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TRANSFORMATION OF TECHNOGENIC WASTE BASED ON WATER TREATMENT SLUDGE INTO GRANULATED FERTILIZER

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Low-temperature transformation of technogenic waste, and water treatment sludge and fly ash of thermal power plants in particular, into long-acting fertilizers is a promising way to reduce their negative impact on the environment. We developed technology of waste utilization that includes determining the composition of the raw material mixture, mixing, granulation and drying of the fertilizer granules. It was stated that the components of the fertilizer should be mixed in the following ratio (wt.%): fly ash 4–6; CaO 20–25; zeolite clinoptiolite 15–20; sludge of water treatment of municipal sewage 50–55; and urea – the remainder. During the mixing of the components and their granulation some physical and chemical processes take place and heat releases; therefore to ensure the required moisture of the granules, they were dried at the temperature of 30–40^{0}C. The obtained porous granules of fertilizer contain (wt.%): total nitrogen 5.1–5.2; total potassium 0.34–0.35; total calcium 21.7; and ammonium nitrogen 0.6–0.7. Zeolite as an adsorbent promotes the gradual release of ammonium from fertilizer into the soil. The results of fertilizer testing showed that sunflower biomass was increased by 7–10% in case of using the fertilizer as compared with the soil without it.

Keywords: sewage sludge, granulated fertilizer, fly ash, zeolite, experimental design, utilization.

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Introduction

The main factors of man-made environmental pollution are insufficiently treated wastewater, solid waste, harmful emissions generated by industrial enterprises and municipal waste, which damage human health, biodiversity and environmental safety of region [1].

According to statistics, the total amount of waste accumulated at specially designated facilities in Ukraine at the end of 2020 is about 15.4 billion tons, 46.8 million tons of which are accumulated in the Ivano-Frankivsk region, including 639.2 thousand tons of ash sludge and 108.6 thousand tons of water treatment sludge with moisture content of about 50%, stored on sludge fields. In the western region, about 800,000 tons of ash and slag are formed annually at Burshtyn thermal power plant, which is partially disposed. The municipal enterprise «Ivano-Frankivsk Vodoekotekhprom» produced about 2 million m^3 of water treatment sludge after a settling tank of biological treatment facilities with moisture of 70–90%, which is pumped out or taken to silt fields.

Depending on the chemical composition, the contents of inorganic and organic components and heavy metals in particular, man-made waste is recommended to use as additives for the production of insulation materials or in certain technological processes, for instance for the manufacture of building materials and products [2], in the bio-energy production [3], as an additive for the cement industry, which reduces the energy consumption of clinker burning [4], and as components of fertilizers [5].

The implementation of environmental policy in the agro-industrial complex attracts considerable interest. The use of sewage sludge and fly ash as raw material for fertilizers has been described in the literature [6–12]. The elemental composition of the fly ash is represented mainly by Ca, Fe, Mg, K, Na, which are necessary for plant growing, and other elements, Si, Al and Ti in particular. However, fly ash also contains many trace elements (B, Se, Mo and other), excess of which can be toxic to plants if used without regard to the needs and composition of the soil. Studies have shown that usage of fly ash and lime in acidic soils can improve their properties and increase yields [6].

The methods of processing of N, P, K, Ca-containing waste and preparation of mineral fertilizers have been described [7]. A detailed technological scheme was developed to obtain complex fertilizer based on activated sludge, fallen leaves and sediment after extraction of phosphates from wastewater, sludge production of calcium nitrate, which for the first time uses a dispersion process that accelerates the settling of activated sludge [8]. It was shown [9] that natural zeolite is an effective adsorbent of ammonium nitrogen and phosphate ions from wastewater to prepare fertilizers. A number of studies [10,11] confirmed that the introduction of sewage sludge into soils significantly increases the content of nutrients, accelerates the growth of crops and has a positive effect on the physical properties of the soil. The use of water treatment sludge and compost with sawdust and straw in the ratio of 3:1 was favorable to cultivate energy osier [12].

