricant which is proved by increasing of values of its quality indicators [2]. However, it is obvious that when $k \rightarrow \infty$ the plastic lubricant loses its properties and acquires the properties of a polymer, which will definitely be reflected in the values of the quality indicators of the plastic lubricant. In some cases, the change in properties is positive. For example, the effective dynamic viscosity of the lubricant changes, its consistency, it goes from the class of very liquid to the class of semi-solid and even solid lubricants, the upper limit of the temperature range of the use of plastic lubricant increases [3-4]. At the same time, there will be a deterioration of adhesive properties, which are among the main properties that ensure the reliable operation of plastic lubricants in units of units, for example, bearings [5-6].

In the recent research it is increasingly suggested to use polymer thickeners in the composition of plastic lubricants [7-9]. It should be noted that adhesive properties of such thickeners will depend on the presence of polar groups (the more these groups the polymer contains and the greater their dipole moments, the higher its adhesive properties are) [10]. In addition to the presence of functional groups, the adhesive properties of polymers are influenced by molecular weight and molecular structure. For example, increase of the molecular weight of the polymer is followed by increase of cohesion and decrease of adhesion [11]. When the concentration of the polymer exceeds a certain value (extreme concentration), a rapid deterioration of adhesive properties will occur in the plastic lubricant.

When determining the quality indicators of plastic lubricants for the target function of the system, in our opinion, it will be most appropriate to choose those that directly determine the conditions of use of the plastic lubricant, namely the temperature and speed range.

Then, the objective function of the system can take the following form:

$$t_{d.p.} = f(k) \quad (1)$$

$$ADG = f(k) \quad (2)$$

where $t_{d.p.}$ – dripping temperature of plastic lubricant, °C; ADG – adhesion properties of plastic lubricant which value depends on the testing method.

In graphic form, taking into account the selected indicators of the quality of plastic lubricant, the target function of the system can be presented in the form shown in Figures 1–2.

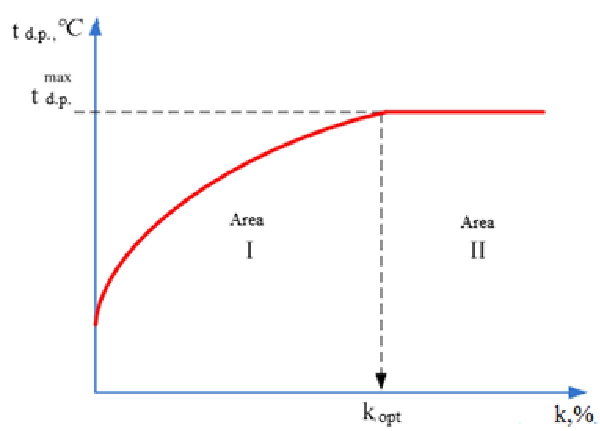

Figure 1. Graphic representation of the target function

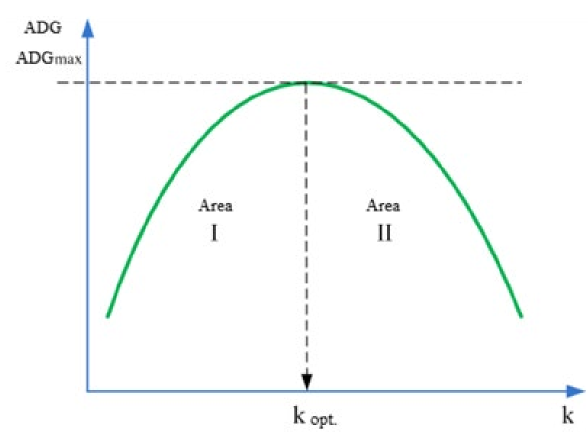

Figure 2. Graphic representation of the area of optimal values for the target function

For the target function, Area I characterizes the raise of $t_{d.p.}$ with the raise of k. The value of $t_{d.p}$ raises up until a certain value of $t_{d.p.}^{max}$ which is determined by melting point of the polymer thickener. Further increase of k value does not affect the value of $t_{d.p.}$ (Area II). Therefore, the maximum value of k which corresponds to the maximum value of $t_{d.p.}$, can be considered the optimal value ($k_{opt.}$).

A slightly different picture is observed for the function. Thus, in Area I, an increase of ADG value is followed by increase of k until a certain value of ADG_{max} is reached. This area characterizes the change in the consistency of the plastic lubricant from class 000 (very thin) to class 3 (semi-solid) or 4 (solid) according to the NLGI classification.

