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Study of the process of purifying potassium humate suspension from suspended particles using industrial centrifuges

A.O. Shkop[1], N.G. Ponomarova[1], A.S. Bosiuk[1,*] and O.V. Shestopalov[1]

[1]National Technical University “Kharkiv Polytechnic Institute”, 2, Kyrpychova St., 61002 Kharkiv, Ukraine

Abstract

Potassium humate suspensions obtained by alkaline extraction of peat using cavitation dispersion contain suspended solid particles that require effective separation to improve product quality. The separation of suspended solid particles larger than 20 μm is particularly important to ensure product purity. The main objectives of the study were to determine the possibility of removing suspended solid particles from potassium humate suspension and to evaluate the efficiency of the separation process on a laboratory and industrial scale. Laboratory tests included sedimentation under the action of Earth's gravity for two months, centrifugation in a laboratory cup centrifuge at different speeds, and analysis of solid content, particle size distribution, pH, and conditional viscosity. Industrial tests were carried out on an Ecomash SHS 311 centrifuge in both batch and continuous modes at different rotor speeds and flow rates. The purified product (fuga) was analysed by sieving through 20 and 40 μm sieves and measuring viscosity. Laboratory sedimentation showed the formation of a compact sediment layer, confirming the presence of suspended solids. Industrial tests demonstrated effective removal of suspended solids at a separation factor (Fr) ≥ 1550, with no visually detectable particles larger than 20 μm in the filtrate. Viscosity measurements correlated well with suspended solids content and were proposed as a rapid control method. Centrifugation effectively removes suspended solids from potassium humate suspensions in both laboratory and industrial conditions. The separation factor significantly affects the efficiency of purification. For operational quality control, sieving in combination with viscosity measurement is recommended. Further laboratory studies are needed to establish the dependence of viscosity on solids content and temperature to improve process control.

Keywords: potassium humate, suspension separation, centrifugal clarification, industrial centrifugation, suspended solids removal, sedimentation efficiency.

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[*]Corresponding author. Email: bosuyk0614@ukr.net

1. Introduction

Potassium humate is a water-soluble salt of humic acid derived from natural sources such as peat, lignite, or leonardite. It is widely used in agriculture as a plant growth stimulant, soil conditioner, and in environmental technologies due to its high cation-exchange capacity and complexing ability with heavy metals and nutrients. The production of potassium humate typically involves alkaline extraction of humic substances from organic raw materials, often enhanced by physical methods such as cavitation or ultrasonic treatment to improve yield and solubility characteristics [1, 2]. Industrial approaches to obtaining potassium humates have been confirmed by studies [3, 4], which ensure high extraction efficiency.

The efficiency of potassium humate as a functional product largely depends on its physicochemical purity, particularly the removal of suspended solid particles that remain after extraction. These particles can negatively affect the product’s application, especially in foliar sprays or fertigation systems where clogging of nozzles is a concern. Therefore, the development of effective methods for separating suspended solids from potassium humate suspensions is a critical step in ensuring product quality and stability [5].

Despite the growing interest in potassium humate applications, there remains a need for detailed studies of separation processes at both laboratory and industrial scales. In particular, centrifugation has shown promise as a reliable and scalable method for clarifying humate suspensions, but optimal process parameters and their influence on final product quality require further investigation.

In addition to its agronomic advantages, recent studies have demonstrated the effectiveness of potassium humate in the processes of water purification from dyes and organic pollutants, in particular due to the ability of humic substances to form stable adsorption complexes with cationic dyes [6]. This opens up additional prospects for its use in water treatment systems, especially when using natural and inexpensive adsorbents.

Other authors also note the positive effect of humic substances on reducing the toxicity of heavy metals in the aquatic environment, increasing the bioavailability of nutrients for microorganisms and plants, and stabilising colloidal systems [7, 8]. This demonstrates the versatility of humates as a technological agent in ecological systems.

