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# Studying the Electrodynamic Parameters of Dehydration of Moisture-containing Waste using an Electroosmotic Dehydrator

**[*1]A.O. Kholudeneva, [2]S.Yu. Efremova, [3]V.V. Konovalov**

[1,2,3] Penza State Technological University,440039 Russian Federation, Penza, pr. Baidukova /ul. Gagarina, 1a/11

*E-mail: linblondy@mail.ru, efremova_s15@mail.ru, konovalov-penza@rambler.ru*

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**Abstract**

The article describes the design of the dehydrator of moisture-containing waste paper production, methods and results of its experimental studies. An adequate statistical expression has been obtained for the mutual influence of voltage by the electrodes, processing time, amount of moisture removed, humidity, current strength by electrodes, required power and energy. Upon reaching the lead, the efficiency of the liquid treatment with the dehydrator decreases sharply. The duration of waste treatment at a dehydrator for 28 V is 0.75 hours, and with a voltage drop of up to 4 V increases to 5 hours. Age less than 10 V. After 1.5 hours of operation at constant tension, the amount of energy supplied does not change. The cause of this dependency is fading work. The most economical mode corresponds to the highest voltage. Depending on the congestion conditions of the technological section of waste processing. Regression models determined the technologically permissible minimum voltage for the interval of change in the amount of waste. The obtained regression models allow us to determine the current strength, power consumption and energy consumption by 70 kg.

**Keywords**

*Dehydrator, Electro-osmosis, Dehydration, Stress, Mathematical Model*

## Introduction

Modern technological features of paper and cardboard production are distinguished by the design and implementation of local water treatment systems in order to reduce pollution discharges to treatment facilities. When trapping organic cellulose fibers, and at the same time mineral components from wastewater of paper machines, the flotation process is actively used.[1]

The solid phase collected from wastewater, consisting of organic fibers and mineral components and impurities (the composition of which is determined depending on the technology of production of finished products), called osprey, could be returned to the main production cycle. However, when using waste paper as organic raw materials to ensure the operation of the paper machine, the osprey is characterized by the presence of a large number of small fibers as well as their fragments. This is due to the repeated saturation of the cellulose fibers contained in the waste paper with water, as well as further processing.[2][3]

Due to the presence of small fragments of fibers in the osprey, it is characterized by high water retention capacity. As a result of this, the osprey has a high grinding in Shopper-Riegler degrees up to 80°SR and, as a result, is characterized by poor dehydration.[4]

In connection with the foregoing, the recycling of osprey in the manufacture of paper and paperboard can cause certain difficulties in the implementation of the technological process: a significant slowdown in the water yield of the raw paper pulp, a decrease in the strength of the paper sheet, an increase in steam consumption in the drying section, which will lead to a decrease in the performance of paper making machines in general.[5][6]

In this regard, pulp and paper enterprises, separated at the local sewage treatment plants, are not reused in technological processes of paper production but transferred for recycling.

Figure 1 shows an enlarged fragment of the technological process for the production of paper for corrugation and cardboard for flat layers of corrugated cardboard on a paper machine, where the recycled secondary fiber - waste paper acts as a raw material. The mass of raw materials used and waste generation is presented per day of the technological process.

