

DETERMINATION OF DEPENDENCIES FOR DEWATERING ASH AND SLAG WASTE OF HEAT ELECTRIC POWER STATIONS ON EQUIPMENT PARAMETERS

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ВИЗНАЧЕННЯ ЗАЛЕЖНОСТЕЙ ЗНЕВОДНЕННЯ ЗОЛОШЛАКОВИХ ВІДХОДІВ ТЕПЛОЕЛЕКТРОСТАНЦІЙ ВІД ПАРАМЕТРІВ ОБЛАДНАННЯ

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ОПРЕДЕЛЕНИЕ ЗАВИСИМОСТЕЙ ОБЕЗВОЖИВАНИЯ ЗОЛОШЛАКОВЫХ ОТХОДОВ ТЕПЛОЭЛЕКТРОСТАНЦИЙ ОТ ПАРАМЕТРОВ ОБОРУДОВАНИЯ

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Annotation. The integrated processing of ash and slag from coal-fired thermal power plants attracts much attention. Waste treatment will reduce the burden on existing storage facilities, carry out the return of unborn coal to the boilers of power plants, and obtain a valuable raw material resource for construction, ferrous and non-ferrous metallurgy. At all thermal power plants in Ukraine, the utilization and storage of ash and slag is carried out hydraulically. Therefore, for all processing technologies, the dehydration of finely divided raw materials is relevant.

The article presents the results of laboratory tests of some new device for dewatering ash and slag waste. The analysis of experimental data on the dehydration of ash and slag waste (fly ash) of the Kramatorsk Thermal Power Plant with a size of $-5 + 0.05$ mm in a dewatering device with a complex effect was represented in the article. It uses a set of effects on raw materials: the imposition of vibrations, electric fields and vacuation. The dehydration efficiency depends on how the parameters of these effects are selected.

Using the linear correlation method, it was found that the dependences of humidity on each of the variable parameters are of a weak nonlinear character. The exact and approximate equations of multiple regression were obtained for the practical estimation of humidity under the combined action of all variable factors. The research results showed that the use of a complex action device is promising for the dehydration of ash and slag waste. The developed generalized regression model of changes in the final moisture content (W_{con}) is suitable for assessing the decrease in humidity of dump fly ash when the process parameters change in the range: $W_{ish} = 30\%$, angle of inclination of the working body $\alpha = 5$ degrees, and changing device parameters in the ranges: vibration exciter frequency $\omega = 1500 \div 3000$ rpm, forced excitation vibration value $F = 0.5 \div 0.8$ kN, electric field voltage $U = 25 \div 100$ V, vacuum pressure chamber $P = 0.063 \div 0.1$ MPa. With a grain size of raw materials $+ 0.63-0.05$ mm, a dehydrating device with a complex effect reduces humidity from 30 to 9%.

Keywords: vibration, evacuation, electroosmosis, dehydration, integrated method.

Introduction. In the modern world, the process of electricity production at thermal power plants (TPP) is carried out by burning fine coal, while a huge amount of ash and slag is formed. Thus, for a typical thermal power plant with a capacity of 1295/1540 MW, 3500 Gcal/hr, the amount of waste is from 120 to 1700 thousand tons per year, depending on the ash content (level) of the burned coal [1, 2]. Ash removal from coal combustion (fly ash) and slag is carried out on ash dumps by hydraulic method in the form of water pulp.

At present, almost all the ash storage facilities are overloaded, but the organization of new ones is problematic due to the lack of free areas of waste land near the existing thermal power plants.

Growing storage areas cause environmental problems due to pollution of groundwater with alkaline highly mineralized filtration waters of dumps.

In addition, TPP under the terms of its schedule work with variable load during the year. Because of this, the area of ash dumps has mobile boundaries, which causes active dusting, leaching (washout) by precipitation. These phenomena cause environmental pollution [1-3].

The aim of the research is to study the particle size distribution of fly ash, identify promising classes for the integrated processing of fly ash, as well as develop a regression model that can predict the change in the final moisture content of fly ash during dehydration by the integrated method.