Recent studies also emphasise the importance of the surface characteristics of humic structures and their sorption capacity for various ions, which affects the effectiveness of both agronomic application and water purification [9, 10].

The effectiveness of coagulation and centrifugation for the purification of organic suspensions has also been proven [11].

Thus, research aimed at improving methods for the purification and stabilisation of potassium humate products is not only of practical importance but also has interdisciplinary significance.

2. Objective and Research Tasks

This study aims to evaluate and optimize the process of separating suspended solid particles from potassium humate suspension under laboratory and industrial conditions using centrifugal technologies.

To achieve this goal, the following tasks must be accomplished:

- determine the feasibility of removing suspended solid particles from potassium humate suspension using centrifugal separation methods;
- assess the effectiveness of separating suspended solids larger than 40 µm from the suspension;
- conduct laboratory-scale analysis to characterize the sedimentation behavior, particle size distribution, and viscosity of the suspension before and after treatment;
- perform industrial-scale trials under both batch and continuous operating modes to identify optimal centrifugation parameters and ensure high-quality clarification of the humate suspension.

3. Research Tasks

Effective separation and dehydration of suspensions is a pressing challenge in chemical and environmental engineering. The centrifugation methods described in [12, 13] demonstrate their applicability for the separation of particles in aqueous suspensions.

In particular, potassium humate suspensions-formed via alkaline extraction and cavitation-assisted dispersion of peat-contain significant quantities of suspended solids that negatively impact their quality and applicability, especially in agricultural and fertigation technologies. Removal of particles larger than 40 µm ensures product clarity and prevents operational issues like nozzle clogging [14].

Similar technological challenges have been extensively studied by Shkop et al. [14] in the context of coal-enrichment sludge treatment. It was demonstrated that sedimentation centrifuges equipped with cylindrical–biconical rotors can achieve 85–93% retention of solid particles up to 3 mm, producing dewatered sediments with moisture contents between 17–25%. The authors also identified strong dependencies between sediment moisture, particle size distribution, and centrifuge capacity.

A complementary study [15, 16] further confirms that centrifugal dewatering efficiency is a function of volumetric capacity, feed characteristics, and separation factor. These findings underscore crucial parallels between coal-sludge treatment and potassium humate processing, particularly in optimizing centrifugation parameters to maximize solid–liquid separation efficiency. Centrifuge performance indicators such as speed, sediment moisture content and solid phase content, as described in [3], are critical for process optimisation.

In order to preliminarily assess the effectiveness of solid particle separation during centrifugation, the theoretical prerequisites for sedimentation were analysed. For systems with particles characterised by small sizes (less than 100 µm), Stokes' law can be applied, which describes the sedimentation velocity of a particle in a viscous medium:

$$v_s = \frac{2}{9} \cdot \frac{(\rho_p - \rho_f)}{\mu} \cdot g \cdot R^2 \tag{1}$$

where v_s – particle settling velocity (m/s); g – acceleration of free fall (m/s^2); ρ_p – particle density (kg/m^3); ρ_f – liquid density (kg/m3); µ – dynamic viscosity of a liquid; R – particle radius.

During centrifugation, linear acceleration is replaced by centrifugal acceleration:

$$g_{ef} = w^2 \cdot R \tag{2}$$

where w – angular velocity of the rotor; R – distance to the axis of rotation.

Therefore, the separation efficiency increases proportionally to the increase in w^2. This principle forms the basis for scaling the centrifugation process, according to which the separation time t is inversely proportional to the centrifugal acceleration:

$$t \sim \frac{1}{w^2} \qquad (3)$$

In this regard, when selecting modes for experiments, separation factor values were used that ensured maximum centrifugal acceleration without exceeding technological limitations on sediment moisture content.

The present study leverages these established methodologies to address the specific case of potassium humate suspensions. Through combined laboratory and industrial trials, it investigates the feasibility of separating suspended solids larger than 40 µm, evaluates the cleanliness of obtained fugate, and explores the influence of centrifugation regimes on suspension clarity and viscosity control.

