STUDY OF TANGENTIAL STICKINESS FORCE OF MIXTURES BASED ON ORGANIC SAPROPEL

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Abstract. Traditional methods of using organic sapropel in agriculture are energy-intensive and require adaptation to modern climatic and economic conditions. The specific characteristics of organic sapropel deposits ensure a moisture content in the range of 92…98%. Therefore, attention should be focused on identifying methods for application of organic sapropel at its natural deposit moisture content without dehydration. To enable mechanized application of sapropel with this moisture content to soil, it is advisable to mix it with organic sorbents. Such organic sorbents include chopped straw from cereal crops, wood sawdust, and similar materials. For the local strip application of a mixture based on sapropel with its natural moisture content during the planting of agricultural crops, we developed a design and manufactured a prototype machine. When justifying the design parameters and operating modes of such machine, the values of the tangential stickiness force of the described mixtures are required. To determine the values of the specific tangential stickiness force and the tangential stickiness coefficient of sapropel-based mixtures, a device for studying shear force, equipped with an electronic displacement indicator, was used. The stickiness force was studied for mixtures of organic sapropel with wood sawdust, chopped flax straw, and winter wheat straw. The sapropel content in the mixtures was varied from 85 to 91%. Stainless steel, reinforced rubber, and polypropylene were used as sliding surfaces. The results of the study showed that the highest tangential stickiness coefficient was observed for the reinforced rubber sliding surface for all mixture variants. The maximum average value of this coefficient, 0.083, was obtained for a mixture with chopped wheat straw at a sapropel content of 91%. The maximum average value of the specific tangential stickiness force, 545 Pa, was obtained for the mixture with wood sawdust on the polypropylene friction surface.

Keywords: sapropel, chopped straw, wood sawdust, mixture, stickiness.

Introduction

Analysis of long-term studies on the use of sapropel as an organic fertilizer confirms its positive effect on soil fertility and crop yields [1-3]. A specific feature of organic sapropel deposits is the high natural moisture content, ranging from 92 to 98%. Therefore, most known methods of using organic sapropel as a fertilizer involve its dewatering to a moisture content of about 60% [4–6]. Dewatering sapropel to this level is associated with significant energy and financial costs, which in turn increases the cost of fertilizers produced on its basis [7].

It is also well known that, in modern agriculture, achieving high crop yields is largely limited by climate change in general and catastrophic depletion of soil moisture reserves in particular. In this context, it should be noted that sapropel consists of three main components: organic matter, mineral matter, and water [8]. The water contained in sapropel can potentially be used for plant water supply.

Previous studies have demonstrated the use of briquettes made from sapropel-flax fibre mixtures to provide plant water nutrition in cases where irrigation is problematic, such as in greenhouses or other enclosed facilities [9]. Experimental research has also confirmed the feasibility of creating a nutrient moisture-retaining layer from mixtures based on organic sapropel, capable of accumulating moisture and releasing it to surrounding soil layers and plants under field conditions when required [10].

These results indicate the expediency of searching for ways to use organic sapropel at its natural deposit moisture content without prior dewatering. To ensure the mechanized application of sapropel with such high moisture content into the soil, it is advisable to mix it with organic sorbents. Such organic sorbents may include chopped cereal straw, flax shives, sawdust, and similar materials.

To substantiate the parameters of machines that enable the implementation of mechanized technologies for applying such sapropel-based mixtures, it is necessary to know their physical and mechanical properties. Numerous studies have been conducted on the properties of sapropel and sapropel-based composites. These studies have determined the mechanical and electrical properties [11;12], plasticity and viscosity [13;14], as well as the coefficients of friction and stickiness of sapropel [15;16]. The thermal conductivity, tensile and compressive strength of composites made from hemp shives and sapropel have also been investigated [17;18].

For localized strip application of a mixture based on sapropel at natural moisture content, followed by planting (sowing) of agricultural crops, a machine design was developed and a prototype was manufactured by the authors [10]. When substantiating the design parameters and operating modes of the dosing beater of such machine, it is necessary to determine the values of the tangential stickiness force of the described mixtures, which have not been previously investigated.

