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Investigation of Drying Process Kinetics of Composite Granules

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Abstract

Among the large number of modern environmental problems in Ukraine, waste of wastewater treatment stations occupies a special place. During biological water treatment, the separated sludge deposits are sent to the silt fields, which are the biggest problem. Today, these fields reached their capacity three times over and pose a danger, the consequences of which go far beyond environmental problems and have grown into a chain of socio-economic, technical, medical-biological and moral-ethical problems. Previously, activated sludge was used as fertilizer in the fields, but in connection with the Chornobyl Disaster, it was banned. As a result, accumulations of silt deposits were formed, which are also called obsolete. A modern solution is the compaction of sediments and the development of energy-efficient technologies for the processing of obsolete sludge and incineration in appropriate facilities. This paper presents the results of the drying process study for composite granules based on peat, sludge and biomass. The effect of coolant temperature on the drying rate shows the 1.4-fold intensification of the drying process. Theoretical studies with the construction of generalized drying curves of composite granules calculated by the method of V. V. Krasnikov showed coincidence with experimental data.

Keywords: obsolete silt deposits; peat; biomass; granules; drying.

1. Definition of the problem to be solved

Improving the ecology of Ukraine is one of the important problems. It is strictly forbidden to store sludge deposits without special permits and conditions, it is impossible to bury them on usual landfills, requirements to sludge platforms are regulated by the state standard of Ukraine DSTU 8727:2017 [1].

According to the Global Alliance on Health and Pollution (GAHP), Ukraine ranks fourth in Europe by the number of deaths due to poor ecology. In 2019, the Verkhovna Rada of Ukraine (Supreme Council of Ukraine) approved the Law "On the Basic Principles of Ukraine's Environmental Policy until 2030", which states that one of the root causes of Ukraine's environmental problems is the slow pace of development and implementation of environmentally friendly, resource and energy saving technologies.

Activated sludge is constantly added to overflowing silt maps, which eventually turns into silt deposits. Sludge maps are special areas for sludge dewatering, but non-compliance with disposal technologies often leads to environmental pollution [2].

Recycling of obsolete sludge deposits from overflowing silt maps is one of the solutions to the problem. The problem of processing obsolete silt deposits is that they have virtually no organic component and excessive ash content [3].

2. Analysis of the recent publications and research works on the problem

There are 4 main methods of sewage sludge disposal: use in agriculture, landfilling, ocean discharge, after treatment and incineration. Technologies for processing sludge deposits in Ukraine and the world, covered in previous publications, have shown that most are aimed at processing activated sludge [3] – [7].

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In addition to traditional methods of wastewater treatment the new, no less effective ones are used in the world.

In the countries of the European Union, aerobic and anaerobic treatment of sewage sludge is significantly preferred. Anaerobic sewage sludge treatment is most commonly used in Spain, the United Kingdom, Italy, Finland and Slovakia, and aerobic sewage sludge treatment technologies are used in the Czech Republic and Poland [8].

Studies have shown that during aerobic transformation humic acids are formed in large quantities in the sediment of wastewater, and during anaerobic transformation proteins and aromatic amino acids are formed, which are part of organo-mineral fertilizers in agriculture [9].

A new science-intensive process of processing a mixture of household waste and sewage sludge is low-temperature pyrolysis, implemented in Japan, Italy, Germany and other countries. Pyrolysis of waste occurs at a temperature of 250 – 400 ºC.

The peculiarity of low-temperature pyrolysis is that the processed sludge turns into hydrocarbon first in the gaseous state, and after its condensation the main product "crude oil" is obtained [10] – [11].

The process of carbonization of sewage sludge is interesting, and in this aspect their heat treatment on sludge sites leads not only to a decrease in accumulation, but also allows the further use of sludge as an alternative fuel [12].

3. Formulation of the goal of the paper

In Ukraine, there is a problem of "obsolete" sludge, which is stored for years and contains almost no organic matter, which complicates the processing process. Therefore, the *aim of the research* is to study the processing of obsolete sludge and the creation of fuel pellets based on them with the addition of peat, biomass and their drying.

4. Presentation and discussion of the research results

To achieve this goal the following task was solved: the study of heat and mass transfer processes in the composite raw materials drying based on peat, obsolete sludge and biomass (buckwheat or sawdust husks).