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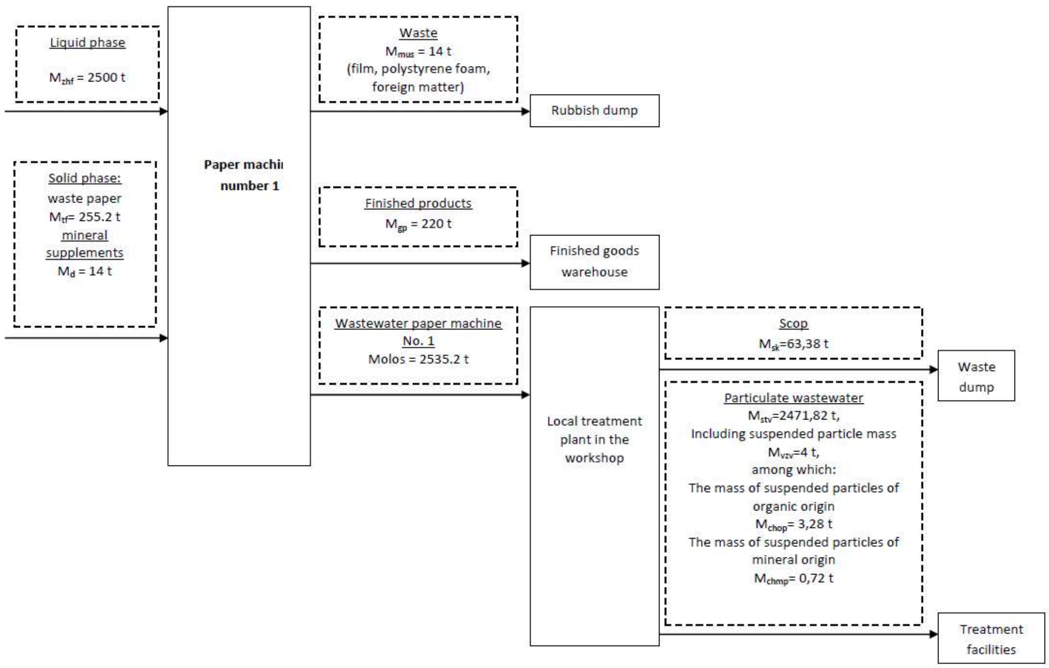


**Figure 1: An Enlarged Fragment of the Technological Process for the Production of Paper for Corrugation and Cardboard for Flat Layers of Corrugated Cardboard on a Paper Machine**

According to the data shown in Figure 1, it can be concluded that about 20000 tons of osprey are formed in a year of operation of a paper machine designed to produce corrugated paper and cardboard for flat layers of corrugated cardboard. Certainly, such a significant amount of waste has a negative impact on the environment. In order to consider the possibility of reducing this effect, it is necessary to study the ways of dehydration of osprey with a view to further use.[7]

**Research Methods**

Consider the possibility of dehydration of moisture-containing waste from pulp and paper using a dehydrator, the principle of which is based on the application of the effect of electro-osmosis.

To implement this process, it is proposed to use a dehydrator installation. The installation contains an electrical insulating casing with electrodes - an anode made in the form of a conductive cover, and a cathode made in the form of a conductive perforated bottom of the casing, which have a space for dehydrated osprey.

The surface of the electrodes, interacting with a dehydrated wet osprey, is equipped with pointed protrusions. The pointed protrusions are made on the anode and cathode in the form of pyramids. The electroosmotic dehydrator has the ability to install under the perforated bottom of the pallet to collect the separated moisture.[8]

Figure 2 shows the projection of the General view of the proposed dehydrator.

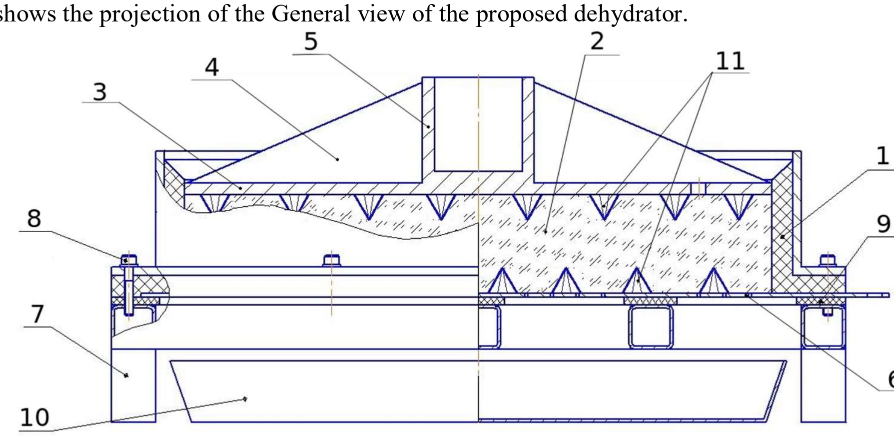


**Figure 2: The Device Dehydrator Moisture-Containing Waste Paper Production**

The proposed device of the dehydrator is an insulating body 1 and electrodes, which form a space between the dehydrated material 2. The anode is made in the form of a conductive cover 3, which moves

