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SUBSTANTIATION OF ELECTRIC FIELD IMPACT USE ON THE PROCESS OF MOISTURE SEPARATION FROM POROUS WASTE STRUCTURES

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ABSTRACT

During the study, information was collected and analyzed on the possibility of an electroosmotic device production - the converter of colloidal polydisperse systems into capillary-porous by electroosmotic dehydration in order to reduce the residual moisture of sewage sludge and pulp and paper industry wastes. Exponents were taken as the models expressing the mass of waste, as the function of drying time and electric current. According to the obtained determination coefficients, they concluded that the models corresponded to the initial experimental data, the use of exponential models were justified for further optimization of colloidal polydisperse system conversion into capillary porous ones.

Disciplinary: Waste Engineering.

1. INTRODUCTION

The purpose of the study is to collect and analyze information on the possibility of an electroosmotic device production - the converter of colloidal polydisperse systems into capillary-porous systems by electroosmotic dehydration in order to reduce the residual moisture of sewage sludge and pulp and paper industry wastes. The analysis of technological innovation production possibility increase in the field of environmental safety of industrial enterprise improvement, the study of insulation material production possibility using dehydrated waste as a raw material (The concept of long-term socio-economic development of the Russian Federation for the period until 2020, 2009). The relevance of the study is confirmed by the urgent need of modern industrial enterprises in innovative approaches to the issue of environmental friendliness of production. In addition, high-quality indicators of imported products create a competitive environment for developing domestic enterprises. The solution to this situation may be an active

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introduction of modern technologies into domestic production.

During various technological processes, a significant amount of wet waste and residues is generated. At the enterprises of the pulp and paper industry (PPI) a large amount of waste is formed. Waste is a large-tonnage, environmentally friendly waste of wastewater treatment plants of the paper industry, which is a composite material containing environmentally friendly components of the raw mix for paper production (The list of priority areas for the development of science, technology, and machinery of the Russian Federation, 2011).

2. METHODOLOGY

Wet waste is a colloidal polydisperse system. However, with decreasing humidity, wet waste takes on the typical properties of capillary-porous materials. For further energy-efficient disposal of wet waste, they considered the possibility of a model production for colloidal polydisperse system conversion into capillary-porous systems, necessary for pressing and electrodynamic separation of moisture from waste structures.

The essence of the model for colloidal polydisperse system conversion into capillary-porous ones for the purpose of further electroosmotic dehydration is to achieve the maximum energy-efficient effect of the dehydration process. Figure 1 schematically shows an optimized device of an electroosmotic installation for debugging a technological process of waste paper production dehydration, where ① is a housing made of insulating material; ② - movable electrode; ③ - fixed electrode with perforation; ④ - top cover with thread for screw ⑤, which creates (regulates) the initial pressure (by torque wrench) for waste compression ⑥. An electric voltage (electric current) is supplied to the electrodes ② and ③ through the wires ⑦ and ⑧, which provides the necessary electric field strength, which causes the effects of particle velocity variation, ⑨ - perforation in the housing around the entire perimeter, which ensures additional convection dehydration after completion of the electroosmosis process during the electrode ② lifting, ⑩ - an external regulator of the housing inclination angle, providing convection dehydration of the lower layers of the mass after completion of the electroosmosis process,⑪- insulation sump for separated moisture collection.