Therefore, the objective of this study was to determine the parameters characterizing the tangential stickiness force of sapropel mixtures with organic sorbents at different moisture contents.

Materials and methods

The tangential force arising on the surface of the working elements used for applying a sapropel-based mixture is determined by the following equation [10]:

$$F_a = sp_0 + pN\,, \tag{1}$$

where s – contact area between the particle of organic fertilizer and the surface of the blade, m^2;
p_0 – specific tangential stickiness force that arises in the absence of normal reaction of the supporting surface, Pa;
p – coefficient accounting for the specific tangential stickiness force arising in the presence of normal reaction of the supporting surface.

For the practical application of equation (1), an experimental determination of the specific tangential stickiness force and the tangential stickiness coefficient was carried out [19;20].

The studies were conducted using a modernized PSG-3M apparatus (Fig. 1). The main component of this device is the working box (5), which consists of two parts: an upper movable part (13) and a lower fixed part (14). The internal cavity of the working box has a cylindrical shape with a diameter of d = 70 mm and was filled with the investigated mixture (16).

A sliding surface specimen (15) was placed on top of the lower part of the working box (14), along which the shear displacement of the tested mixture was performed. The normal load applied to the specimen was generated by weights placed on the platform of the lower loading suspension (10). The force was transmitted to the material specimen through a two-stage pulley (9) with a radius ratio of 1:10, a loading frame (6), and a perforated punch (12).

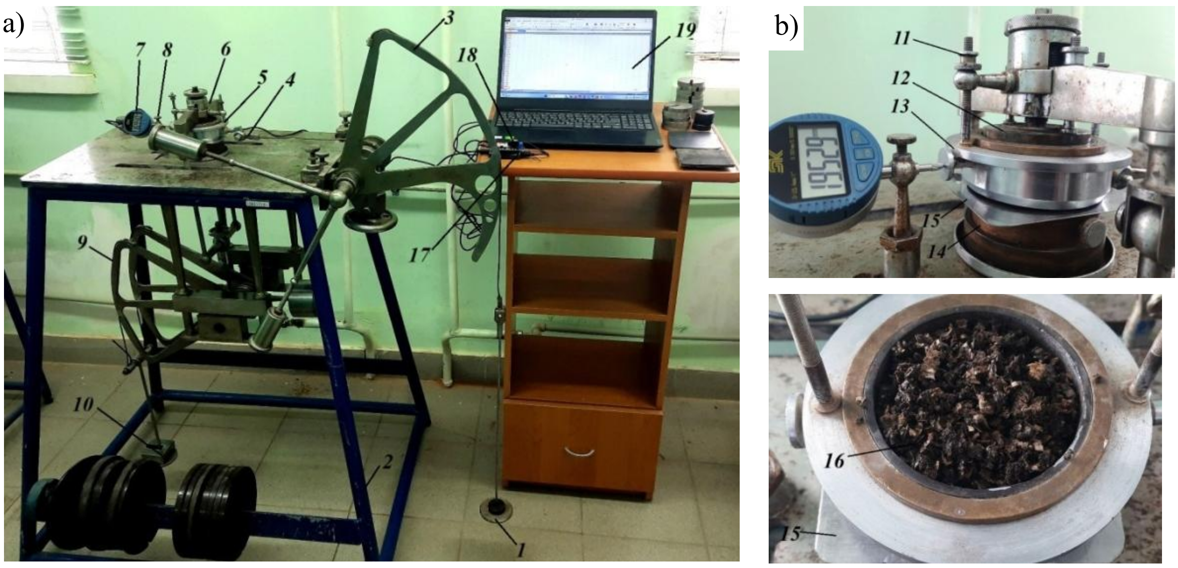

Fig. 1. **General view of the laboratory setup based on the PSG-3M apparatus (a) and the working box (b):** 1 – side loading suspension; 2 – frame; 3, 9 – pulley; 4 – traction rod; 5 – working box; 6 – loading frame; 7 – displacement indicator; 8 – bracket; 10 – lower loading suspension; 11 –adjusting nuts; 12 – perforated punch; 13, 14 – upper movable and lower part of the working box; 15 – sliding surface sample; 16 – investigated mixture; 17 – signal converter; 18 – time relay; 19 – PC