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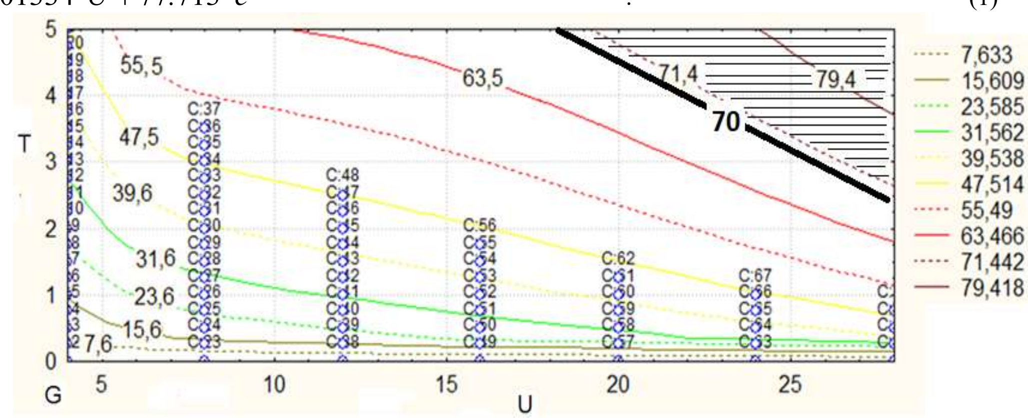
vertically inside the body 1 under its own weight, under the action of a press or under the action of a clamping screw. To ensure the necessary strength and functionality, the cover 3 is provided with stiffeners 4 and a node 5 for connecting to a device that provides movement.
The cathode is made in the form of a conductive perforated bottom 6 mounted on the frame 7 using bolts 8 and insulating gaskets 9. The frame holds the housing 1 over the pallet 10.
The surface of the anode and/or cathode interacting with the dehydrated porous material 2 is provided with pointed protrusions 11 in the form of cones or pyramids of the same material as the electrodes. In this case, the protrusions 11 can be located separately or in contact with each other by the bases, forming a continuous surface.
The proposed device operates as follows. The dehydrated porous material 2 (for example, a moisture-containing sewage sludge from the pulp and paper industry - osprey) is placed inside the housing 1 and squeezed by its cover 3. In this case, the protrusions 11 are pressed into the porous material 2, and excess moisture flows through the perforated bottom 6 into the tray 8. Then voltage is applied to the electrodes and final dehydration is carried out due to electro-osmosis.
Due to the presence of protrusions, the contact area of the electrodes with the dehydrated material is significantly increased, which greatly accelerates the process of moisture separation. In addition, such "loosening" of the porous material prevents the formation of excessively dense layers that impede the effective action of the electric field and delay the passage of moisture. At the same time, the implementation of the peaked peaks eliminates the need to take additional actions for their penetration into the porous material. The resulting dehydrated mass can subsequently be used as a component of various kinds of building mixtures or other materials.
To ensure maximum energy efficiency of the electroosmotic dehydration process, it is necessary to conduct a series of experiments with variable voltage parameters between the electrodes U (B) = 4, 8, 12, 16, 20, 24, 28.