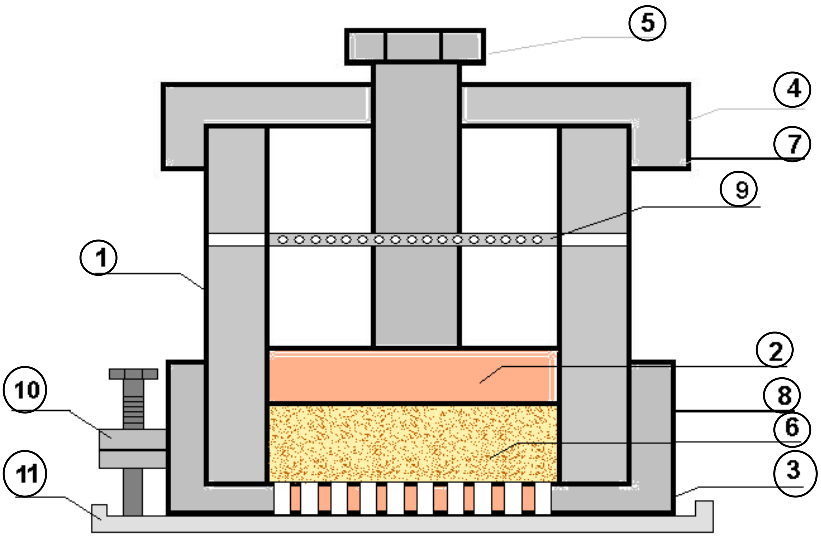

Figure 1: Laboratory electroosmotic device.

The abovementioned technical solution allows to carry out most energy-efficient electroosmotic dehydration process as compared to the state of technology, since by varying direct and alternating current with an output voltage of, for example, 8, 16, 24 V and an output current of a voltage source of

20 A, the effect of Joule heat generation is achieved (the data on thermal energy released during dehydration is given in Table 1), which promotes dehydration without additional energy costs (Pegat, 2009).

Table 1: The energy released in waste during the action of osmosis

t^{*},h	0	0.08	0.16	0.25	0.33	0.42	
W_{0},W	0	3.919	6.96223	9.5808	11.3588	12.888	
$t^{*},ч$	0.5	0.58	0.66	0.75	0.83	0.91	1
W_{0},W	13.9274	14.7340	15.360	15.8993	16.265	16.5494	16.7939

Thus, the technical solution contributes to the additional separation of moisture under the action of gravity and partial convection drying, thanks to the perforated cathode and the device casing.

To increase water loss and improve the energy efficiency of the system, you can change the structure of the waste solid phase. This seems possible to achieve in several ways: by coagulating the waste with various chemicals, flocculation, or the introduction of certain filler materials, thermal conditioning (a sharp change in temperature - freezing or thawing), as well as by magnetic or electromagnetic processing. The result of these methods is a significant enlargement of waste particles, and the average surface area of the dispersed phase and dispersion medium decrease. Thus, the average surface energy decreases and the bonding forces of moisture with solid particles are weakened significantly. The redistribution of types (forms) of moisture bonding is actively carried out, while the content of "free water" increases due to the total amount of "bound" decrease. Moreover, all the above methods are quite expensive (Dudyshev et al., 2006; Rasouli et al., 2019; Santana et al., 2017).

The research results show that a significant amount of liquid can be removed from the waste volume by the electroosmosis method without resorting to the use of coagulants and at the same time the energy consumption can be less than during thermal drying use. They determined after a series of experiments, that the method of electroosmosis removes moisture from wet waste quite effectively.

According to the analysis, the electrokinetic phenomenon of moisture transfer through the pore space of capillary-porous media, caused by an external electric field superimposed on the diaphragm, was one of the first observed by Professor F.F. Reis, which he called "water-driving power." Subsequently, this phenomenon was called "electroosmosis", which means the movement of a fluid relative to the solid skeleton of a porous material under the influence of an electric field in the direction determined by the sign of the electrokinetic potential (Kholudeneva et al., 2016; Rahideh & Mazloum, 2019). When they implement the process of electroosmosis, the difference in phase charges leads to the movement of mobile counterions in a constant electric field together with the liquid phase to the corresponding pole of the current source. The electroosmotic transfer of fluid through the pore space of a capillary-porous body is determined by the electrokinetic potential and the structure of the double electric layer at the phase interface

The linear electroosmotic velocity of the fluid V_l is determined by

$$V_l = V_g + \frac{I\xi\varsigma}{4\pi^2\eta\chi r^2} \qquad (1),$$

and volumetric electroosmotic fluid velocity V_o will be

$$V_o = \frac{I\xi\varsigma}{4\pi\eta\chi}, \qquad (2),$$

where

V_g – hydrostatic speed;

I – current strength;

ξ – dielectric conductivity;

χ – the electrical conductivity of the liquid;

η – liquid viscosity;

r – capillary radius;

ς – electrokinetic potential (Kholudeneva, 2016).