Processing of ash and slag waste of TPP attracts more attention because this product is a valuable technogenic raw material [2-7]. The most relevant is work on the creation of a comprehensive waste-free technology for the extraction of silicate fraction, metal (in the form of iron splices) and unburned coal. Each of these products has industrial interest.

As an illustration, we give a typical example of indicators of ash and slag waste (fly ash) of the Kramatorsk TPP [3]. This material was used by us for experimental studies, which are reflected below in this article.

For a correct analysis of the control points of TPP ash storage were selected six samples. After drying, the samples were dispersed into size classes. In each class, after firing (roasting) and burning out of carbon by magnetic separation, the output of the magnetic fraction – intergrown pieces of iron - was determined. The results of the analysis, averaged over six samples, are presented in the Table 1.

Table 1 - Granulometric composition and the weight output of aggregates (intergrown pieces) of iron in the dump fly ash

Particle size classes, mm	Output, %	Output of aggregates of iron, %
Source material	100	83
-0.63+0.25	8	50
-0.25+0.1	31	81
-0.1+0.05	38	87
-0.05	23	94

Table 2 - Silicates content of dump fly ash

Particle size classes, mm	Silicates content, %					
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
-0.63+0.25	-	-	-	-	-	32.03
-0.25+0.1	38.7	48.54	72.46	83.54	-	50.21
-0.1+0.05	50.0	55.73	78.21	87.19	76.53	60.61
-0.05	79.9	83.95	89.2	90.29	87.7	81.8

Table 2 shows the ash distribution in the specified size classes for each sample.

As can be seen from Tables 1 and 2, intergrown pieces of iron and unburned carbon are unevenly distributed by size classes. The lowest ash content and

correspondingly high carbon content are observed in the upper classes starting from 0.63 mm and up to 0.1 mm inclusive. With a decrease in the size, the carbon content naturally decreases (Table 2).

The number of rich in carbon classes is large enough, their output is 39 % of the total mass of raw materials (Table 1). Extraction and return of unburned coal to the thermal power plant boilers will compensate up to 20 % of the daily needs of the thermal power plant in coal, which is estimated at about 1.5 thousand tons, as well as will reduce the purchase of coal and transport costs for delivery [3]. One of the reasons for the profitability of the technology for the extraction of waste components-coal, metal fraction and silicate part, is that all components are finely dispersed. This eliminates the expensive operations of additional grinding of raw materials in preparation for magnetic or electrical separation and is convenient for the direct use of coal and silicates.

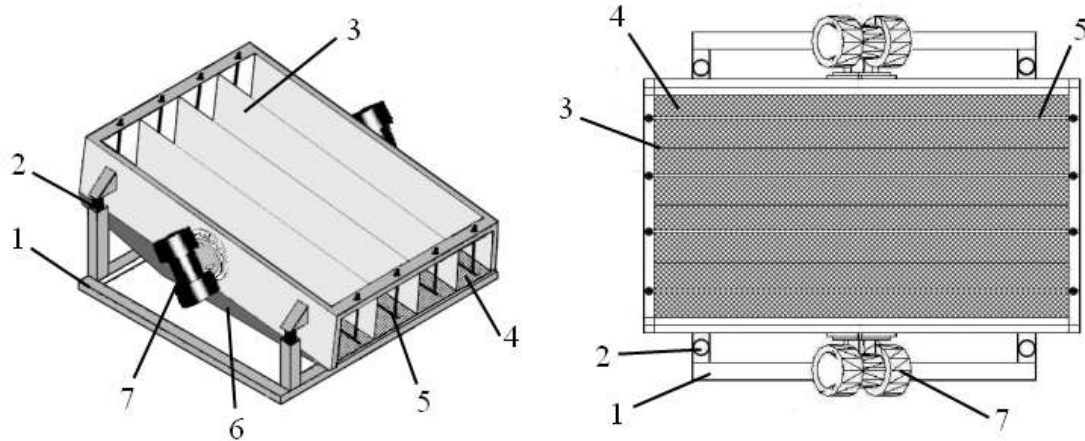
Modern research on the processing of ash and slag waste is aimed at the development and improvement of technology and equipment, the expansion of the application of ash [1-7]. For example, about 300 technologies of processing and use of ash and slag waste are known [4], however in the majority of them we are talking about the dry product - the fly ash which was not in contact with water. Dry storage of ash and slag waste is a promising method, which is an alternative to hydraulic waste disposal and wet storage [5, 6]. It consists in the pneumatic collection of ash and dehydration of slag in the hydraulic removal from the furnaces of boilers. Dry storage of ash and slag eliminates the costly barrier dams and special anti-filtration screens in the construction of dumps. The main negative impact on the environment is dusting during loading and transportation. However, today dry storage of ash waste abroad is used in small volumes, and in Ukraine is not used at all [5-7].