4. Materials and methods

For the study, a potassium humate suspension (Fig. 1) from one of the existing production facilities was used, which was obtained by diluting peat with water, dispersing the resulting suspension using a cavitator, and adding alkali to extract humic acids into water.

The suspension was centrifuged to assess the efficiency of removing insoluble particles both in laboratory conditions, using a laboratory beaker centrifuge with variable speed modes, and in industrial conditions, using an Ecomash SHS 311 unit operating in batch and continuous modes. Measuring cylinders were used to quantitatively determine the volume of the formed sediment.

Figure 1. Potassium humate suspension samples: Sample No. 1 – potassium humate sample settled in a gravitational field for 2 months; Sample No. 2 – freshly obtained potassium humate sample.

During laboratory tests, the following indicators of the initial suspension and the resulting slurry were determined:

- solid phase content in the form of suspended insoluble particles by filtering the suspension through filter paper with a pore size of 5 µm;
- the granulometric composition of the solid phase by wet sieving of a sample of potassium humate suspension on vibrating screens with cell sizes of 20, 40, 63, 100, 200, 300, 500 and 630 microns;
- dry residue was determined by evaporation of the suspension at a temperature of 105˚C.

The suspension was subjected to centrifugation to assess removal efficiency of insoluble particles. Industrial research was conducted on the Ecomash SHS 311 centrifuge in batch and continuous modes.

Tests in batch mode were carried out according to the scheme shown in Fig. 2.

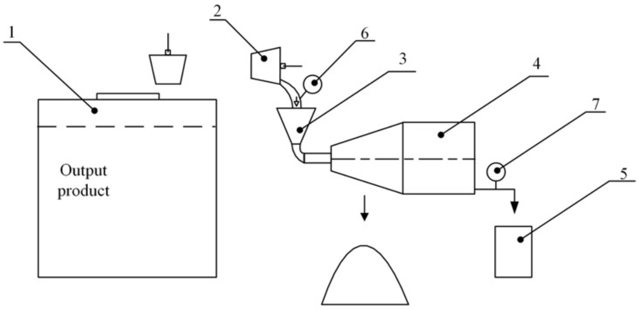

Figure 2. Scheme of industrial tests for the separation of potassium humate suspension in batch mode: 1 – container with initial suspension; 2 – 12-litre bucket; 3 – funnel; 4 – Ecomash SHS 311 centrifuge; 5 – container for collecting the filtrate; 6 – feed sample; 7 – fugate sample.

Figure 2 shows a flow chart of industrial tests for the separation of potassium humate suspension in batch mode. The initial suspension (1) with a volume of 11 litres was manually fed into the funnel (3) using a bucket (2), through which it entered the Ecomash SHS 311 centrifuge (4). After the centrifugation stage was completed, the purified liquid (fuga) flowed by gravity into a collection container (5). Before feeding the suspension into the unit, a feed sample (6) was taken, and after the process, a fuga sample (7) was taken. The procedure was repeated in several cycles to ensure the representativeness of the results. The suspension feed rate was approximately 0.4 l/s, and the duration of each cycle was 30 seconds.

The efficiency of the phase separation process in a centrifuge depends on the centrifugal acceleration created, which is determined by the so-called separation (fugal) coefficient.

The test was conducted in two modes:

- rotor speed 2450 rpm (Fr=1033), relative screw speed 4 rpm;
- rotor speed 3500 rpm (Fr=2109), relative screw speed 6.7 rpm.

The technological scheme for conducting tests in continuous mode is shown in Fig. 3.