The shearing force was applied by means of a traction rod (4), a two-stage pulley (3) with a stage radius ratio of 1:10, and a side loading suspension (1). To ensure shear of the mixture in the plane of its contact with the sliding surface sample (15), a clearance of 0.5–1.0 mm was created between them. For this purpose, the upper part of the working box (13) was raised using two adjusting nuts (11). The shear displacement of the upper part of the working box (13) was recorded using a displacement indicator (7) mounted in a bracket (8). The working box (6) together with the force-application mechanisms was installed on a special frame (2).

To record the magnitude of the shear displacement of the upper part of the working box (13) in real time, the apparatus was equipped with an electronic displacement indicator (7), a signal converter (17), and a time relay (18). Owing to this configuration, displacement values were recorded on a personal computer (19) in a Microsoft Excel spreadsheet at a frequency of 3 s^{-1}.

Stickiness characteristics were determined for mixtures of sapropel with chopped winter wheat straw (initial moisture content 13.6%), wood sawdust (initial moisture content 10.5%), and chopped flax straw (initial moisture content 11.8%). The mixtures contained organic sapropel with a moisture content of 92.2%, extracted from Lake Burkiv, Volyn region. The sapropel content in the mixtures was 85%, 87%, 89%, and 91%. The mixtures were prepared by manual mixing using a spatula. Prior to the experiments, the moisture content of the prepared mixtures was determined using the drying method.

As sliding surfaces, stainless steel, polypropylene, and reinforced rubber were investigated. The experiments were carried out under three levels of normal load: 30 N, 45 N, and 60 N. Each load was applied to a new sample of the investigated mixture. For each value of normal load, the experiment was performed with three repetitions.

The experimental procedure was implemented as follows. A sample of the sliding surface was placed in the lower movable part of the working box, while the upper part was filled with a sample of the sapropel-based mixture. After that, a punch was installed on top of the sample and the normal load N was applied. A predetermined clearance was set between the upper part of the working box and the sliding surface sample. The digital displacement indicator was fixed in the bracket so that its probe rested against the rod of the upper part of the working box, and the indicator readings were within the range of 18-22 mm.

Subsequently, the first step of the shear force was applied (the magnitude of each load step was approximately 5% of the normal load), and the displacement of the upper working box was recorded on a personal computer for 120 s. After that, the sample was unloaded, and the average sliding velocity of the upper part of the working box was calculated on the PC. If the sliding velocity was less than 0.5 $mm \cdot s^{-1}$, an additional load corresponding to the specified increment was placed on the platform of the side loading suspension.

The experiment at a given normal load was considered complete when the average sliding velocity of the upper part of the working box was equal to or greater than 0.5 $mm \cdot s^{-1}$. The total weight of the loads on the platform of the side loading suspension at this moment was considered the limiting tangential stickiness force F_a.

Subsequently, a linear approximation of the experimentally obtained values of the limiting tangential stickiness force F_a corresponding to the applied normal load N was performed. From the resulting linear equation, the stickiness coefficient p was determined as the slope of the straight line. The specific limiting tangential stickiness force p_0 was calculated by dividing the value of the intercept of the equation by the contact area s between the mixture and the sliding surface (the base area of the internal cavity of the upper part of the working box).

Results and discussion

As a result of determining the moisture content of the mixtures, average values were obtained and are presented in the form of a histogram in Fig. 2. The results indicate that the influence of differences in the initial moisture content of the organic sorbents on the moisture content of the mixture lies within the experimental error and therefore is not significant.

Based on the average values of the stickiness coefficient p and the specific limiting tangential stickiness force p_0 obtained from the experiment, graphical dependencies were constructed (Fig. 3-5).