The earliest known model of the double electric layer structure, which made it possible to explain not only the fact of electrokinetic phenomenon existence but also to quantify the value of the capacitance of the double electric layer, was proposed by Helmholtz (Kholudeneva, 2016; Hosseinzadeh et al., 2019).

When they apply technological innovation in the form of dehydration of paper production wastes, the final result is achieved, which is not only the production of unique products - insulation but also the achievement of environmental and social effect: more than 2000 m3 of waste does not enter the soil (the data only for Penza paper factories with average power indicators), thus, the negative impact on the human body caused by rotting and decomposition of waste is reduced (Kholudeneva & Ryzhakov, 2016).

The results of experiments on the study of electroosmosis, identified on the developed installation, are presented in Table 2, reflect the process of mass reduction m_j (Fig. 2) and the process of current reduction i_j (Figure 3).

Table 2: Experimental data on the study of electroosmosis.

t_j	0	0.16	0.33	0.5	0.66	0.83	1
m_j	70	48	38	35	32	29	27
i_j	2.5	1.63	1.21	0.8	0.53	0.31	0.09

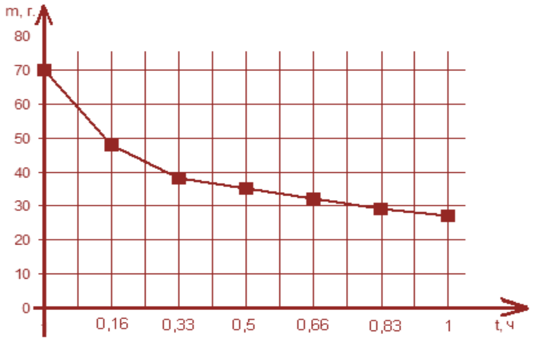

Figure 2: Experimental graph of weight loss during electroosmotic dehydration of waste.

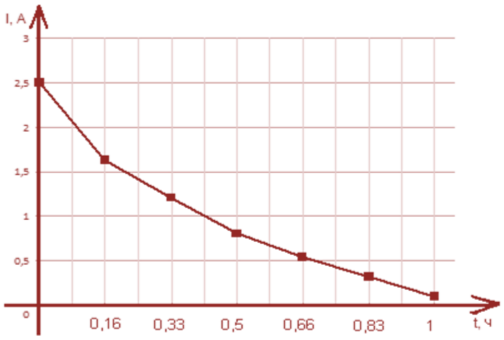

Figure 3: Experimental graph of current decrease during dehydration (drying)

From these data it follows that one can take the following exponents as the models expressing the mass of the waste, as the function of drying time and the value of electric current (under certain initial conditions): to change the mass of waste

$$m(t_j) = m_0 \cdot e^{-\frac{t_j}{\tau_m}}, \qquad (3)$$

where m_0 - the initial value of the waste mass loaded into the device,

τ_m - the time constant of waste mass reduction

t_j - the time point of mass control $t_j \in \{0; t_1; \ldots t_m\}$,

and for the current change

$$i(t_j) = I_0 \cdot e^{-\frac{t_j}{\tau_i}} \qquad (4),$$

where I_0 - the initial value of the electric current flowing through the waste,

τ_i - the time constant of the current reduction process at $U = const$ on the plates (electrodes) of the device.

As observations have shown, the waste dries to a certain extent by convective means during restart and in the process of the electroosmosis effect control. This loss was excluded in the processing of experimental data and in the further study of electroosmosis. This allowed us to assess the relationship between the electric current flowing through the waste and the decrease of its mass caused by electroosmosis more accurately.