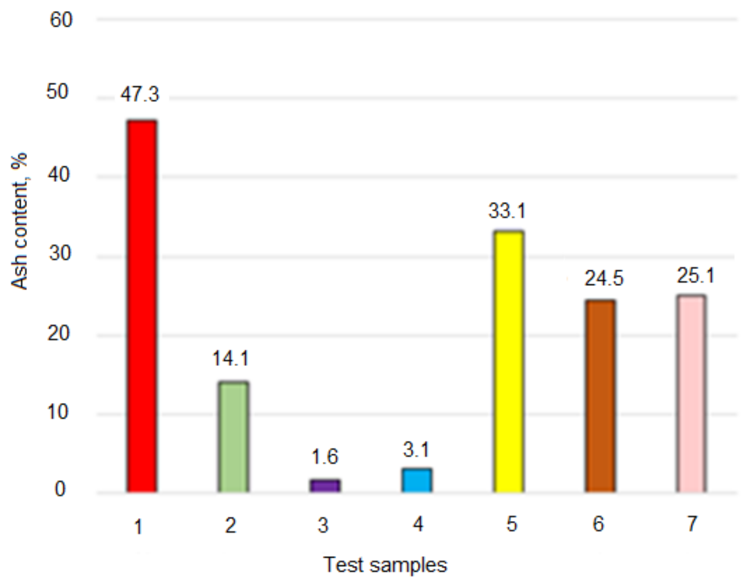

Fig. 1. Ash content of compositions and their components:
1 - sludge deposits; 2 - milling "fresh" peat; 3 - buckwheat husk;
4 - sawdust; 5 - two-component composition based on sludge deposits and peat;
6 - three-component composition based on sludge deposits, peat and buckwheat husks;
7 - three-component composition based on silt, peat and sawdust.

Compositions were created on the basis of obsolete sludge deposits, peat and biomass. Fig. 1 shows the ash content of the created compositions and their components. The figure shows that adding peat to sludge deposits and creating a two-component composition can reduce ash content 1.4-fold. Creating a three-component composition with the addition of two-component on the basis of sludge and peat biomass can reduce the ash content by 1.8–1.9 times [13].

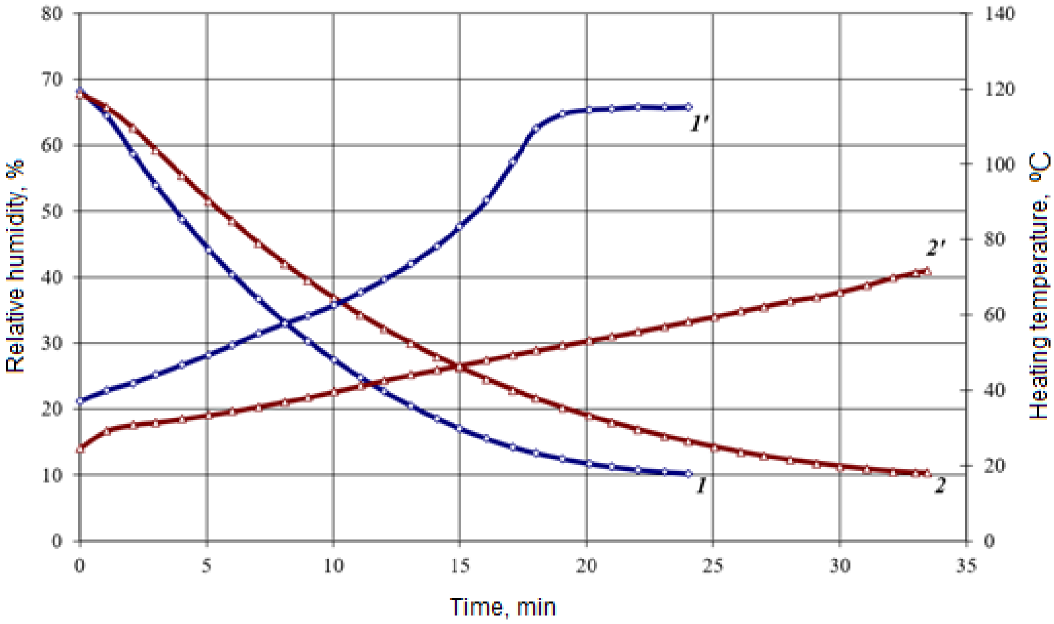

Fig. 2. Change in moisture content of sludge-peat granules (1, 2) and temperature in the middle of the granules (1', 2') in the proportion of 50 % sludge / 50% peat at V = 2 m/s, d = 6 mm: 1, 1' – 120 ºC; 2, 2' – 80 ºC.