In Area II increase of k value defines changing of the hardness of plastic lubricant to class 5 (very hard) or even 6 (especially hard). At the same time, decrease of the number of molecules of the dispersion area which form an adsorption layer on the surface of the particles of the polymer thickener defines the deterioration of adhesive properties of plastic lubricant deteriorate significantly. Therefore, the value k, which corresponds to the value of ADG_{max}, can be considered the extremum of the function and the optimal value (k_{opt}).

Then, based on the above information, the range of optimal values for the function will be limited to the minimum allowable values of $t_{d.p.}$ and ADG (see Fig. 3).

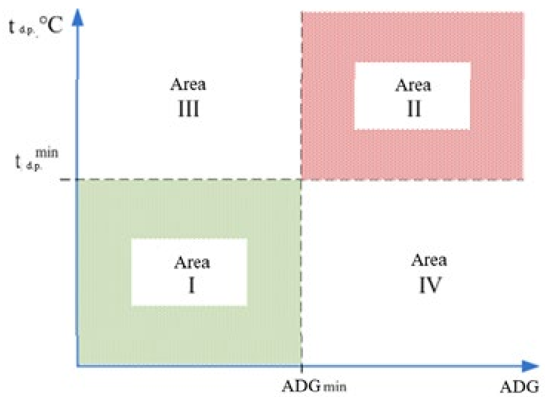

Figure 3. Graphic representation of the area of optimal values of the target function $t_{d.p.}$ = f (ADG)

The values of $t_{d.p.}^{min}$ and ADG_{min} for each type of plastic lubricant are set individually, depending on the conditions of its use.

Area I is characterized by unsatisfactory operational properties and may correspond to plastic lubricants produced with violation of the technological regulations of production, i.e. non-conditioned products subject to processing or disposal.

Area II can be considered the region of optimal values, which corresponds to universal plastic lubricants, which, due to their high operational properties, can be used in a sufficiently wide range of operating conditions (for example, antifriction lubricants).

Areas III and IV correspond to special types of plastic lubricants, which, due to the coloring of one of their properties, find a very limited application in specific conditions (for example, preservation, railway and cable).

To determine the optimal concentration of a polymer thickener in a plastic lubricant graphs of the functions: "effective dynamic viscosity - concentration of thickener", "penetration - concentration of thickener", "slip temperature - concentration of thickener" can also be used.

The appearance of the target function when determining the region of optimal values (see Fig. 3) may change depending on the selected quality indicators that will characterize the ability of the plastic lubricant to perform its functions in the specific conditions of its use.

3. Materials and methods

As materials for research, plastic lubricants obtained from secondary raw materials were chosen. Nowadays lubricants produced in a such way are considered the most promising in terms of energy saving [12], minimizing of the negative impact of waste on the environment [13] and prevention of man-made disasters [14]. Used lubricating oils (industrial BP Energol CS68, hydraulic HLP-46, motor SAE15W-40, transmission SAE 75W-90) were the dispersion medium of such lubricants, and the thickener was crushed solid secondary polyethylene (HDPE, LDPE) and polypropylene (PP).

4. Results and their discussion

Using our proposed method of determining the adhesive properties of plastic lubricants using a centrifuge [15], the value of ADG was defined by the value of the critical rotation speed

ω_{cr} at which A=50 % (the amount of plastic lubricant that remained on the metal plate comparing to the initial value). The obtained results were represented as graphs of function ω_{cr}=f(k) that allows to define the optimal concentration of the thickener for each group of base oil (see Figures 4–6).

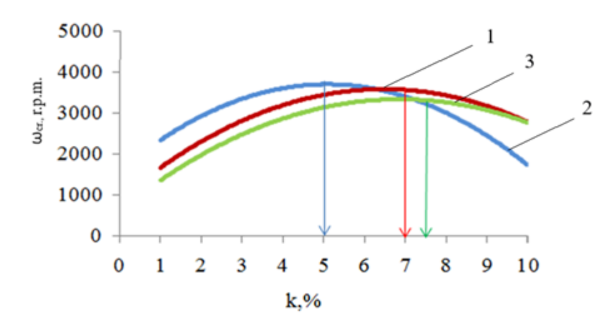

Figure 4. Affect of the value of k on the $\omega_{cr.}$ for lubricants based on SAE15W-40: 1 – HDPE; 2 – LDPE; 3 – PP.