In order to avoid the influence of waste initial mass fluctuations, which occur when the unit is loaded, we pass from the subject scales of mass *m(t)* and current *i(t)* to universal $\delta_m(t)$ and $\delta_i(t)$, following the formulas:

$$\delta_m(t_j) = \frac{m_{oc}(t_j)}{m_o} = e^{-\frac{t}{\tau_m}} \qquad (5),$$

$$\delta_i(t_j) = \frac{i_{oc}(t_j)}{I_o} = e^{-\frac{t}{\tau_i}} \qquad (6)$$

The data of Table 3 is presented in units of universal scales.

Table 3. Experimental data on the study of electroosmosis in universal scales

$j_ч$	0	0.16	0.33	0.5	0.66	0.83	1
$\delta_m(t_j)$	1	0.69	0.54	0.5	0.46	0.41	0.39
$\delta_i(t_j)$	1	0.65	0.48	0.32	0.12	0.09	0.03

The main parameters in the model (5) and (6) are time constants τ_m and τ_i. To evaluate them, we linearize the model by a logarithm

$$\ln \delta_m(t_j) \cdot \tau_m = -t_j \qquad (7);$$

$$\ln \delta_i(t_j) \cdot \tau_i = -t_j \qquad (8)$$

and use the well-known least-squares method (LSM) rules.

Then, taking into account (7) and (8), the sum of squares (S^2) for *m* and *i* can be written as

$$S_m^2 = \sum (t_j - \ln \delta_m(t_j) \cdot \tau_m)^2 \qquad (9),$$

$$S_i^2 = \sum (t_j - \ln \delta_i(t_j) \cdot \tau_i)^2 \qquad (10),$$

where $t_j, \delta_m(t_j), \delta_i(t_j)$ - the experiment data.

$$\frac{\partial S_m^2}{\partial \tau_m} = \sum_{j=0}^{n} \left[t_j + \ln \delta_m(t_j) \cdot \tau_m \right] \cdot \ln \delta_m(t_j) = 0 \qquad (11),$$

$$\frac{\partial S_i^2}{\partial \tau_i} = \sum_{j=0}^{n} \left[t_j + \ln \tilde{\delta}_i(t_j) \cdot \tau_i \right] \cdot \ln \tilde{\delta}_i(t_j) = 0 \qquad (12).$$

After simple transformations we get

$$\tau_m = \frac{\sum_{j=0}^{n} (t_j \cdot \ln \delta_m(t_j))}{\sum_{j=0}^{n} (\ln \delta_m(t_j))^2} \qquad (13),$$

$$\tau_i = \frac{\sum_{j=0}^{n} (t_j \cdot \ln \delta_i(t_j))}{\sum_{j=0}^{n} (\ln \delta_i(t_j))^2} \qquad (14).$$

According to the experiment results, it turns out that:

τ_m^* =0.856 h.; $\tau_i^* = 0{,}323$ h.

Here we check the correspondence of the models to the initial experimental statistics by evaluation the determination coefficients.

$$n_{\tilde{\delta}_m} = \sqrt{1 - \frac{\sum_i (\delta_m(t_j) - \bar{\delta}_m\ (t_j))^2}{\sum_i (\delta_m(t_j) - \tilde{\delta}_m\ (t_j))^2}} \qquad (15);$$

$$n_{\tilde{\delta}_i} = \sqrt{1 - \frac{\sum_i (\delta_i(t_j) - \bar{\delta}_i(t_j))^2}{\sum_i (\delta_i(t_j) - \tilde{\delta}_i(t_j))^2}} \qquad (16);$$

$n_{\tilde{\delta}_m} = 0{,}905$; $n_{\tilde{\delta}_i} = 0{,}764$.

According to the obtained determination coefficients, we can conclude that the models correspond to the initial experimental data.

From Figures (2) and (3), it follows that $m(t)$ and $i(t)$ are partially interconnected, and to a large extent have differences according to the calculation data (2.4 times). This is the evidence that another factor also affects the drying process of electroosmosis: it is likely that the effect of Joule heat accumulated in the waste makes its influence. This process is specific and requires additional studies, which will be carried out in a separate article.