The largest amount of biomass and energy per unit of area in agrocenoses is provided by using fresh sewage sludge (80 tons/ha). Studies of the impact of fly ash and sewage sludge have shown a significant increase in wheat yield and plant biomass due to an increase in organic matter and total nitrogen content after sludge introduction into soil. Sewage sludge has an increased content of heavy metals (Cu, Zn, Mn, Ni and Pb) [11]. It was shown that the pH value of sewage sludge deposited on the soil should be above 6.0 to avoid increasing mobility of heavy metals in the sludge, which can lead to contamination of plants with heavy metals [12]. The use of biodegradable polymers for encapsulation of fertilizer granules seems to be promising [13].

Therefore, significant accumulation and use of municipal sewage sludge as a component of fertilizer, depending on its chemical composition, is an important environmental safety issue and requires further research. Thus, conducting research of the transformation of sludge of municipal wastewater treatment into granulated fertilizer, which allows establishing the composition of the raw material mixture and the relevant parameters of technology, will ensure the disposal of hazardous waste.

The aim of the study is to determine the optimal composition of the raw material mixture based on the municipal water treatment sludge and the process parameters for obtaining granulated fertilizers of acceptable size, density and moisture.

Materials and experimental methods

It is important to know the composition of the sludge (organic content, ammonium compounds, and moisture) to carry out the recycling of water treatment sludge. This affects the method of disposal and determines the possibilities of sludge use. The main problem of sludge conversion is its high moisture.

The results of the study of the chemical composition of municipal sewage sludge, as well as other components of the proposed raw material mixture are given in Tables 1 and 2. The proposed

Table 1

Component and chemical composition of waste and additives

Wastes and additives	Content, wt.%								
	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	P_2O_5	N_{total}	C_{total}	H_2O and others
quicklime	2.5	1.6	1.5	89.6	0.4	–	–	–	4.4
zeolite clinoptiolite	71.5	13.7	2.1	2.1	3.3	–	–	–	7.3
sewage sludge	5.4	4.2	6.2	8.5	0.4	2.1	1.2	21.3	50.7
fly ash	52.6	27.1	11.3	3.6	3.1	–	–	–	2.3
urea	–	–	–	–	–	–	46.7	20.0	33.3

Table 2

Chemical composition of sewage sludge of Ivano-Frankivsk

Sludge sample	Content, wt.%						
	ash	N_{total}	P_{total}	K_{total}	Ca	organic matter	moisture
mud map No. 1-2016	54.9	1.5	2.0	0.29	12.4	45.1	49.5
mud map No. 2-2018	51.5	1.2	2.4	0.34	12.9	48.5	50.9
mud map No. 3-2020	51.7	2.3	2.2	0.32	12.7	48.3	51.7

additive components reduce the moisture content of sludge and increase the content of N, P, K, Ca, which are important for the fertilizer. The four major oxides of nonorganic part of sludge are silica, alumina, calcium and iron oxides (Table 1).

Fly ash as a microfiller causes a decrease of inner granular hollows, and simultaneously with other additives allows fabricating materials with increased strength [2]. To obtain organic-mineral long-acting fertilizer, it was proposed to use zeolite with excellent adsorption properties. This component ensures complete absorption of nutrients and their prolonged release into the soil and the plants. Introduction of natural dispersed sorbent, zeolite and calcium oxide, into the sludge water treatment will cause the effective reduction of moisture at the stage of preparation of the raw mixture for the granulation process.

Quicklime was used for dehydration and disinfection of sewage sludge. The addition of quicklime provides an increase in the alkalinity of the sludge and the growth of temperature in the process of interaction with water. The odor of sewage sludge is lost and the development of harmful microorganisms stops at pH higher than 10 [7]. Theoretically, when 1 mole (56 g) of CaO is slaked, 63.7 kJ of heat are released and 18 g of water are bound:

$$CaO+H_2O \rightarrow Ca(OH)_2+63.7\ kJ.$$

An increase in the temperature causes the dehydration and pasteurization of sludge. The theoretical increase in temperature of the mixture of sludge and lime is calculated according to the following common formula, which takes into account the masses of sludge (m_{sl}) and lime (m_{CaO}), and the heat capacities of sludge (c_{sl}) and lime (c_{CaO}):

$$\Delta t = \frac{1160 \cdot A \cdot m_{CaO}}{m_{sl}c_{sl} + m_{CaO}c_{CaO}}, \qquad (1)$$

where 1160 is the amount of energy released during the slaking of 1 kg of CaO (kJ/kg); and A is the activity of lime.