Fig. 2. **Histogram of the average moisture content *W* of the mixtures at sapropel contents *C***

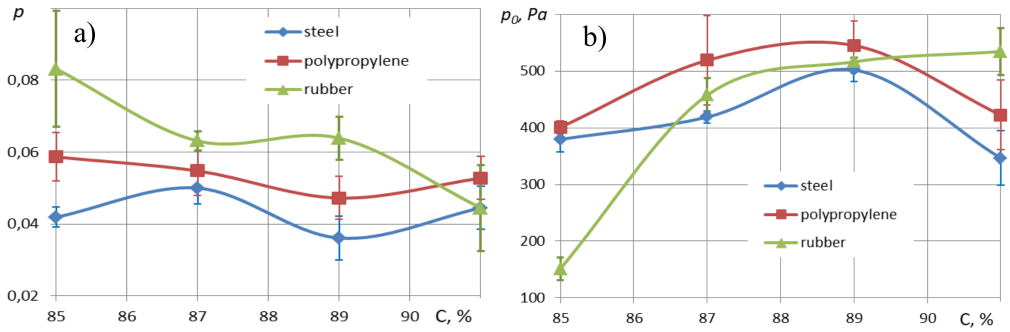

Fig. 3. **Dependence of the tangential stickiness coefficient of the sapropel–wood sawdust mixture *p* (a) and the specific tangential stickiness force p_0 (b) on the sapropel content *C***

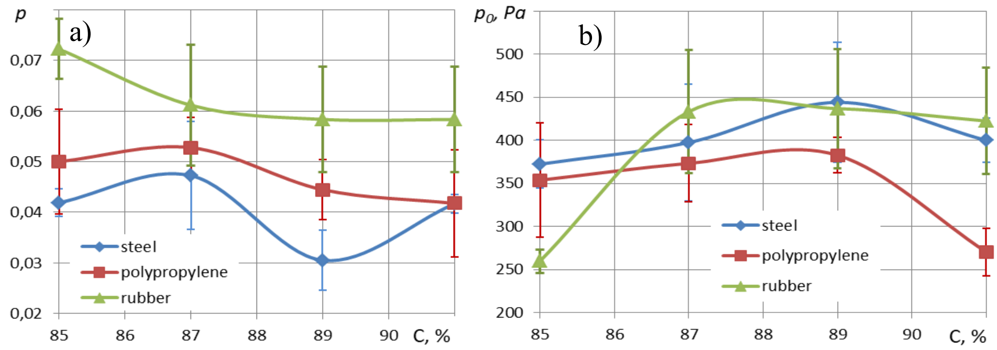

Fig. 4. **Dependence of the tangential stickiness coefficient of the sapropel–chopped flax straw mixture *p* (a) and the specific tangential stickiness force p_0 (b) on the sapropel content *C***

Analysis of the obtained results shows that the reinforced rubber sliding surface is characterized by the highest tangential stickiness coefficient *p* for all mixture variants. The maximum average value of this coefficient $p = 0.083$ was obtained for the mixture with chopped wheat straw at a sapropel content of $C = 91\%$. At the same time, the highest values of the specific tangential stickiness force p_0 were obtained for mixtures based on wood sawdust and chopped wheat straw when using a polypropylene sliding surface. The maximum average value of this parameter $p_0 = 545$ Pa, was also recorded at a sapropel content of $C = 91\%$. With the sapropel content *C* of 85% to 89% in most test variants, minimum values of *p* and p_0 were found for sliding surfaces made of steel and polypropylene.

Therefore, given the cost of parts made of stainless steel, the working bodies of agricultural machines for applying the studied mixtures should be made of polypropylene. And to form a nutritious moisture-retaining layer with the maximum content of sapropel (moisture), it is rational to use mixtures with the content $C = 89\%$.