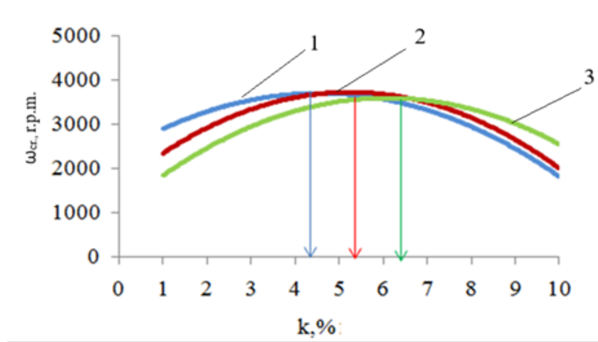

Figure 5. Affect of the value of k on the $\omega_{cr.}$ for lubricants based on SAE 75W-90: 1 – HDPE; 2 – LDPE; 3 – PP

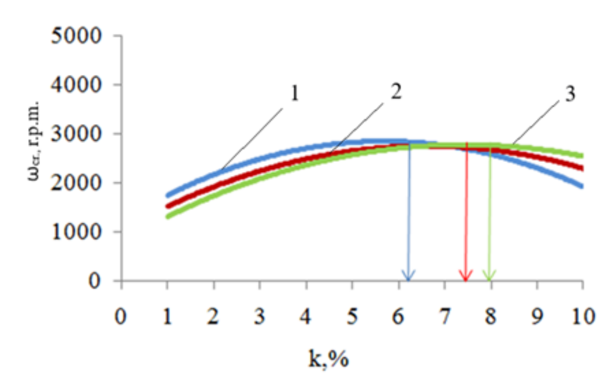

Figure 6. Affect of the value of k on the $\omega_{cr.}$ for lubricants based on BP Energol CS68 and HLP-46: 1 – HDPE; 2 – LDPE; 3 – PP

The provided research showed that with an increase in the value of k, there is an increase in the value of ADG, expressed in $\omega_{cr.}$, to a certain maximum value. Further, when k increases, the value of ADG decreases, which indicates the deterioration of the adhesive properties of the plastic lubricant.

Therefore, the value of ADG at which ωcr reaches its maximum value, is the extremum point of the function ω_{cr}=f(k), and therefore the function ADG=f(k). In this case, the value k corresponding to it can be considered the optimal value for the considered range of values.

It should be mentioned that the optimal value of k depends on the viscosity of the base oil and the ability of the polymer to retain it in the composition of the plastic lubricant. Plastic lubricants based on BP Energol CS68 and HLP-46 oils, given the fairly close values of kinematic viscosity, which cause the complete identity of the obtained dependencies, are presented on one graph (see Fig. 6).

The optimal values of k for plastic lubricants that are based on different motor oils are calculated using the data presented on Figs. 4-6 are listed in Table 1.

Table 1. Optimal values of k, for different components of plastic lubricants

Base oil	Value of k, % for each type of polymer		
	HDPE	LDPE	PP
SAE15W-40	5,0	7,0	7,5
SAE 75W-90	4,3	5,2	6,2
BP Energol CS68 and HLP-46	6,3	7,4	8,0

5. Conclusions

The results of the conducted research indicate that when preparing the formulations of plastic lubricants at the design stage of their production, the concentration of the polymer thickener can be calculated using such an indicator as the adhesive properties of the plastic lubricant (ADG). An increase in the concentration of polymer thickener in the composition of the lubricant beyond a certain optimal value leads to the fact that the lubricant acquires some polymer properties and loses the properties of a plastic lubricant – the ability to hold on vertical surfaces under the influence of external forces, which is expressed in values (ADG).

Using the method of determining the ADG of the lubricant using a laboratory centrifuge, it was established that the optimal concentration in the composition of the HDPE lubricant is: 5.0 % for SAE15W-40 oil, 4.3 % for SAE 75W-90 oil, 6.3 % for BP oil Energol CS68 and HLP-46; in the case of LDPE, this concentration is equal to 7.0 % for SAE15W-40 oil, 5.2 % for SAE 75W-90 oil, 7.4 % for BP Energol CS68 and HLP-46 oil; in the case of PP, this concentration is equal to 7.5 % for SAE15W-40 oil, 6.2 % for SAE 75W-90 oil, 8.0 % for BP Energol CS68 and HLP-46 oil.

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