The presence of lime provides an increase in the strength of the granules during heat treatment due to pozzolanic reactions with the other components (fly ash and zeolite) with formation of low-basic calcium hydrosilicates and calcium hydroaluminates:

$$Ca(OH)_2+2Al(OH)_3 \rightarrow Ca(AlO_2)_2 \cdot 4H_2O,$$

$$(0.8-1.5)Ca(OH)_2+SiO_2+nH_2O \rightarrow$$
$$\rightarrow (0.8-1.5)CaO \cdot SiO_2 \cdot nH_2O.$$

Lump construction quicklime of grade II with the content of active CaO and MgO (lime activity) 85% was used in our study.

Granulation of the raw material mixture based on water treatment sludge for fertilizers is best done in a screw device and it requires the introduction of an additive, which increases the viscosity of the mixture. Urea is used for this purpose. This component provides both viscous properties of liquid phase and an increase in the content of ammonium nitrogen.

During the hydrolysis of urea, ammonium carbonate is formed and decomposed in the soil with the release of NH_3 [14]:

$$CO(NH_2)_2+H_2O=(NH_4)_2CO_3,$$

$$(NH_4)_2CO_3=2NH_3+CO_2+H_2O.$$

Ammonia is adsorbed by zeolite, which provides a prolonged effect of the fertilizer. A laboratory mill was used to mix fly ash, zeolite flour, calcium compounds and sewage sludge in certain proportions.

The next technological operation of the proposed method is the formation of granules using a screw granulator. The advantages of granulated fertilizers are ease of transportation and application into soil with their even distribution. The fertilizers do not dust and are slowly washed away by groundwater due to granulation. Then granules were directed for thermal treatment at 30–50^{0}C for 0.5–1.0 hour. The process of the granules treatment was carried out in a laboratory dryer.

The moisture content of granular fertilizers was determined in accordance with the state standard DSTU EN 12048:2005 by gravimetric method at the temperature of 105±2^{0}C. The content of total nitrogen and adsorbed ammonia was determined in accordance with the state standard DSTU 7911:2015. Determination of total nitrogen is based on the mineralization of a sample of fertilizer with concentrated sulfuric acid in the presence of hydrochloric acid. The content of ammonium nitrogen in extracts was determined by photometric method with Nessler's reagent. The flame-photometric method was used to determine the mass fraction of total potassium and total phosphorus. Laboratory studies of fertilizer samples also included the determination of the content of mobile forms of the following trace elements and heavy metals: Zn, Co and Cu according to the state standards DSTU 4770.2, DSTU 4770.5 and DSTU 4770.6, respectively.

The bulk density and strength of the granules are important indicators for storage and transportation of fertilizers. The porosity of the granules provides long-term action of fertilizers. The bulk density of the obtained granular porous materials was conducted according to the methods given in the state standard DSTU ISO 3944:2003. The granular fertilizer was put into a weighed vessel with capacity of 1 L from a height of 100 mm above its upper edge, forming a cone above the upper part of the vessel. The cone was removed with a metal ruler and the vessel with fertilizer is weighed.

The porosity of the granules was determined taking into account an average density of granules determined according to the state standard GOST 33832-2016. About 50 g of the prepared sample was placed in a glass. Oil was poured into 600 cm^3 glass to cover the granules and was mixed so that the surface of all granules was wet. The glass was covered with clock glass and kept for an hour at the temperature of 25^0C. The industrial oil I-40A was used. The content of the glass was filtered through a sieve and held for an hour to remove excess oil. Samples of granules were placed on a flat surface of two sheets of filter paper. At the top of the sample, another sheet of filter paper was placed. Granules were rolled between two sheets of filter paper, applying a little pressure and conducting 24 circular motions. Immediately after rolling, the granules were weighed. Porosity was calculated by the following formula:

$$X = \frac{m_2 - m_1}{m_1}, \qquad (2)$$

where m_2 is the initial weight of the sample; and m_1 is the weight of the sample after treatment.

The sample-cubes 20×20×20 mm were formed and heat treated to determine the strength of materials based on water treatment sludge. The samples were tested using a hydraulic press with maximum force of 50 kN. The method of mathematical experimental design was used to determine the component composition of fertilizers based on sludge water treatment and fly ash [15].