It follows that the parameters of the models can vary. The latter will be implemented by varying the electric field on the device electrodes, but this fact is the detailing of the technological process implementation.

The results of individual experiments show that the electroosmosis drying mode and electrophoresis mode can be represented by exponents, but these exponents have different time constants.

It should be noted that the processes of electroosmosis and electrophoresis can take place in the experimental dosage of waste at the same time: with the residual volume (mass) of water and the technological dosage of the binder (liquid glass).

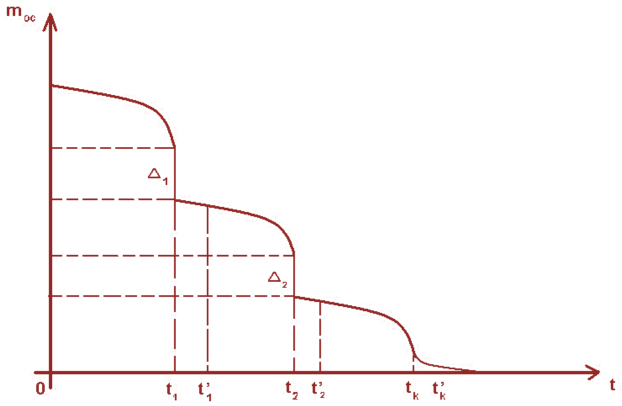

Figure 4: The results of experiments of waste drying with electroosmosis and electrophoresis, taking into account the loss of waste mass upon reboot

As indirect measurements have shown, the essence of the method is the following: $\Delta_1, \Delta_2, \ldots$ - - the “loss” of waste mass during the reboot in the process of the effect of electroosmosis control, i.e. in this case, the waste dries to a certain extent by convective means. This loss must be excluded from the study of electroosmosis. This procedure will make it possible to assess more accurately the correlation between the electric current flowing through the waste and the "loss" of its mass caused by electroosmosis.

After the conversion (deduction of mass loss $\Delta_1, \Delta_2, \ldots$) the graph takes the following form:

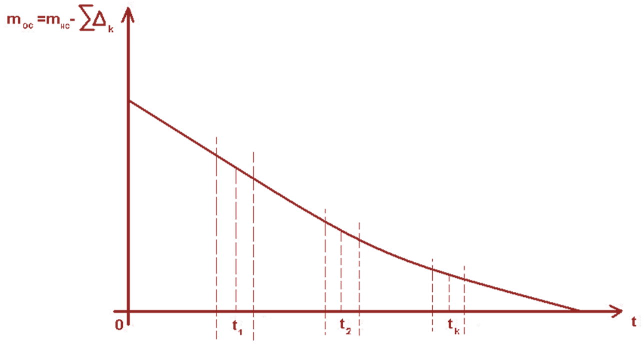

Figure 5: The results of waste drying experiments with electroosmosis and electrophoresis, taking into account the loss of waste mass during reboot after conversion.

$$m(\bar{t}_1) = \frac{m(t_1) + m(t'_1)}{2}$$

$$m(\bar{t}_2) = \frac{m(t_2) + m(t'_2)}{2}$$

$$\ldots \qquad (17).$$

According to (17), the model parameter is estimated. Let’s take the exponent $m_{oc}(t) = m_{oc}^{e^{-\frac{t}{\tau}}}(t_0)$ or $\delta_{нос}(t) = \frac{m_{oc}(t)}{m_{oc}(t_0)} = e^{-t/\tau}$ as its analytical transformation,

where τ — unknown parameter.

Similar calculations should be repeated to evaluate the parameters of electroosmosis and electrophoresis current (in the latter case, it is necessary to evaluate the changes (increase or decrease) in the waste mass more accurately).