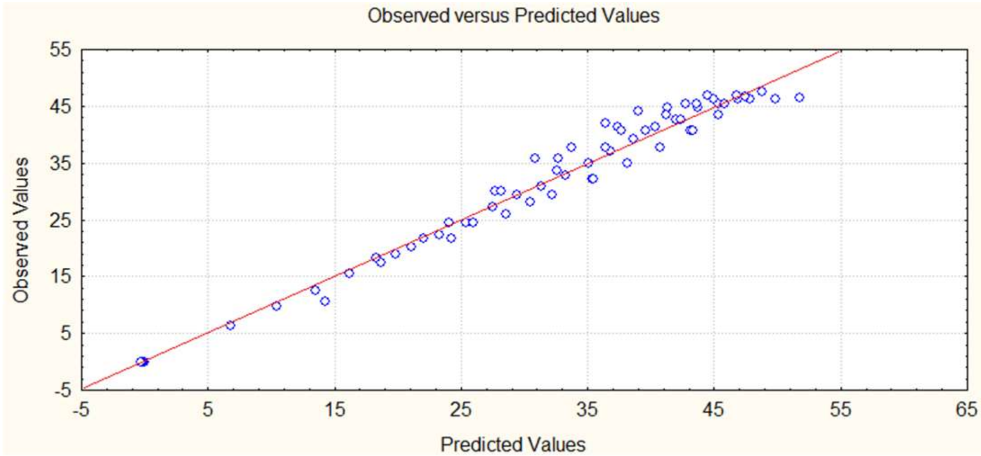
**Research Result**
In the process of conducting research, results were obtained that, after regression processing, are presented in the form of statistical models.
When conducting research on the parameters of the paper-based liquid waste dehydrator, water was withdrawn from the portion of the liquid waste portion equal to 70 kg. As a result, the humidity of the waste decreased.
The amount of water discharged G (kg) from the treated portion of the waste (Fig. 3) depends on the voltage U (V) supplied to the electrodes and the exposure duration T (h). The amount of water discharged (h) during the treatment is described by the expression:

$$G = -0.01334 \cdot U + 77.713 \cdot e^{\left(-25.34 + 27.576 \cdot T^{0.04} \cdot U^{-0.39} + 10.5 \cdot U^{0.167} - 21.83/U\right)}. \quad (1)$$




(a)




(b)

**Figure 3: Effect of Voltage between Electrodes U (V) and Processing Time T (h) on the Amount of Moisture Removed G (kg):**
**(a) - Two-Dimensional Section of the Model; (b) - Graph of Compliance of Calculated and Experimental Values**

Values of statistical indicators: confidence probability by F-test = 0.898257≈0.9 and Pearson's correlation coefficient R = 0.988725, indicate the adequacy of the obtained model. Placing the calculated (by the regression model) and experimental data on and near the red line (Fig. 3.b) indicates good convergence of the results.

With increasing voltage, the intensity of moisture removal from waste increases, i.e. device performance will increase (Fig. 4). In the initial period of processing, the intensity of moisture removal is high, and then decreases. When 55.5 kg of moisture is removed from a portion of processed waste weighing 70 kg, a significant slowdown in moisture removal is observed. That is, when the removal of 70% of moisture from the initial mass of waste is achieved, the efficiency of liquid removal decreases sharply. With decreasing voltage, the processing time increases, and with a voltage of less than 10 V, the increase in the required time increases significantly.

The strength of the current passing through the electrodes I (A) during the processing time (Fig. 4) is described by the expression:

$$I = 0.231 \cdot U - 2.467 \cdot e^{\left(-7.33+5.18 \cdot T^{0.056} \cdot U^{0.162} - 8.87 \cdot U^{-0.72} + 8.863/U\right)} \quad (2)$$

Values of statistical indicators: confidence probability by F-test = 0.986857 and Pearson correlation coefficient R = 0.99482, indicate the adequacy of the obtained model.