Granulation of two- and three-component compositions was performed on a screw mechanical device [14]. Drying kinetics studies were performed on a convective drying stand, which allows heat treatment with a drying agent at a temperature of 80 – 120 °C and a speed of 0.5 – 5 m/s, with automatic information collection [15].

Figure 2 shows the drying kinetics and temperature curves of sludge-peat granules on a convective drying stand at the temperatures of 80 ºC and 120 °C in the proportion of 50 % sludge / 50 % peat.

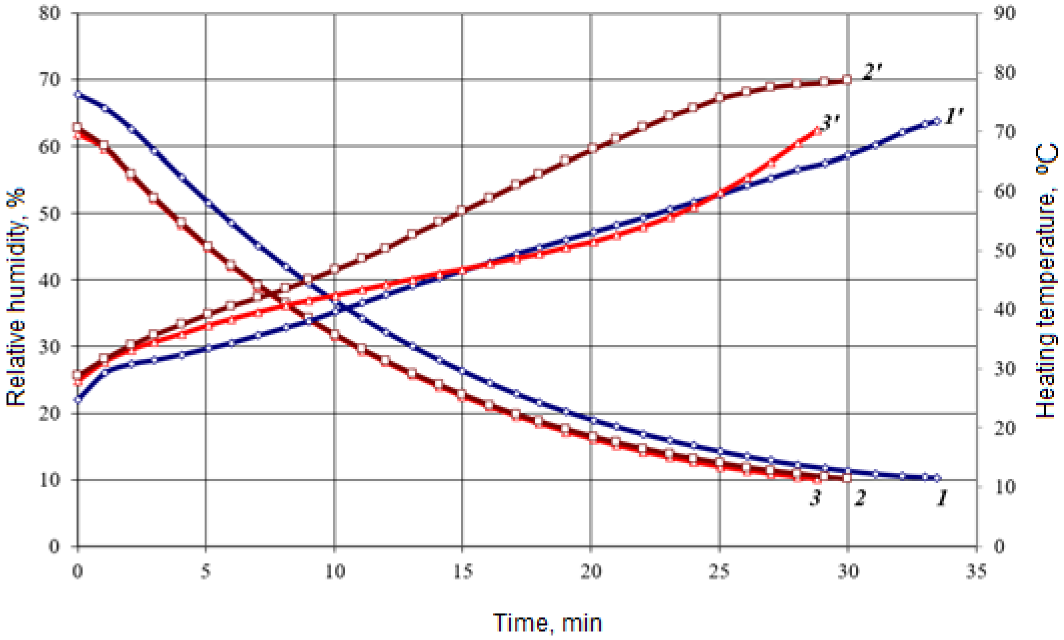

Fig. 3. Change in moisture content (1, 2, 3) and temperature in the middle of the granules (1', 2', 3').
Two- and three-component granules at t = 80 ºC, V = 2 m/s, d = 6 mm:
1,1' – two-component granules in proportion 50 % sludge / 50 % peat;
2, 2' – three-component granules in proportion 45 % sludge / 45 % peat / 10 % buckwheat husks;
3, 3' – three-component granules in proportion 45 % sludge / 45 % peat / 10 % sawdust.