Results and discussion

In the first stage of research, approbation studies were conducted to ensure the required moisture of the raw material mixture based on municipal sewage sludge. The proposed components, such as zeolite and quicklime, absorb moisture due to its interaction with CaO and adsorption by zeolite.

The theoretical increase in temperature is 60–200^0C when 0.25–1.0 parts of CaO per 1.0 part of water treatment sludge were introduced (Fig. 1).

Part of the heat is dissipated into the environment and the rest is spent on water evaporating and heating other components of the mixture under real conditions. Therefore, the actual temperature of the mixture is in the range of 45–70^0C.

Experimental and approbation studies of the formation of a raw mixture containing five components were performed by mixing the components at different ratios, which are shown in Table 3. Treatment time was the same (0.5 hour).

Experimental results show that an increase in the temperature of the mixture sludge+CaO+zeolite is 34–55^0C at the average ratio of 1:0.8:1.2. Thus, the addition of CaO will reduce energy consumption at the final stage of granule drying. It should be noted that trial experiments showed that the raw material mixture has no plastic (molding) properties and a crumbly mixture is formed when the ratio sludge:CaO was 1:1, without other components. Thus, a ratio sludge:CaO of 1:0.5 or less was used in further experiments.

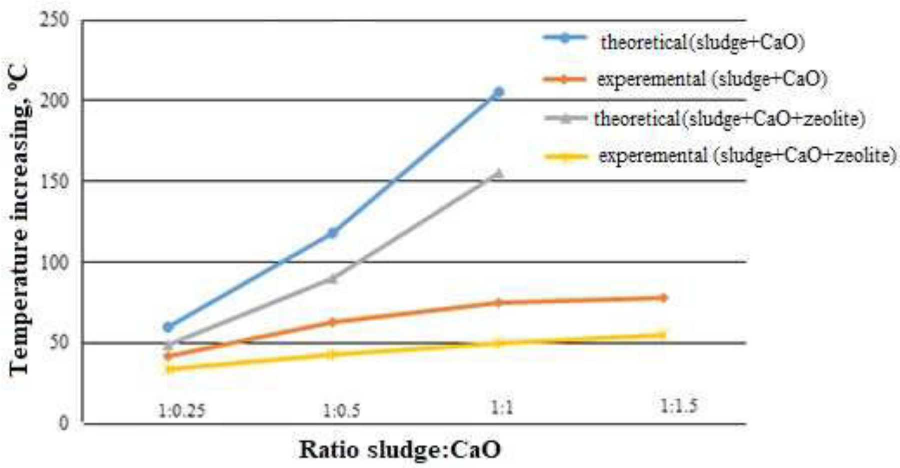

Fig. 1. Theoretical and experimental temperature increasing of mixtures

Table 3

The ratio of components and technological and process parameters

Number of sample	Mixture composition, g					Temperature, ^0C
	fly ash	sludge	lime	zeolite	urea	
1	70	392	200	340	55	60
2	80	350	200	350	54	63
3	100	360	245	375	70	65
4	54	265	190	240	45	66
5	58	264	208	390	50	62
6	85	305	245	330	65	67
7	60	280	345	215	50	69

In the second stage of experimental studies, the following average ratios of components were used: ash 0.2, sludge 2, lime 1, zeolite 0.8 to obtain granules of fertilizer they are shown in Table 4.

The method of experimental design is used to study the possibility of utilization of the maximum amount of water treatment sludge and to optimize of the formulation [15]. The variation factors are chosen as the prescription factors (sludge content in the mixture) X_1=2, 3, and 4 wt. parts and technological factors (processing temperature) X_2=30, 40, and 50^{0}C (Table 4). The ratio between pozzolanic additive (zeolite clinoptilolite and fly ash) in the mixture is about 4:1. The amount of urea in the raw mixture is 5 wt.%. Heat treatment of the samples lasted 0.5 h.

The following control parameters are chosen for experiments: Y_1 is the compressive strength of samples (MPa); Y_2 is the porosity (%); and Y_3 is the bulk density of porous granular material (kg/m^3). The design matrix of the experiment for the utilization of water treatment sludge is given in Table 5.

The regression coefficients are calculated by using the matrix approach of regression analysis and finding the regression coefficients of equations (Table 6).