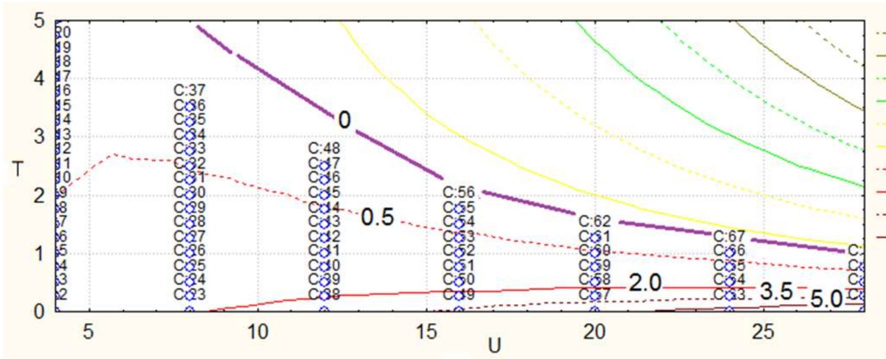
Given the similar resistance of the waste, the current strength increases with increasing input voltage (Fig. 4). In view of the separation of the solid and liquid phases of the waste, as a current conductor, the current intensity decreases over time. The current strength is gradually approaching zero. Negative current values are not possible and exist only on the model, only in the area where the use of a dehydrator is not advisable. The current strength of 0.5 A remains after 1-2 hours of waste treatment. With increasing voltage up to 28 V, the indicated current value appears earlier.[9][10]

The power consumption P (W) of the electrical device during the waste treatment (Fig. 6) is described by the expression:

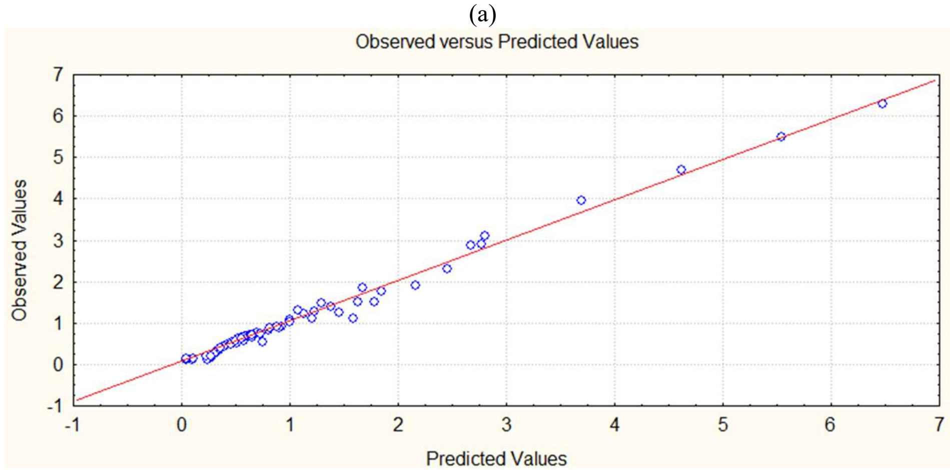
$$P = -0.07 \cdot U + 2.88 \cdot e^{\left(-15.126+15.42 \cdot T^{0.084} \cdot U^{-0.475} + 9.635 \cdot U^{0.146} - 18.166/U\right)} \quad (3)$$

Values of statistical indicators: confidence probability by F-test = 0.983273 and Pearson correlation coefficient R = 0.995794, indicate the adequacy of the obtained model.

An increase in voltage (Fig. 6) proportionally leads to an increase in power consumption due to an increase in current strength. Due to the small residual current, after 2 hours of processing, the increase in power begins to decrease. However, the amount of power consumed is constantly growing. This is affected by a decrease in the distance between the electrodes with increasing processing time, which increases the specific voltage per unit distance between the electrodes.