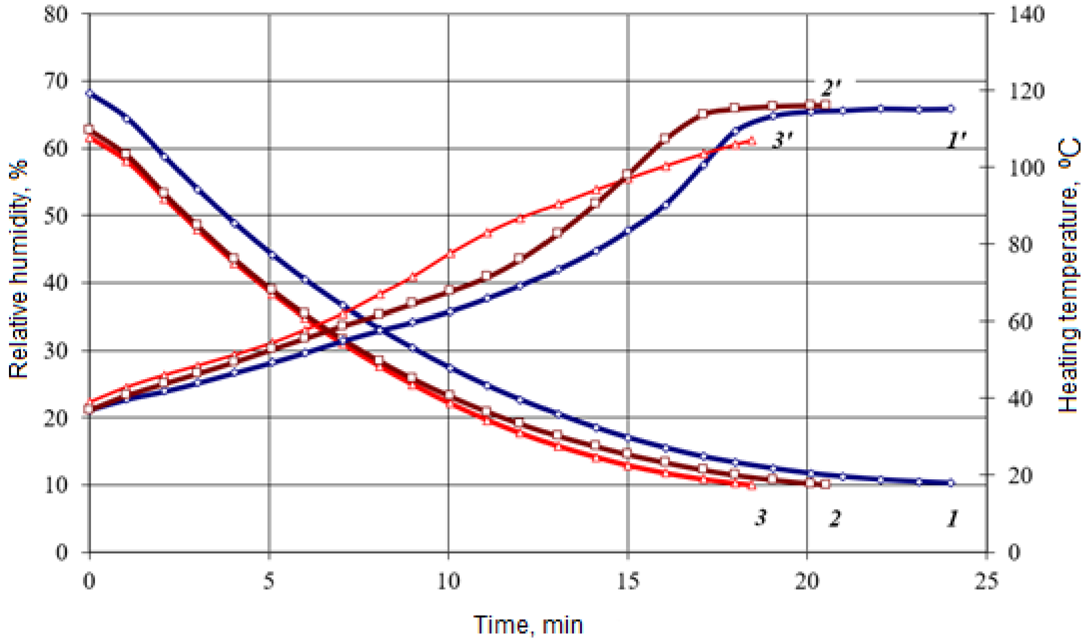

Fig. 4. Change in moisture content (1, 2, 3) and temperature in the middle of the granules (1’, 2’, 3’).
Two- and three-component granules at t = 120 ºC, V = 2 m/s, d = 6 mm:
1, 1’ – two-component granules in proportion 50 % sludge / 50 % peat;
2, 2’ – three-component granules in proportion 45 % sludge / 45 % peat / 10 % buckwheat husk;
3, 3’ - three-component granules in proportion 45 % sludge / 45 % peat / 10 % sawdust.

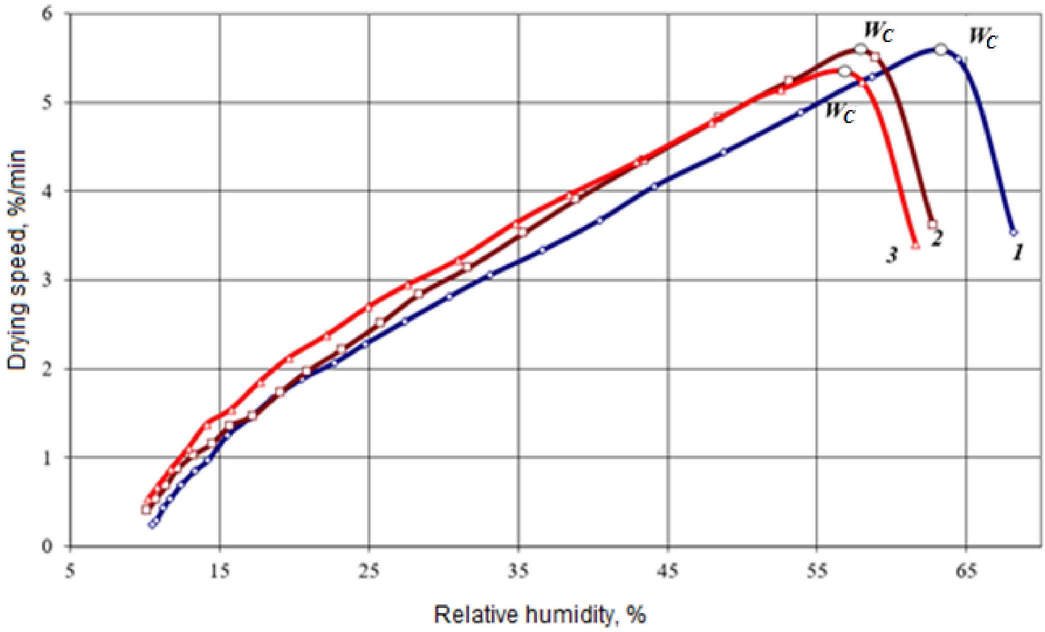

Fig. 5. Changing the drying rate of two- and three-component granules.
Mode parameters t = 120 ºC, V = 2 m/s, d = 6 mm:
1 – two-component granules in proportion 50 % sludge / 50 % peat;
2 – three-component granules in proportion 45 % sludge / 45 % peat / 10 % buckwheat husk;
3 – three-component granules in proportion 45 % sludge / 45 % peat / 10 % sawdust.