Analysis of regression coefficients allows making a number of technological conclusions. Thus, negative value of the coefficient b_1 indicates that the introduction of sludge into the mixture causes decreasing of strength of the porous material granules, and negative value b_2 indicates that an increase in the temperature causes a decrease in the porosity of the granules. The introduction of the maximum amount of sludge and an increase in the curing temperature has a negative effect on the strength of the granules (the negative values of the coefficients b_{11} and b_{22}). An increased bulk density of granular

Table 4

The ratio of components and technological parameters of the process

Number of sample	Mixture composition, g					Parameters	
	fly ash	sludge	lime	zeolite	urea	Temperature, ^0C	Time, h
1	90	900	450	360	90	30	0.5
2	90	900	450	360	90	40	0.5
3	90	900	450	360	90	50	0.5
4	60	900	300	240	75	30	0.5
5	60	900	300	240	75	40	0.5
6	60	900	300	240	75	50	0.5
7	45	900	225	180	67	30	0.5
8	45	900	225	180	67	40	0.5
9	45	900	225	180	67	50	0.5

Table 5

Design matrix and full two-factor experiment results

No.	Design matrix				Control parameter		
	X_1	X_2	Sludge content, (X_1), wt. part	Temperature (X_2), ^0C	Compressive strength, MPa	Porosity, %	Bulk density, кg/m^3
					Y_1	Y_2	Y_3
1	–1	–1	2	30	2.4	56	245
2	–1	0	2	40	3.5	52	255
3	–1	+1	2	50	3.7	50	260
4	0	–1	3	30	3.4	53	320
5	0	0	3	40	3.7	50	355
6	0	+1	3	50	3.8	47	360
7	+1	–1	4	30	2.3	59	250
8	+1	0	4	40	2.7	56	270
9	+1	+1	4	50	2.9	54	285

Table 6

Regression coefficients for optimization parameters

Parameter	Regression coefficients					
	b_0	b_1	b_2	b_{12}	b_{11}	b_{22}
Y_1	3.53	–0.13	0.17	–0.48	–0.40	–0.30
Y_2	49.67	1.83	–2.83	0.85	–4.50	0.50
Y_3	349.44	7.50	15.00	5.50	–84.17	–6.67

material is observed when increasing the processing temperature (coefficient b_2). The effect of parameter X_1 on the maximum value on the decrease of bulk density, strength and increasing of porosity is more significant than the effects of parameter X_2.

According to the test results, the 3D plots of the compressive strength of the granular material, porosity, and bulk density of the granules, (Y_1, Y_2, and Y_3, respectively) were drawn (Fig. 2).

Analysis of graphical dependences of changes of the main indicators, porosity, bulk density of granules, and compressive strength of granule material on the treatment temperature and sludge content shows that the optimal value of granule strength can be achieved when using the following composition of the raw material mixture (wt.%): sludge 55, lime 20, zeolite 15, fly ash 4, and urea – the rest. Optimal porosity can be achieved by using the following composition (wt.%): sludge 50, lime 23, zeolite 19, fly ash 5, and urea – the rest.

The technology of utilization of water treatment sludge consists of pumping the sludge by pumps from the tank into the mixer, where other components of the raw material mixture, which is homogenized with dry components: quicklime, zeolite, fly ash, and urea. The granulation process of the raw material mixture is effectively conducted in the screw granulator. Heat treatment of granules was carried out in tunnel-type aggregate at different temperatures, depending on the moisture, the composition of the water treatment sludge and the content of the added components.