(a)




(b)

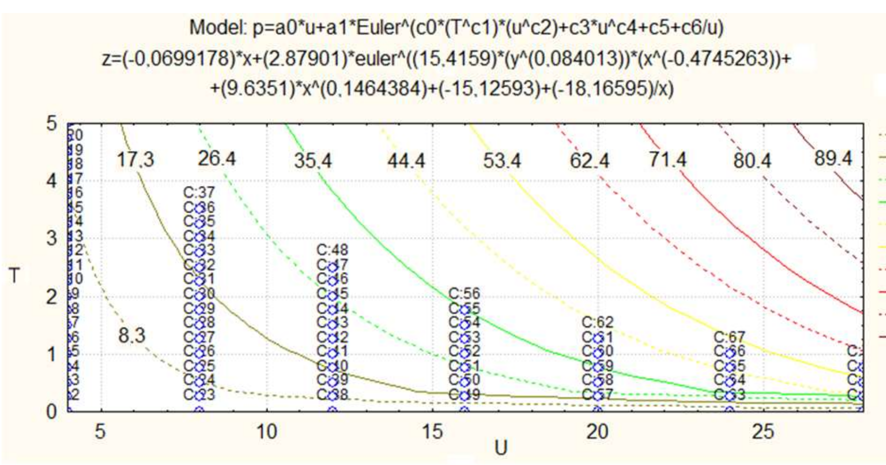
**Figure 4: The Effect of Voltage between the Electrodes U (V) and the Processing Time T (h) for the Current Strength I (A): (a) Two-Dimensional Section of the Regression Model; (b) - Graph of Compliance of Calculated and Experimental Values**

The amount of energy supplied to the dehydrator (work, J) is described by the expression:

$$A = 0.000656 \cdot U - 0.002 \cdot e^{\left(-0.132 - 0.257 \cdot T^{0.744} \cdot U^{0.677} + 0.762 \cdot U^{0.35} - 2.985/U\right)} \quad (4)$$

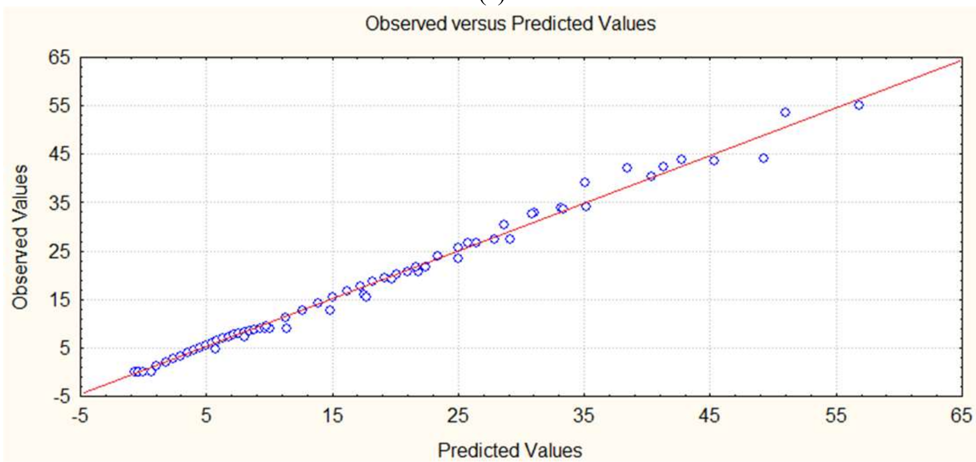
Values of statistical indicators: confidence probability by F-test = 0.968799 and Pearson correlation coefficient R = 0.992997, indicate the adequacy of the obtained model.

The nature of the change in the energy supplied to the dehydrator (operation) generally corresponds to the power consumed by the device (Fig. 5). However, after 1.5 hours of operation at constant voltage, the amount of energy supplied does not change significantly. In this case, the dependence of the magnitude of the expended work on the magnitude of the applied voltage is close to linear. The most economical mode corresponds to a lower voltage value.