We get $\delta_{\text{нос}}(t_i)$ and $i_{oc}(t_i)$. With this in mind, we find the estimates of the correlation functions.

$$r(\delta_{\text{нос}} i_{oc}) = \frac{k(\delta_{\text{нос}} i_{oc})}{\delta(\delta_{\text{нос}})\delta(i_{oc})} = \frac{\sum \delta_{\text{нос}}(t_i) - \frac{m_{\text{нос}}(t_i)}{m_{\text{нос}}(t_0)})(i_{oc}(t_i) - I_{oc}(t_i))}{\sqrt{\frac{1}{\text{n -1}}\sum_1^n \left[(\delta_{\text{нос}}(t_i) - \frac{m_{\text{нос}}(t_i)}{m_{\text{нос}}(t_0)}\right]^2} \cdot \sqrt{\frac{1}{\text{n -1}}\sum_1^n (i_{oc}(t_i) - I_{oc}(t_i))^2}} \quad (18).$$

Indirect measurement data and their analysis allow us to conclude that the process of electroosmosis and electrophoresis is manifested together. Their differentiation is difficult. Therefore, it is necessary to use phenomenological estimates (the time and time constant of experimental data censoring) based on experimental data [11]. In further experiments, we will measure the mass of waste (m_j), corresponding to the time instant (t_j), where j is the number of the temporary section $(j \in \{0,1,2,...n...\})$.

3. CONCLUSION

During the study, information was collected and analyzed on the possibility of electroosmotic device production - the converter of colloidal polydisperse systems into capillary-porous ones by electroosmotic dehydration in order to reduce the residual moisture of sewage sludge and pulp and paper industry wastes. An optimized installation model is proposed. The analysis of the possibility of technological innovation possibility increase in the field of environmental safety improvement of industrial enterprises. Exponents were taken as the models expressing the mass of waste, as the function of drying time and electric current value. According to the obtained determination coefficients, it was concluded that the models corresponded to the initial experimental data, the use of exponent models was justified for further optimization of colloidal polydisperse system conversion into capillary porous ones. The studied model of wet waste conversion into raw materials for building according to the obtained experimental data can significantly reduce the cost of utilization by enterprises and increase the environmental level of the pulp and paper industry.

4. REFERENCES

Dudyshev, V. D., Semashko, V. D., Rokhmistrov, O. V., & Litikov, A. P. (2006). The device for moisture removal from porous materials. Patent of the Russian Federation RU 52735 U1. Publ. on 04/27/2006. Bull. Number 12.

Kholudeneva, A. O. (2016). The research of the electroosmotic dehydration features of porous waste taking into account the osmosis physical model influence and the voltage values dynamics. *International Journal of Engineering Research 11*(19), 9842.

Kholudeneva, A. O. (2016). Theoretical substantiation of automated information-measuring system introduction possibility to control the process of electroosmosis. Collection of scientific papers of the international scientific and practical conference "Information technologies in economic and technical problems" Penza: publishing house of PenzGSU. 197–200.

Kholudeneva, A. O., Zhigalin, S. N., Ryzhakov, V. V., & Kupryashin V. A. (2016). Development of an ecologically clean technology for the recycling of paper production wastes. Collection of doc. from intern. scientific and practical. conf. "Youth and science: modernization and innovative development of the country." Part 3. - Penza: PSU, 248 - 250.

Kholudeneva, A.O., & Ryzhakov, V. V. (2016). Processes of drying of moisture-containing materials: problems of ecology and choice of theoretical, schematic and experimental directions for their resolution. *International Journal of Applied Engineering*, India.

Pegat, A. (2009). Fuzzy modeling and control. M.: Binom. *Knowledge laboratory.* 798 p.

The concept of long-term socio-economic development of the Russian Federation for the period until 2020 (approved by the order N 1121-p of the Russian Federation Government on August 8, 2009).

Electronic fund of legal and scientific-technical documentation. http://docs.cntd.ru/document/902130343

The list of priority areas for the development of science, technology and machinery of the Russian Federation (approved by Decree No. 899 from the President of the Russian Federation on July 7, 2011). Electronic fund of legal and scientific and technical documentation. http://docs.cntd.ru/document/902287707

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