The dependence of the tangential stickiness coefficient *p* and the specific tangential stickiness force p_0 on the sapropel content *C* in all experimental variants exhibits a nearly linear form. For example, a linear approximation of the experimental values of the tangential stickiness coefficient *p* and specific tangential stickiness force p_0 of a mixture of sapropel with chopped straw for a sliding surface made of reinforced rubber provides the values of the coefficient of determination $R^2 = 0.6794$ and $R^2 = 0.7775$, respectively. Also, the maximum values of the standard deviation of the experimental values of p and p_0 of the mixture of sapropel with chopped straw for the sliding surface of polypropylene $\sigma = 0.0096$ and $\sigma = 57.3183$ Pa, respectively, were obtained. This indicates a significant dispersion of the experimental data.

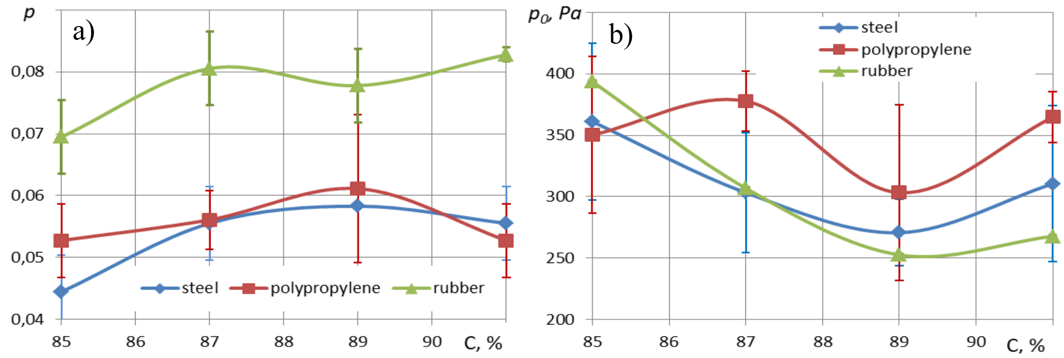

Fig. 5. **Dependence of the tangential stickiness coefficient of the sapropel–chopped wheat straw mixture *p* (a) and the specific tangential stickiness force p_0 (b) on the sapropel content *C***

Under such conditions, it is advisable to use the average maximum values of the stickiness parameters of sapropel-based mixtures in theoretical calculations, regardless of their variation within the investigated range of the sapropel content *C*.

Conclusions

The efficiency of using organic sapropel with natural moisture content can be increased by mixing it with available organic sorbents. Such sorbents may include chopped straw of cereal crops and flax, wood sawdust, etc. The study of the moisture content of sapropel mixtures with the indicated sorbents showed that the initial moisture content of the sorbent does not have a significant effect on the moisture content of the mixture. When the sapropel content in the mixture ranges from 85% to 91% at a sapropel moisture of 92%, the moisture content of the mixture varies within the range of 79% to 85%.

The highest tangential stickiness coefficient p was observed for the reinforced rubber sliding surface for all investigated mixture variants. The maximum average value of this coefficient, $p = 0.083$, was obtained for the mixture with chopped wheat straw at a sapropel content of $C = 91\%$.

At the same time, the highest values of the specific tangential stickiness force p_0 were obtained for mixtures based on wood sawdust and chopped wheat straw when using a polypropylene sliding surface. The maximum average value of this parameter, $p_0 = 545$ Pa, was also recorded at a sapropel content of $C = 91\%$. Since the dependence of the tangential stickiness coefficient p and the specific tangential stickiness force p_0 on the sapropel content C in all experimental variants has a nearly linear form, it is advisable to use the average maximum values of the stickiness parameters of sapropel-based mixtures in theoretical calculations.

To reduce stickiness on the working bodies of agricultural machines when applying the investigated mixtures, it is recommended to manufacture these working surfaces from polypropylene. In this case, the sapropel content in the mixtures should not exceed 89%.

Author contributions

Conceptualization, I.Ts.; methodology, I.Ts., S.Kh and T.Ts.; software, I.Ts. and V.H; validation, I.Ts. and T.Ts.; investigation, I.Ts., T.Ts. and S.Kh; data curation, V.H. and I.Ts.; writing – original draft preparation, I.Ts.; writing – review and editing, I.Ts. and V.H.; visualization, T.Ts. and S.Kh. All authors have read and agreed to the published version of the manuscript.

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