All coal thermal power plants and thermal power plants of Ukraine have a hydraulic ash removal system. Therefore, in order to use huge reserves of ash storages for processing, at the first stage it is necessary to solve the problem of dehydration of fine raw materials. To solve it, we improve the design of centrifuges, screens and hydrocyclones, as well as develop devices with any additional effects, for example, pulsed [8].

As one of the solutions to the problem of dehydration of fine material the Institute of geotechnical mechanics developed a device for dehydration of complex action [9]. Its appeal lies in the simultaneous use of three methods of dehydration: vibration, vacuum and electrokinetic (electroosmotic). This article describes the results of the tests of this device in the dehydration of wastes Novo-Kramatorsk thermal power plant (Table 1, 2) and theoretical analysis of experimental data.

Experimental studies. The dehydrating device [9] is made in the form of a box with a mesh bottom (Fig. 1). With the help of vibration, which is created by an inertial vibration exciter (7), there is a continuous movement of the bulk wet mass on an inclined perforated (mesh) surface. The removed liquid passes through the rock mass layer towards the perforated surface and is removed to the drain. The rate of liquid seepage is controlled and can be increased by the creation of the underpressure

in a vacuum chamber (6). In this case, air thrust generated by vacuuming will act on the liquid, in addition to gravitational forces.



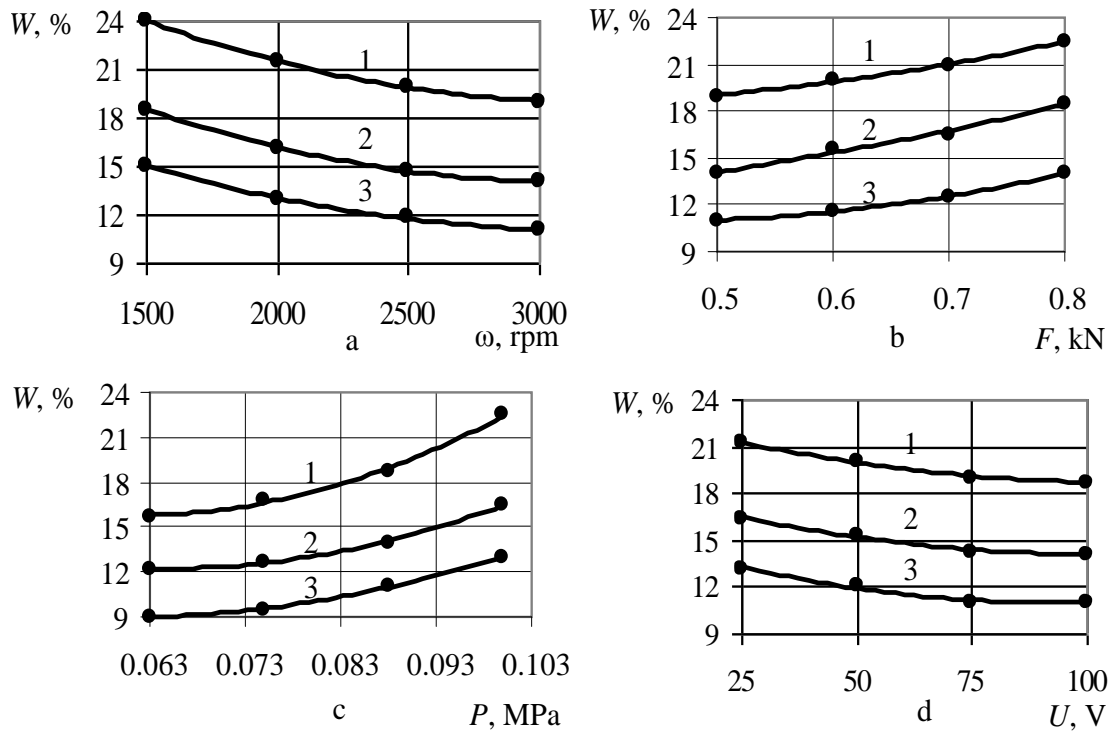
1 – support frame; 2 – rubber shock- absorbers; 3 – partition; 4 – perforated surface;
5 – conductive rod; 6 – vacuum chamber; 7 – inertial vibration exciter