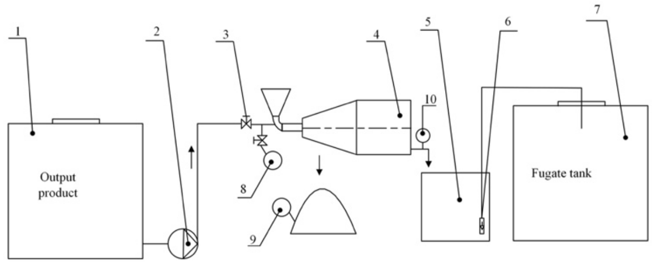

Figure 3. Scheme for conducting industrial tests of potassium humate suspension separation in continuous (flow) mode: 1 – initial suspension tank; 2 – feed pump; 3 – ball valve; 4 – Ecomash SHS 311 centrifugal unit; 5 – filtrate collection tank; 6 – filtrate pump; 7 – filtrate collector; 8 – feed sample; 9 – sediment sample (cake); 10 – filtrate sample.

The initial suspension from the tank (item 1) was continuously fed by a pump (item 2) through a ball valve (item 3) to the Ecomash SHS 311 centrifuge (item 4) at a stable flow rate of 600 l/h. The dewatered filtrate was drained by gravity to a collection tank (item 5), from where it was pumped (item 6) to a storage tank (item 7). Feed samples (item 8) were taken directly from the pipeline before entering the centrifuge, filtrate samples (item 10) were taken after draining the purified liquid, and sediment samples (item 9) were taken from the rotor after dewatering.

5. Results and discussion

5.1 Results of laboratory testing of potassium humate suspension samples

The potassium humate suspension sample (Fig. 1) appears as an opaque liquid that does not clarify during settling. After prolonged settling, a 5 mm layer of compacted sediment is observed at the bottom of the cylinder, indicating the presence of insoluble suspended particles.

The sieve composition of suspended substances in 1 litre of potassium humate suspension is presented in Table 1.

Table 1. Sieve composition of suspended substances

Particle size, mm	Particle mass, g	Share of particles, %
≥ 0,63	0,00	0,00
0,5…0,63	0,01	
0,3…0,5	0,05	0,45
0,2…0,3	0,15	
0,1…0,2	0,75	1,56
0,063…0,1	0,65	1,35
0,04…0,063	1	2,08
0,02…0,04	2,2	4,58
≤0,02	43,19	89,98
∑	48	100

The analysis of the table shows that 90% of solid insoluble particles in the suspension are less than 20 microns in size, with a total amount of 48 g in 1 litre of suspension. Such particles do not settle in the suspension during settling, so the possibility of their precipitation in a laboratory centrifuge was investigated.

The results of the precipitation of solid insoluble particles of the suspension in a laboratory beaker centrifuge are presented in Table 2.

Table 2. Separation of the suspension by different separation factors (Fr)

Separation factor	Volumetric output of fugate, %	Volume of wet sludge output, %
990	85	15
2286	79	21

Analysis of the data in Table 2 shows that increasing the rotation speed of the laboratory centrifuge rotor from Fr = 990 to Fr = 2286 leads to an increase in the sediment volume from 15.0 ± 0.5% to 21. 0 ± 0.7% of the total suspension volume, which indicates a slight intensification of the process with a significant increase in the separation factor. This indicates a decrease in the efficiency of the increase with a further increase in centrifugal acceleration, which may be associated with a limitation in the sedimentation rate of the smallest particles. According to Stokes' equation, the sedimentation rate of particles is directly proportional to the centrifugal factor, but when a certain particle size limit is reached (less than 5–10 μm), fluid resistance becomes dominant, and further growth of Fr has limited effectiveness. Thus, it is advisable to choose Fr values of ≈ 1500–1600, which provide an acceptable level of separation with minimal energy consumption.

The determination of the dry residue content when drying the sample and fugates per 1 litre of suspension is presented in Table 3.

Table 3. Dry residue content in 1 litre of potassium humate suspension

No	Product name	Weight of 1 litre of suspension, g	Dry residue, g
1	Initial suspension	1062,3-1062,7	122
2	Fugate laboratory beaker centrifuge with a separation factor of Fr=990	1053,6	98
3	Fugate laboratory beaker centrifuge unit with a separation factor of Fr=2286	1053,5	97,5

The hydrogen index of the fugates was pH = 11.8.