The duration of drying of peat granules with increase in coolant temperature from 80 to 120 °C decreases by 29.5 % (Fig. 2). The heating of the granules at a coolant temperature of 80 ºC is uniform and at a humidity of 10 % of the granules is 72 °C, at a temperature of 120 °C the heating of the granules is more intense and at the corresponding humidity is 115 °C.

Fig. 3 and 4 show the change in moisture content and temperature in the middle of the layer of two- and three-component granules at coolant temperatures 80 °C and 120 °C. Figure 3 shows that the three-component mixtures drying at a coolant temperature of 80 °C accelerates the process by 10 – 16 %. The highest warming temperature is observed in three-component granules of 45 % sludge / 45 % peat / 10 % buckwheat husk and is 78.7 ºC, the lowest warming of 70.3 °C is observed in three-component granules 45 % sludge / 45 % peat / 10 % sawdust.

When three- component granules are dried at a coolant temperature of 120 °C, the process is faster by 13 – 25 % vs. two- component granules based on sludge and peat (Fig. 4). Heating of three-component granules based on sludge deposits, peat and buckwheat husks (curve 2') has the nature of heating of two-component granules based on sludge deposits and peat (curve 1') and the temperature is 116 °C. Three-component granules based on sludge, peat and sawdust have a heating temperature of 107 °C.

Fig. 5 shows the dependence of the drying rate on the moisture content of two- and three-component granules. In two-component sludge-peat granules, the drying rate at the critical point *Wc* is the same as in the three-component granules based on sludge deposits, peat and buckwheat husks and is 5.7 %/min. The three component granules based on sludge, peat and sawdust have a lower drying rate at the critical point *Wc* which is 5.3 %/min.

To calculate the kinetics of heat and moisture exchange during drying of composite granules, the method of V. V. Krasnikov was used [16], [17]. Analyzing the generalized drying curves, we can say that all modes fall on one curve with an error of not more 10 % (Fig. 6). By value *Nmax τ* the fastest process occurs when drying three-component granules in the proportion of 45 % sludge / 45 % peat / 10 % sawdust.