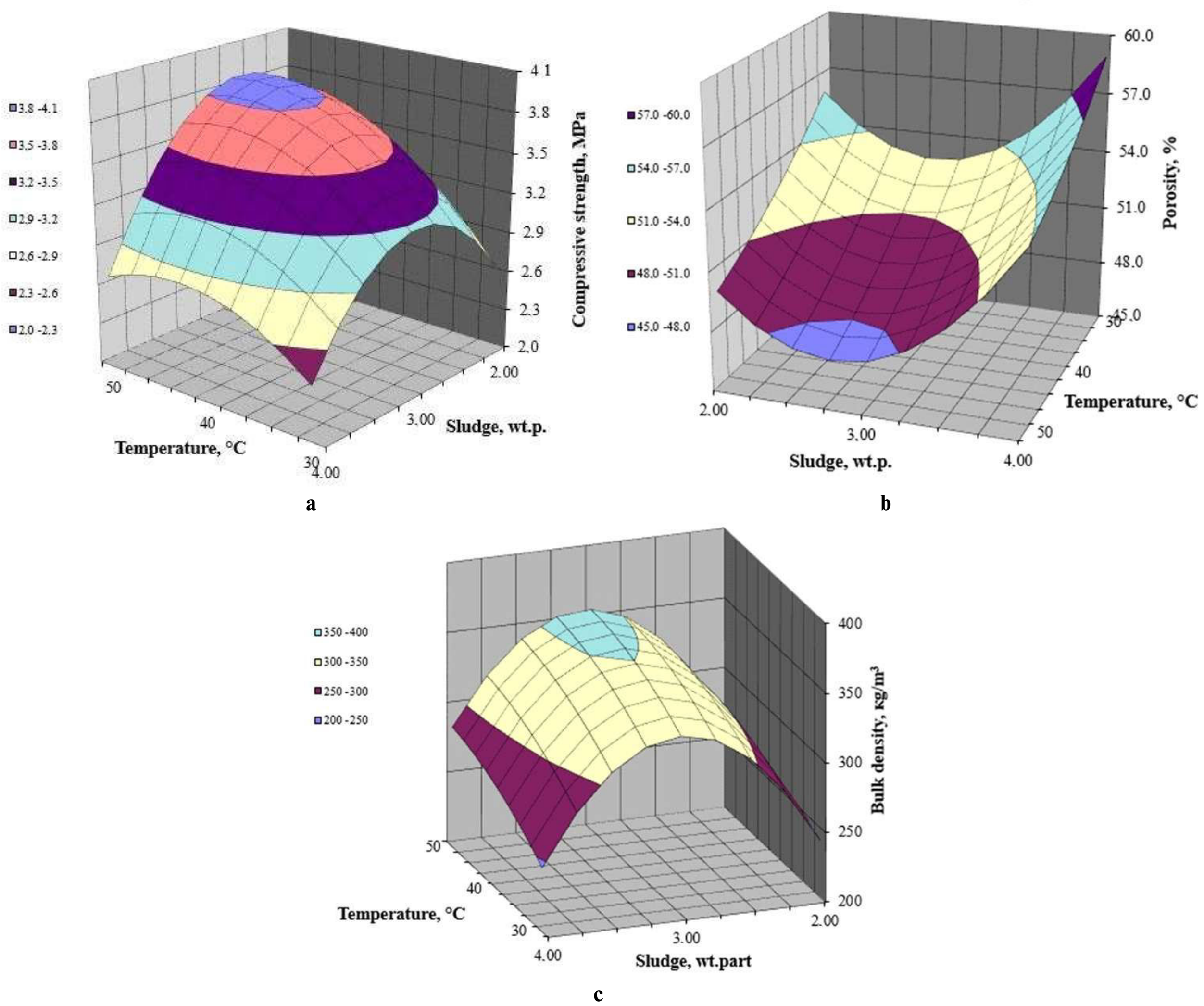

Fig. 2. Response surfaces of compressive strength of material (a), porosity (b), and bulk density (c) of granules

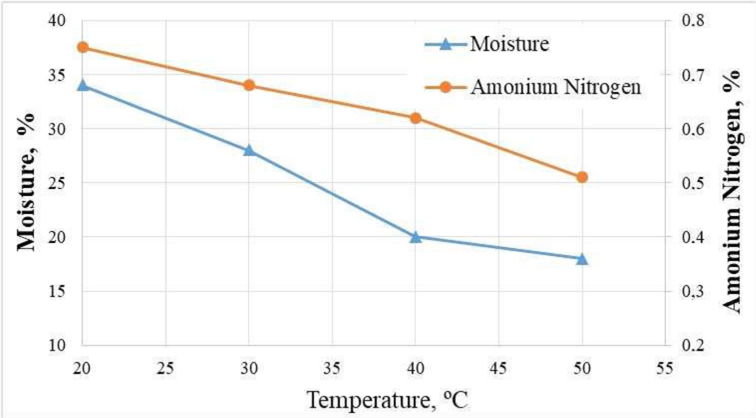

Fig. 3. Change of moisture and ammonium nitrogen content in granules of samples No. 5

The proposed method of granulating fertilizers of prolonged action based on water treatment sludge consists of three following stages: the mixing of dry components with water treatment sludge according to the established optimal ratio and the formation of the raw material; mixing of the raw mixture with urea and their granulation; and drying granules in the thermal device.