The fugates obtained in a laboratory centrifuge and the initial suspension were mixed with water in a ratio of 1000 ml of water to 2 ml of sample. During visual inspection of the diluted samples, it can be seen that there are suspended solid phase particles in the initial feed, but no particles are visible in the centrifuge filtrate.

5.2 Industrial testing of the process of separating potassium humate suspension on the Ecomash SHS 311 centrifuge

The results of testing the centrifuge in batch mode (Fig. 2) and in continuous mode (Fig. 3) are shown in Table 4.

Table 4. Results of the industrial experiment

No	Product name	Weight 1 l, g	Dry residue, g	Sediment moisture content, %
1	Initial suspension (centrifuge feed)	1062,3-1062,7	122	–
2	Fugate centrifuge Ecomash SHS 311 with a separation factor Fr=1033 and relative screw speed of 4 rpm (periodic mode)	1045	93,5	–
3	Fugate centrifuge Ecomash SHS 311 with a separation factor Fr= 1550 and relative screw speed of 4 rpm (continuous mode)	1057,7	105,5	68,7-69,5
4	Fugate centrifuge Ecomash SHS 311 with a separation factor Fr= 2109 and relative screw speed of 6.7 rpm (periodic mode)	1056,25	97…99,5	–

The analysis of the results shows that in continuous mode, 16.5 g of solid particles are removed from each litre of suspension. Taking into account the data in Table 1, the centrifuge in continuous mode retains approximately one third of the insoluble particles, namely all particles larger than 20 µm, as well as 6.5 g of particles smaller than 20 µm.

The fugate from the Ecomash SHS 311 centrifuge, obtained under different centrifugation modes, was poured through 40 and 20 µm control sieves (Table 5).

Table 5. Amount of solid phase retained by 20 and 40 µm sieves when pouring 1 litre of the fugate from the Ecomash SHS 311 centrifuge

Sieve size, µm	Solid content in the feed, g	Solid phase content in grout, g		
		Fugue in periodic mode Fr=1033	Continuous mode fugate Fr=1550	Fugue in periodic mode Fr=2109
40	5,44	0,15	0,00	0,00
20	4,58	0,1	0,00	0,00

The fugates obtained in the Ecomash SHS 311 centrifuge and the initial feed were mixed with water in a ratio of 1000 ml of water to 2 ml of sample. During visual inspection of the diluted samples, it can be seen that the initial feed contains suspended solids. In the centrifuge's fougate, at a separation factor of 1033, there are isolated particles of suspended solids. No particles of suspended solids were detected in the centrifuge's fougate at a separation factor of 1550 and above with the naked eye.

6. Conclusions

Research has shown that potassium humate suspension contains approximately 48 g/l of solid insoluble particles, of which up to 40% can be removed by centrifugation in batch mode and up to 35% in continuous mode using the Ecomash SHS 311 unit. Centrifuging the suspension at a rate of 600 l/h with a separation factor of Fr ≈ 1550 ensures complete removal of particles larger than 20 μm from the filtrate.

The proposed continuous centrifuge unit of the OGSh-311L-03-UHL4 type with an approximate capacity of 0.6–1 m³/hour and a separation factor of at least Fr = 1500 is technologically feasible for the preliminary purification of potassium humate suspension from suspended solids.

Economic efficiency can be manifested in reduced wear and clogging of nozzles and filtration equipment, which reduces the cost of repair and maintenance of technological systems. The prospect of process automation will increase the stability and reproducibility of cleaning results, as well as reduce the need for operator intervention, while large-scale implementation involves adapting the installation to existing production lines with the appropriate selection of parameters (flow rate, Fr, temperature), which opens up the potential for integration into closed water treatment cycles in chemical production.

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