Figure 1 - General view of the dehydrating device

The movement of the material on the working surface occurs in constant contact with the electrodes (5), which are made in the form of conductive rods. The imposition of a constant electric field causes the phenomena of electroosmosis and electrophoresis. In this case, there is a movement of negatively charged colloidal and fine clay particles to the positive pole of the source, and water – to the negative. By removing excess water from the cathodes due to electrophoresis, it is possible to reduce the moisture content of the material and its compaction. Electro-osmosis leads to a decrease in the capillary and pore humidity due to the weakening of surface tension of the liquid in the pore channels.

Experimental studies of the process of complex dehydration of fly ash were aimed at determining the parameters of the device affecting the final moisture W . The initial moisture content of the material was $W_0 = 30\%$. The following operating and design parameters of the device were changing: the area of the perforated surface, the angle of inclination of the working body of α , the oscillation frequency of the exciter ω (rpm-rotation per minute), the magnitude of the disturbing force (stress) F the exciter, the voltage of the electric field U , the pressure in the vacuum chamber P . During the experiments, one of the parameters was initially varied for the other fixed ones. Then the experiments were repeated for another variable and other fixed parameters. Thus, the pair correlation dependences of moisture on each of the four variable parameters were obtained (Fig. 2).

As shown in Figure 2 all the dependencies have a weak non-linear character. Each of the parameters has a close correlation with humidity, the pair correlation coefficient for them was not lower than 0.985. Further analysis was to establish the dependence of the indicators of dehydration from all the influencing parameters.



a - from the intensity of the electric field.

b - from the vibration frequency.

c - from the pressure in the vacuum chamber.

d - from the disturbing force of the vibration exciter

Working surface area S : 1 – 0.08; 2 – 0.56; 3 – 1.12 (m^2)

Figure 2 - Dependence of moisture on the parameters of the device of complex dehydration of ash and slag waste

Theoretical studies. To obtain the dependence of moisture on all variable factors, a database of experimental data was prepared, which included 39 experiments. Constants in all experiments were the initial moisture of the samples $W_0 = 30\%$ and the angle of inclination of the working body $\alpha = 5^\circ$. The experiments were performed for three values of the perforated surface area on which the dryable product was placed: $S = 0.08$; 0.56 and 1.12 m^2 . Four variable factors for each value of the square were changed within the following limits:

- vibration frequency of the vibration exciter $\omega = 1500 - 3000$ rpm, in increments 500 rpm;

- the magnitude of the disturbing force of the vibration exciter $F = 0.5 - 0.8$ kN, in increments 0.1 kN;

- the intensity of the electric field $U = 25 - 100$ V, in increments 25 V.

- the pressure in the vacuum chamber $P = 0.063 - 0.1$ MPa, in increments 0.012 MPa;

It was found that with different combinations of device parameters the moisture can be reduced from 30 to 9%. The linear correlation of each of the parameters with moisture is weakly nonlinear.

To construct a generalized mathematical model of moisture changes from

variables S , ω , F , U , P , the method of regression analysis using the built-in functions of the statistical data processing program "SPSS Statistics" was used [10]. The degree of approximation of regression equations was estimated by the value of the square of the correlation coefficient R^2 .