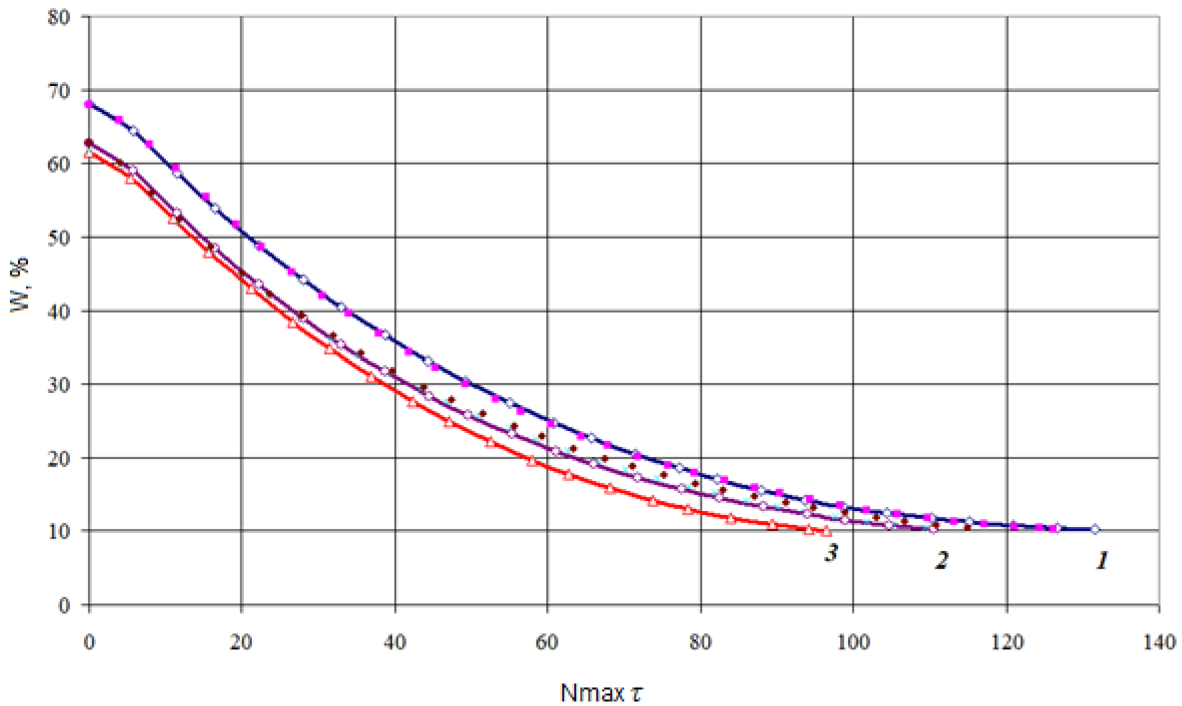

Fig. 6. Generalized drying curves of composite granules in the coordinate system $W – N_{max}\ \tau$:
1 – silt-peat granules in proportion 50 % sludge / 50 % peat;
2 – three-component granules in proportion 45 % sludge / 45 % peat / 10 % buckwheat husk;
3 – three-component granules in proportion 45 % sludge / 45 % peat / 10 % sawdust.

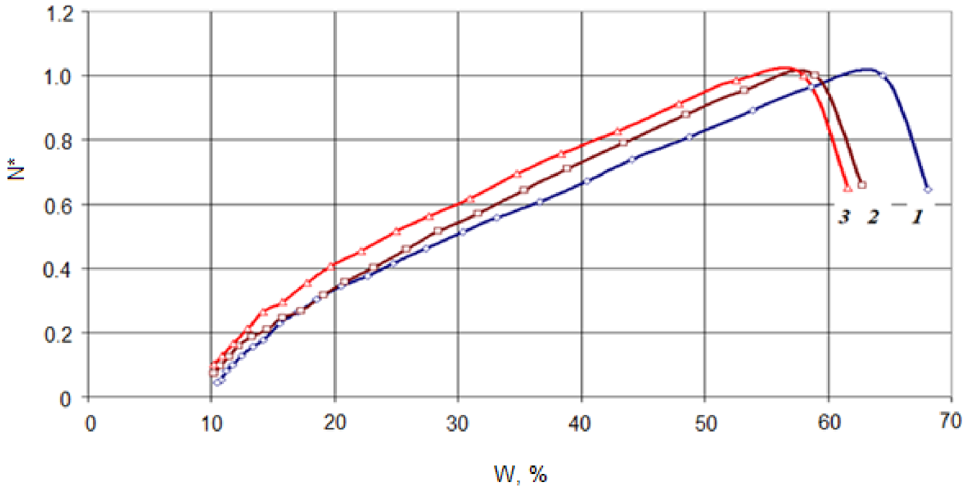

Fig.7. Generalized drying curves of composite granules:
1 – sludge-peat granules in proportion 50 % sludge / 50 % peat;
2 – three-component granules in proportion 45 % sludge / 45 % peat / 10 % buckwheat husk;
3 – three-component granules in proportion 45 % sludge / 45 % peat / 10 % sawdust.

Carrying out graphical differentiation of the generalized curve of drying kinetics presented in Fig. 6, we obtained a generalized drying curve of composite granules, which is presented in Fig. 7.