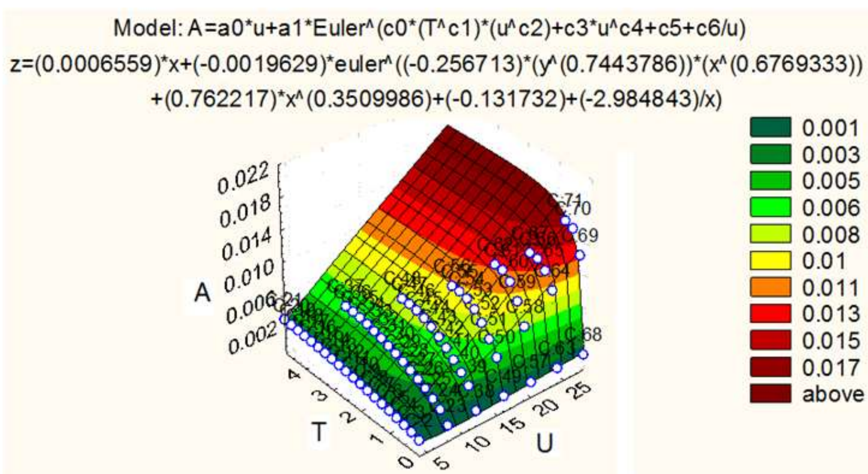

 

(a)

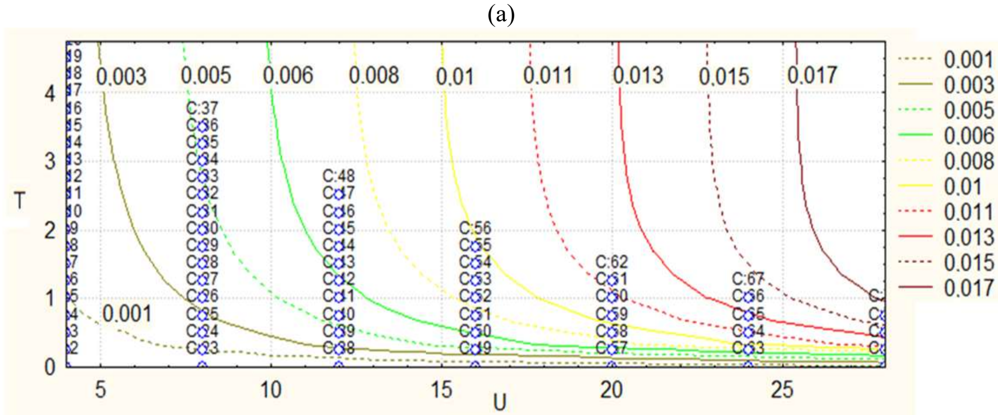



(b)

**Figure 5: Effect of Voltage between Electrodes U (V) and Processing Time T (h) on Power Consumption P (Wt): (a) is the Two-Dimensional Section of the Model; (b) –Conformity Chart of Calculated and Experimental Values**




(a)

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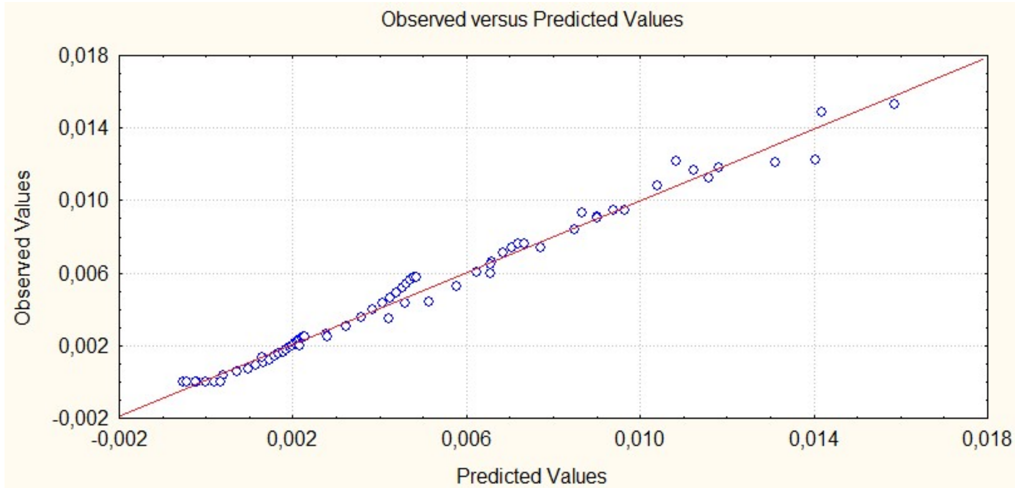