First of all, a qualitative assessment of the impact on the humidity of each individual factor in their joint action was carried out. For this purpose, a simple linear regression dependence was constructed $W = f(S, \omega, F, U, P)$. In the program SPSS Statistics option «Enter» was used - forcible inclusion of all variables (variable factors). The equation is obtained:

$$W = 32.144 - 7.076 \cdot S - 0.004\omega + 7.62 \cdot F - 0.066 \cdot U - 6.623 \cdot P \quad (1)$$

$$R^2 = 0.888$$

Note, that the use in the program "SPSS Statistics" the "Step-by-step selection" option and the model selection with maximum R^2 gives almost the same equation.

The sign (character) of the coefficient for the parameters S , ω , F , U , P in the equation (1) shows a positive or negative effect on moisture has this parameter. As you can see, an increase in the parameters S , U , ω leads to a decrease in moisture, they have a negative coefficient. The increase of the parameters R , F adversely affects the moisture. It is not advisable to analyze the influence of the parameters on the value of the coefficients, since they are nonequilibrium, for example, ω is measured in thousands of units, and P in hundredths of units.

Equation (1) has a low approximation, $R^2 = 0.888$. The value of R^2 can be increased if you build a more complex regression equation, for example, in the form of a full quadratic form. In favor of a more complex regression equation says installed above the fact that all private pair correlations of $W(F)$, $W(P)$, $W(S)$, $W(U)$, $W(\omega)$ have weakly-nonlinear character. That is, the generalized regression equation must include nonlinear terms.

To construct the regression dependence of W on all factors, we set the target function as a full quadratic form. To reduce the number of terms in the regression equation, we used "SPSS Statistics" program the "Step-by-step selection" option: *METHOD=STEPWISE* (S , ω , F , U , P , S^2 , $S\omega$, SF , SU , SP , ω^2 , ωF , ωU , ωP , F^2 , FU , FP , U^2 , UP , P^2).

The selection criterion was chosen based on the significance (probability) of F-statistics: inclusion - 0.05, removal - 0.1. The confidence interval level of 95 % was chosen for the regression coefficients.

The calculation obtained 13 regression models for which R^2 varies from 0.822 to 0.998. The selected model with the highest accuracy of approximation in terms of R^2 , the equation for the regression has the form:

$$W = 30.361 - 0.013 \cdot \omega + 2.32 \cdot 10^{-6} \cdot \omega^2 - 256.855 \cdot F \cdot P - 0.065 \cdot F \cdot U - \quad (2)$$

$$- 92.519 \cdot S \cdot P + 1972.17 \cdot P^2 + 3.241 \cdot S^2 - 3.759 \cdot S + 29.488 F^2$$

$$R^2 = 0.996$$

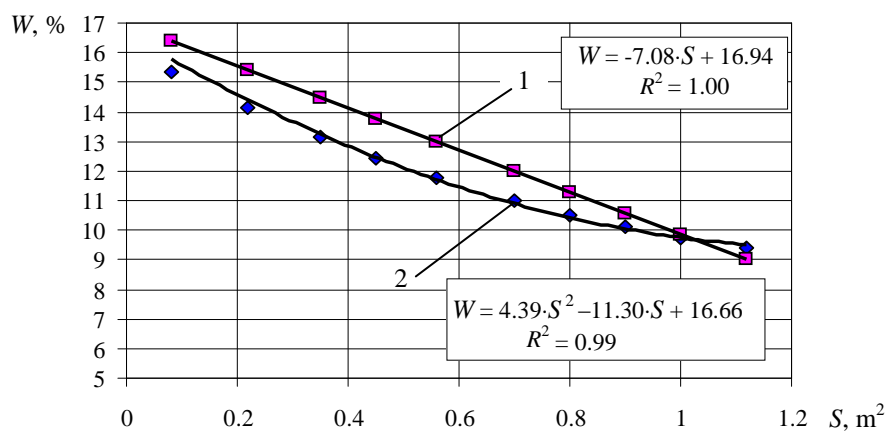
Thus, when using the method of step-by-step selection of 20 variables, 9 variables

were included in the model (2). In this case, it involves all five variable factors - S , ω , F , U , P and takes into account the nonlinearity that makes each of them. The approximation accuracy of the generalized regression equation (2) compared to (1) increased significantly, R^2 increased from 0.888 to 0.996.