To study the temperature effect on the change of moisture and ammonium nitrogen content after thorough mixing, the composite raw material was passed through a laboratory extruder and there granules were obtained with a size of 5×15 mm. They were left in sealed containers for stabilization during the day. The method of determining the mass fraction of moisture was based on determining the weight loss of the sample after drying to constant weight in dryer.

Dependences of change of moisture and ammonium nitrogen on the drying temperature are shown in Fig. 3.

Analysis of the experimental results shows that to prevent ammonia losses and the necessary physical parameters of the granules, drying should be carried out at the temperatures 30–40^{0}C, which will ensure the content of ammonium nitrogen of 0.62–0.68%.

As a result of additional heat treatment of the samples of mixtures No. 1 (Table 5) at the temperature of 40^{0}C for 0.5 h, the samples of porous materials were obtained. Porous materials obtained from a mixture of No. 1–3 are characterized by lower strength and higher bulk density (Table 7). Granules prepared from mixtures of No. 4–6 have higher strength. Longer processing time causes an increase in the strength of the material by 4–17%. The porosity of the granules decreases by 5–19% with increasing the processing time.

As a result of two-factor experiment, the following optimum composition of a raw mixture is established (wt.%): fly ash 4–6; CaO 20–25; zeolite 15–20; sludge of water treatment of municipal sewage 50–55, and urea – the rest.

Study of the prepared granulated material was carried out according to the protocol of researches of definition of qualitative indicators (Table 8).

Table 7

Physical and mechanical parameters of granulated materials

Number of mixture	Bulk density, kg/m^3	Strength, MPa	Porosity, %
1	250	2.5	54.2
2	265	3.6	50.4
3	300	3.8	47.3
4	380	3.9	52.1
5	305	4.2	51.4
6	320	3.9	49.5
7	300	2.7	50.9
8	320	3.3	52.7

Table 8

Characteristics of granulated fertilizers

Component	Content				
	Number of samples				
	1	2	4	5	7
Ca, %	26.4	25.7	21.7	21.8	18.9
N_{total}, %	4.96	4.93	5.2	5.10	5.21
ammonium nitrogen, %	0.6	0.5	0.7	0.6	0.7
P, %	0.51	0.50	0.53	0.55	0.56
K, %	0.34	0.33	0.34	0.35	0.38
organic matter, %	17.2	17.6	22.3	22.3	25.6
Co, mg/kg	4.9	4.9	5.7	5.4	6.1
Cu, mg/kg	10.1	10.3	11.6	11.4	12.4
Zn, mg/kg	3.5	3.5	4.2	4.1	4.9

Element content in the obtained composition of fertilizer is on average (wt.%): total calcium 21.7; total nitrogen 5.1–5.2; and ammonium nitrogen 0.6–0.7. The content of metal impurities, which are present in the sludge of water treatment in the largest amount, but dont exceed the allowed norms for soils.

The effect of the obtained fertilizer on the growth of sunflower biomass was estimated experimentally. Standard fertilizer (ammonium nitrate) and a universal soil mixture (according to the technical regulations TU-14.3-311-21682-001.2008) were used to compare the efficiency of the obtained fertilizer. The obtained organic-mineral fertilizer was tested by adding 20 g to 10 L of soil substrate during sunflower cultivation. For control, soil without fertilizers was used, as well as soil with ammonium nitrate (2 g/10 L). The plants were grown under room condition for two months. The plants were then harvested, dried and weighed. Only the dry weight of the sunflower is part above the soil was considered to be its biomass. When fertilizer based on sludge water treatment was used, plants increase their biomass by 7–10% during 2 months as compared with soil without fertilizer. At that time, sunflower biomass increased by 10–15% when soil containing ammonium nitrate was used.