The total duration of the drying process τ_T (without taking into account the warm-up period) consists of the duration of drying in the first period τ_I, in the 1-st τ_1, 2-nd τ_2 and 3-d τ_3 parts of the second period:

$$\tau_T = \tau_I + \tau_1 + \tau_2 + \tau_3 . \quad (1)$$

Since the first period of drying, when drying the granules, is not observed, formula (1) takes the below form:

$$\tau_T = \tau_1 + \tau_2 + \tau_3 .$$

Duration of drying in the 1st part of the second period:

$$\tau_1 = \frac{1}{\chi_1 N} \lg \frac{Wc_1}{Wc_2}. \quad (2)$$

Duration of drying in the 2nd part of the second period:

$$\tau_2 = \frac{1}{\chi_2 N} \lg \frac{Wc_2}{Wc_3}. \quad (3)$$

Duration of drying in the 3rd part of the second period:

$$\tau_3 = \frac{1}{\chi_3 N} \lg \frac{Wc_3}{Wc}. \quad (4)$$

The total duration of the process:

$$\tau_T = \frac{1}{N}\left(\frac{1}{\chi_1} \lg \frac{Wc_1}{Wc_2} + \frac{1}{\chi_2} \lg \frac{Wc_2}{Wc_3} + \frac{1}{\chi_3} \lg \frac{Wc_3}{Wc}\right). \quad (5)$$

where N is maximum drying speed; Wc_1, Wc_2, Wc_3 are critical moisture contents in 1-st, 2-nd, 3-d part of second period; χ_1, χ_2, χ_3 are relative drying ratios in the relevant parts.

The total drying time of the granules is calculated and summarized in the Table 1.

Table 1. The duration of the drying process of composite granules.

Number	Name of composite granules	Estimated duration of the drying process, min
1	Sludge-peat (50 % sludge / 50 % peat)	$\tau_T = \frac{112.47}{N}$
2	Sludge-peat with the addition of buckwheat husk (45 % sludge / 45 % peat / 10 % buckwheat husk)	$\tau_T = \frac{86}{N}$
3	Sludge -peat with sawdust addition (45 % of silt / 45 % of peat / 10 % of sawdust)	$\tau_T = \frac{78.4}{N}$

The value of N at different stages of the drying process in the second period is determined by the empirical dependences shown in Table 1.

5. Conclusion

Research of the kinetics of the drying process of composite granules are dedicated to the development of a unified approach to the effective processing of sludge with the addition of flammable fillers such as milling peat, buckwheat husk, wood waste (sawdust). The use of composite mixtures in the form of granules with the optimal ratio of components allows solving rational problems of the gradual elimination of huge volumes of obsolete sludge from sewage treatment plants, which puts them on the verge of inoperability, which causes negative environmental impact and geological hazards.

The processes of drying composite granules based on obsolete sludge, peat and biomass were studied and effective drying regimes were determined. Based on experimental studies, it was determined that the addition of an organic component in the form of sawdust or buckwheat husk reduces the drying time and increases the drying speed. It is proved that at a coolant temperature of 80 ºC the drying time increases in comparison with 120 ºC approximately 1.4-fold. Relative coefficients and drying coefficients were calculated, formulas for the two- and three-component granule drying duration were received.

To calculate the kinetics of heat and moisture exchange during the drying of composite granules, the method of V. V. Krasnikov was used. Kinetic regularities of convective drying of two- and three-component granular compositions were determined and generalized.

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Дослідження кінетики процесу сушіння композиційних гранул

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Анотація

Поміж великої кількості сучасних екологічних проблем в Україні особливе місце займають відходи станцій очистки стічних вод. Під час біологічної очистки води, відокремлені мулові відкладення направляють на мулові поля, які є найбільшою проблемою. Ці поля на сьогоднішній день переповнені втричі та несуть небезпеку, наслідки якої вийшли далеко за межі проблем довкілля і переросли у ланцюг соціально-економічних, технічних, медико-біологічних та морально-етичних проблем. Раніше активний мул використовували як добриво на полях, проте в зв’язку із Чорнобильською аварією це заборонили. Внаслідок цього утворились нагромадження мулових відкладень, які ще називають застарілими. Сучасним рішенням є ущільнення відкладень та розробка енергоефективних технологій переробки застарілих мулових відкладень та спалювання у відповідних установках. В даній статті наведені результати дослідження процесу сушіння для композиційних гранул на основі торфу, мулових відкладень та біомаси. Вплив температури теплоносія на швидкість сушіння, показує інтенсифікацію процесу сушіння приблизно у 1,4 рази. Проведені теоретичні дослідження з побудовою узагальнених кривих сушіння композиційних гранул розрахованих за методом В. В. Краснікова показали співпадіння з експериментальними даними.

Ключові слова: застарілі мулові осади; торф; біомаса; гранули; сушіння.