The obtained regression models (1) and (2) make possible to predict the change in moisture for different combinations of device parameters. In this case, the model (1) gives an approximate estimate, and (2) - sufficiently accurate.

For example, we estimate the effect of drying area S on moisture.

According to equation (1), from the common range of variation of the parameters, as optimal, it is advisable to choose P and F the minimal value, and U and ω - the maximum. These parameters are: $P = 0.063$ MPa, $F = 0.5$ kN, $U = 100$ V and $\omega = 3000$ rpm. For these fixed parameters, the dependences of $W(S)$ are obtained from the regression equations (1) and (2), which are shown in Figure 3.



1 – at the approximate regression model (1); 2- at adequate regression model (2)

$S = 0.08\text{--}1.12$ m² at $P = 0.063$ MPa, $F = 0,5$ kN, $U = 100$ V, $\omega = 3000$ rpm, $W_0 = 30$ %

Figure 3 - The dependence of the moisture content W of the area of drying in the range

The approximate regression model (1) gives a rough estimate of the dependence of moisture on the drying area, it is expressed by a linear equation:

$$W = 16.94 - 7.08 \cdot S \quad (3)$$

The regression model (2) has a high degree of approximation, the dependence of moisture changes with increasing drying area square has the form of a nonlinear quadratic function:

$$W = 16.66 - 11.3 \cdot S + 4.39 \cdot S^2 \quad (4)$$

Equations (3) and (4) are applicable in the drying area range $S = 0.08\text{--}1.12$ m² at $P=0.063$ MPa, $F=0.5$ kN, $U=100$ V and $\omega=3000$ rpm.

When comparing the calculation of equation (3) with that of equation (4), the maximum difference in moisture is 1.3 % (Fig. 3). Such discrepancy may be significant, so equation (1) can only serve as an approximate estimate.

For practical application, it is advisable to use a regression model (2) as having a

high accuracy of approximation. Model (2) allows to determine the final moisture content of the product at the initial moisture $W_0 = 30\%$, angle of inclination of the working body $\alpha = 5^\circ$ and change the device parameters in the ranges: vibration frequency of the exciter $\omega = 1500 - 3000$ rpm, the magnitude of the disturbing force of the vibration exciter $F = 0.5 - 0.8$ kN, the intensity of the electric field $U = 25 - 100$ V, pressure in the vacuum chamber $P = 0.063 - 0.1$ MPa.

Conclusions. The processing of ash and slag waste from thermal power plants is constrained by the need for dehydration of finely dispersed ash storage products. A drying device with the combined effects of vibration, electroosmosis and vacuum has been developed. The results of experimental studies on the dehydration of ash and slag waste (fly ash) of the Kramatorsk coal power plant with a particle size of $+0.63 - 0.05$ mm are presented. They showed that, depending on the parameters of the device, humidity can be reduced from 30 to 9%. An analysis of the experiments showed that the partial pairwise correlations of humidity with any of the device parameters are weak nonlinear. Exact and approximate regression models have been developed for the practical assessment of the final moisture content of a product, depending on all parameters of the device. The equations cover the following range of variation of the device parameters: vibration excitation frequency $\omega = 1500 - 3000$ rpm, disturbing force of the vibration exciter $F = 0.5 - 0.8$ kN, electric field voltage $U = 25 - 100$ V, pressure in the vacuum chamber $P = 0.063 - 0.1$ MPa. The regression equations make it possible to estimate the final moisture content of the product with an initial moisture content of $W_0 = 30\%$ and an inclination angle of the working body of $\alpha = 5^\circ$. The developed complex action device for the dehydration of finely dispersed raw materials is promising for use in the technologies for processing products of ash plants of thermal power plants, it provides a decrease in the moisture content of ash and slag waste from 30% to 9%.