The fabricated fertilizer also contains calcium compounds required for acidic soils and some amount of ammonium adsorbed by the zeolite, which can be absorbed by plants from the pores of the zeolite for a long time. The obtained fertilizer has a positive effect on plant growth; it can be used in contaminated and low fertility soils during reclamation works in the final stage of liquidation of man-made landfills and abandonment of the wells of the oil and gas complex.

Conclusions

1. The results of theoretical and experimental studies showed that the optimal composition of the raw material mixture for granulated fertilizer with the required physical and chemical properties should be as follows (wt.%): fly ash 4–6; CaO 20–25; zeolite 15–20; sludge of water treatment of municipal sewage 50–55, and urea – the rest.

2. Drying of granules should be carried out at the temperature of up to 40^0C to ensure the following physical parameters of the granules: strength of 3.4–3.7 MPa, porosity of up to 47–53%, and bulk density of 320–350 kg/m^3, which mainly depend on the ratio of the components of the raw material mixture.

3. The final composition contains elements in the following quantities: total nitrogen 5.1–5.2%; total potassium 0.34–0.35%; total calcium 21.7%; and ammonium nitrogen 0.6–0.7%. The content of trace elements and heavy metals (Zn, Co and Cu) does not exceed the allowable. The biomass of sunflower increases by 7–10% when fertilizer based on sludge water treatment is used.

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ПЕРЕТВОРЕННЯ ТЕХНОГЕННИХ ВІДХОДІВ НА ОСНОВІ ОСАДУ ВОДООЧИЩЕННЯ У ГРАНУЛЬОВАНЕ ДОБРИВО

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Перспективним напрямом зменшення негативного впливу техногенних відходів, зокрема шламів водоочищення та золи-винесення теплоелектростанцій, на навколишнє середовище є їх перетворення у добрива пролонгованої дії за низькотемпературною технологією. Розроблена технологія утилізації техногенних відходів включає встановлення складу сировинної суміші, спосіб перемішування і грануляції та процес сушіння гранул добрива. Встановлено, що компоненти суміші рекомендується змішувати у таких співвідношеннях (мас.%): зола 4–6, CaO 20–25; цеоліт клиноптіоліт 15–20; шлам водоочищення комунальних стоків 50–55, карбамід – решта. У результаті змішування компонентів і грануляції суміші відбуваються фізико-хімічні процеси з виділенням теплоти, і для забезпечення необхідної вологості гранул виконували їх підсушування при температурі 30–40^{0}C. Розроблене добриво містить (мас.%): загальний азот 5,1–5,2, загальний калій 0,34–0,35, загальний кальцій 21,7, азот амонійний 0,6–0,7. Компонент добрива – цеоліт – поступово виділяє попередньо адсорбовані іони амонію в ґрунт. Результати випробувань добрив показали збільшення біомаси соняшнику на 7–10% у разі використання добрив порівняно з ґрунтом без добрив.

Ключові слова: осад водоочищення, гранульоване добриво, зола-винесення, цеоліт, планування експерименту, утилізація.

TRANSFORMATION OF TECHNOGENIC WASTE BASED ON WATER TREATMENT SLUDGE INTO GRANULATED FERTILIZER

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Low-temperature transformation of technogenic waste, and water treatment sludge and fly ash of thermal power plants in particular, into long-acting fertilizers is a promising way to reduce their negative impact on the environment. We developed technology of waste utilization that includes determining the composition of the raw material mixture, mixing, granulation and drying of the fertilizer granules. It was stated that the components of the fertilizer should be mixed in the following ratio (wt.%): fly ash 4–6; CaO 20–25; zeolite clinoptiolite 15–20; sludge of water treatment of municipal sewage 50–55; and urea – the remainder. During the mixing of the components and their granulation some physical and chemical processes take place and heat releases; therefore to ensure the required moisture of the granules, they were dried at the temperature of 30–40^{0}C. The obtained porous granules of fertilizer contain (wt.%): total nitrogen 5.1–5.2; total potassium 0.34–0.35; total calcium 21.7; and ammonium nitrogen 0.6–0.7. Zeolite as an adsorbent promotes the gradual release of ammonium from fertilizer into the soil. The results of fertilizer testing showed that sunflower biomass was increased by 7–10% in case of using the fertilizer as compared with the soil without it.

Keywords: sewage sludge; granulated fertilizer; fly ash; zeolite; experimental design; utilization.

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