(c)

**Figure 6: Influence of Voltage between Electrodes U (V) and Processing Time T (h) on Energy Consumption (Work) A (J): (a) is the Surface of the Regression Model; (b) - Two-Dimensional Section of the Model; (c) - Graph of Compliance of Calculated and Experimental Values**

Over time, the storage or treatment of waste is a natural process of separation of the emulsion of waste. In this case, the moisture content of the thick part of the liquid decreases. In the case of processing waste with an initial moisture content less than the initial one, the required processing time will be determined as:

$$T = T\left(W_k\right) - T(W_n). \qquad (5)$$

Where $T\left(W_k\right), T(W_n)$ – processing time according to the schedule of Fig. 8 or f. (6);

$\left(W_k\right), (W_n)$ – humidity of waste at the beginning and end of the proposed treatment, 0.01%.

The dehydrator cycle time is Tc (h):

$$T_C = T_Z + T + T_V + T_D. \qquad (6)$$

where $T_Z$ – the duration of filling the working cavity of the dehydrator, h;

$T_V$ – the duration of the emptying of the working cavity of the dehydrator, h;

$T_D$ – duration of unaccounted operations, h.

Given the number of working capacities (pcs.) Of the dehydrator with the mass of the working portion of the waste (kg), the productivity of the waste treatment equipment will be:

$$Q_0 = \frac{M \cdot Z}{T_Z + T + T_V + T_D} \geq Q_S = \frac{M_S}{N \cdot T_C \cdot \tau}. \qquad (7)$$

where $Q_S$ – the average productivity of the site per day, kg / h;

$M_S$ – daily waste weight, kg;

$T_C$ – the duration of the shift in waste treatment, h;

$N$ – the number of work shifts per day, pcs.;

$\tau$ – coefficient of utilization of shift time.

The maximum allowable time for processing a portion of waste will be, h:

$$T = \frac{M \cdot Z \cdot N \cdot T_C \cdot \tau}{M_S} - \left(T_Z + T_V + T_D\right). \qquad (8)$$

Using Fig. 4 (or ph. 2) with the set value of the processing time T, setting the required value of the change in humidity W, the minimum value of the voltage supplied to the electrodes is determined. Accordingly, the energy consumption, power and current strength (see Fig. 5-6, form. (3) - (8)) will correspond to the parameters when processing waste products of the indicated humidity interval according to the accepted voltage between the electrodes and the processing time.

 

In this case, the required performance of the waste treatment section is ensured with minimal energy consumption.

## Conclusion

The results of experimental studies of the papermaking waste dehydrator formed the basis for adequate statistical expressions of the mutual influence of the voltage between the electrodes, the processing time, the amount of moisture removed, the moisture content of the waste, the current strength between the electrodes, the consumed power and energy.

Upon reaching the removal of 70% of moisture from the initial mass of waste, the efficiency of liquid removal by the dehydrator decreases sharply. The duration of waste treatment at a dehydrator for 28 V is 0.75 hours, and with a voltage drop of up to 4 V, it increases to 5 hours. The increase in the required processing time increases significantly at a voltage of less than 10 V. After 1.5 hours of operation at a constant voltage, the amount of energy supplied is significantly does not change. In this case, the dependence of the magnitude of the expended work on the magnitude of the applied voltage is close to linear. The most economical mode corresponds to a lower voltage value.

Dependencies are established that allow you to set the maximum technological time for processing waste based on the operating conditions of the technological section of waste treatment. Based on the regression models, the technologically permissible minimum voltage at the electrodes is determined based on the interval of variation in the humidity of the waste. The obtained regression models allow us to determine the current strength, power consumption and energy consumption per 70 kg portion of processed waste paper production.

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