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Анотація. Комплексна переробка золи і шлаків вугільних теплових електростанцій привертає велику увагу. Переробка відходів дозволить знизити навантаження на існуючі сховища, здійснити повернення незгорілого вугілля в котли електростанцій, отримати цінний сировинний ресурс для будівництва, чорної і кольорової металургії. На всіх теплових електростанціях України утилізація і складування золи і шлаків виконується гідравлічним способом. Тому для всіх технологій переробки актуальне зневоднення тонкодисперсної сировини. У статті викладені результати лабораторних випробувань нового пристрою для зневоднення золошлакових відходів. Проведено аналіз експериментальних даних по зневодненню золошлакових відходів (золи-віднесення) Краматорської теплоелектростанції розміром $-5 + 0,05$ мм в зневоднюється пристрої з комплексним впливом. У ньому використовується комплекс впливів на сировину: накладення вібраційних коливань, електричного поля і вакуумування. Від того, як підібрані параметри цих впливів залежить ефективність зневоднення. Методом парних лінійних кореляцій отримано, що вологість залежить від кожного зі змінних параметрів і мають слабкий нелінійний характер. Отримані точне і наближене рівняння множинної регресії для практичної оцінки вологості при сукупній дії всіх змінних факторів. Результати досліджень показали, що використання пристрою комплексної дії є перспективним для зневоднення золошлакових відходів. Розроблена узагальнена регресійна модель зміни кінцевої вологості (W_{con}) придатна для оцінки зниження вологості відвальної золи-винесення при зміні параметрів процесу в діапазоні: $W_{ish} = 30\%$, куту нахилу робочого органу $\alpha = 5$ град. і зміні параметрів пристрою в діапазонах: частота коливань вібробудника $\omega = 1500 \div 3000$ об / хв, величина вимушених коливань вібробудника $F = 0,5 \div 0,8$ кН, напруга електричного поля $U = 25 \div 100$ В, тиск у вакуумній камері $P = 0,063 \div 0,1$ мПа. При крупності сировини $+ 0.63-0.05$ мм, зневоднюючий пристрій комплексного дії дозволяє знизити вологість з 30 до 9%.

Ключові слова: вібрація, вакуумування, електроосмос, зневоднення, комплексний метод.

Анотація. Комплексная переработка золы и шлаков угольных тепловых электростанций привлекает большое внимание. Переработка отходов позволит снизить нагрузку на существующие хранилища, осуществить возврат не сгоревшего угля в котлы электростанций, получить ценный сырьевой ресурс для строительства, черной и цветной металлургии. На всех тепловых электростанциях Украины утилизация и складирование золы и шлаков выполняется гидравлическим способом. Поэтому для всех технологий переработки актуально обезвоживание тонкодисперсного сырья. В статье изложены результаты лабораторных испытаний нового устройства для обезвоживания золошлаковых отходов. Проведен анализ экспериментальных данных по обезвоживанию золошлаковых отходов (золы-уноса) Краматорской теплоэлектростанции размером $-5 + 0,05$ мм в обезвоживающем устройстве с комплексным воздействием. В нем используется комплекс воздействий на сырье: наложение вибрационных колебаний, электрического поля и вакуумирование. От того, как подобраны параметры этих воздействий зависит эффективность обезвоживания. Методом парных линейных корреляций получено, что зависимости влажности от каждого из переменных параметров имеют слабый нелинейный характер. Получены точное и приближенное уравнения множественной регрессии для практической оценки влажности при совокупном действии всех переменных факторов. Результаты исследований показали, что использование устройства комплексного действия является перспективным для обезвоживания золошлаковых отходов. Разработанная обобщенная регрессионная модель изменения конечной влажности (W_{con}) пригодна для оценки снижения влажности отвальной золы-уноса при изменении параметров процесса в диапазоне: $W_{\text{ish}}=30\%$, углу наклона рабочего органа $\alpha=5$ град. и изменении параметров устройства в диапазонах: частота колебаний вибровозбудителя $\omega=1500\div 3000$ об/мин, величина вынужденных колебаний вибровозбудителя $F=0,5\div 0,8$ кН, напряжение электрического поля $U=25\div 100$ В, давление в вакуумной камере $P=0,063\div 0,1$ мПа. При крупности сырья $+0.63-0.05$ мм, обезвоживающее устройство комплексного действия позволяет снизить влажность с 30 до 9%.

Ключевые слова: вибрация, вакуумирование, электроосмос, обезвоживание, комплексный метод.

Стаття надійшла до редакції 01.07. 2019

Рекомендовано до друку д-ром техн. наук Б.О. Блюссом