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Investigation of the process of incineration of obsolete sludge

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Preservation of natural resources and the environment is an urgent task in human development. In Ukraine, there is a problem of overcrowded sludge sites, which negatively affect the environment by polluting groundwater and soils with toxic substances. Most sludge sites contain sludge that is over 30 years old and is called obsolete. The aim of the article was to study the process of incineration of obsolete sludge. Fuel characteristics of sludge deposits were determined. The obtained indicator of the specific heat of combustion of sludge deposits is close to peat, which will further create a composite fuel. The combustion process of a separate particle of sludge, which determined the duration and speed of combustion, was studied. Taking the results of the obtained experiments on the combustion of a particle of sludge into account, a study of flare combustion was conducted. The research showed that the process of combustion of sludge particles in the flare corresponds to the generally accepted process of combustion of solid fuel in the flare.

Keywords: sludge deposits, combustion, alternative fuel

INTRODUCTION

Sewage treatment plants can potentially become a source of additional raw materials for alternative energy sources. Due to the shortcomings of wastewater treatment technologies in Ukraine, their potential is not fully utilised. Thus, a wastewater treatment plant that does not involve the use of sludge was built in Lviv. The sludge sites cover an area of 22 hectares with 1.6 million tons of sludge, and they are replenished with 3 t of fresh sludge daily [1]. In Kyiv, at the Botnytsia Aeration Station, sludge sites cover an area of 272 ha and pose a great danger because they are actually packed three times beyond capacity: instead of the 3.5 million tons planned, they contain 10 million tons of sludge mass [2]. In general, sewerage systems consume energy and resources while creating waste and products that are not recyclable.

At sewage treatment plants, treated water, and a group of substances called sewage sludge are formed. The main wastewater disposal methods worldwide are agriculture, landfills, ocean dumping, and incineration [3–6].

Landfill disposal is planned to be reduced in the future. Germany plans to increase the use of sludge in agriculture from 25% to 40%. In Finland, of the total amount of sludge used as fertiliser, one-third is used on-site and one-third is used for the construction of major roads; 17% is used for urban landscaping, and about 16% is composted [7, 8].

In developed countries, such as Japan and the United States, incineration is the main method of sewage sludge treatment. This main advantage of this method is that regardless of climate and season, it requires less space for disposal, and a small amount of ash product can be safely used in road construction [7].

Unlike other countries, Ukraine has the problem of the so-called sludge sites with 'obsolete' sludge, which has been stored for many years and almost completely removed organic impurities, greatly complicating the cleaning process. 'Active' sludge contains about 80% of organic and 20% of mineral impurities [9]. In most cases, the areas provided for storing sludge in Ukraine are overcrowded and do not cope with the continuous flow of sediments that require additional area (over 120 hectares per year) [10]. For example, in Kyiv and Kherson, the sediment has not been removed for more than 25 years, and in Smila for over 30 years.

The aim of the work was to study the process of combustion of obsolete sludge deposits in a separate particle and in a two-stage fuel combustion device.

The combustion of a particle of sludge allows determining both the combustion process itself and its components: fuel ignition, flame structure, fuel burnout, and its attenuation. The results obtained can be used in the combustion of fuel in various combustion methods: in a flare, in a bed, etc., or the creation of new combustion methods.

Obsolete sludge from the city of Fastiv in Ukraine was used to conduct incineration experiments. Before the study, obsolete sludge was dried (Table 1). The initial moisture content of the sludge before drying was 63.1% [11].

Technical analysis of sludge was based on the method that allows determining the hygroscopic moisture, ash content, and volatile content [12].

Hygroscopic moisture was determined by the formula, %:

$$W = \frac{m_2 - m_3}{m_3 - m_1} \cdot 100, \quad (1)$$

where m_1 is the mass of an empty box (with lid), g; m_2 – weight of boxes with a sample before drying, g; m_3 – weight of boxes with a sample after drying, g

Ash content was determined by the formula, %:

$$A = \frac{m_3 - m_1}{m_2 - m_1} \cdot 100, \quad (2)$$

where m_1 is the crucible weight, g; m_2 – the weight of the crucible with breakdown, g; m_3 – weight of the crucible with ash, g.

The yield of volatiles was determined by the formula, %:

$$V^a = \frac{m_2 - m_3}{m_2 - m_1} \cdot 100 - W^a, \quad (3)$$

where m_1 is the weight of the crucible, g; m_2 – weight of the crucible with breakdown to be determined, g; m_3 – weight of the crucible after determination, g; W^a – analytical moisture, %.

The yield of volatiles on the combustible mass of fuel (with no ash and no water mass) was determined by the formula, %:

$$V^c = \frac{V^a \cdot 100}{100 - (W^a - A^a)}, \quad (4)$$

where V^a is the yield of volatiles, %; W^a – analytical moisture, %; A^a – analytical ash content, %.

Figure 1 shows the appearance of obsolete sludge and its remains after technical analysis. As shown in Fig. 1, during the technical analysis, after the yield of volatiles from obsolete sludge

Fig. 1. The types of sludge and its residues after technical analysis: a – obsolete sludge, b – obsolete sludge after removal of volatile, c – ash obsolete sludge

(Fig. 1b), the remaining coke residue and determination of ash content (Fig. 1c) was ash.

The results of the technical analysis are shown in Table 1. As presented, the combustible mass of sludge (sludge without moisture and ash) is 58.49%. The content of volatiles for the combustible mass is 66.86%. These parameters should ensure easy flammability of sludge and high heat of combustion.

The heat of combustion was determined by a method that corresponds to standard methods for solid fuels DSTU ISO 1928: 2006 'Solid mineral fuels. Determination of the highest heat of combustion by combustion in a calorimetric bomb and calculation of the lowest heat of combustion', GOST 147-95 (ISO 1928-76) 'Interstate standard. Solid mineral fuel. Determination of the highest heat of combustion and calculation of the lowest heat of combustion', and the European standard EN 14918: 2009 'Solid Biofuels – Method for the determination of calorific value' [13–15]. The calorimetric complex KTS-4 (Institute of Engineering Thermophysics of the National Academy of Sciences of Ukraine, Ukraine) was used to conduct a large number of experiments to determine the calorific value of biofuel samples of different physical states [16–23] to determine the heat of combustion.

The results of determining the heat of combustion of sludge are presented in Table 2.

As shown, the heat of combustion of sludge is quite high, and its indicators are close to those of peat, the fuel close to it. Thus, peat (in the state of delivery) has an average lower heat of combustion of 15.00 MJ/kg with a volatile amount of 42.2% [24], and sludge 11.964 MJ/kg with a volatile amount of 39.11%.

An experimental setup created for this purpose was used to conduct experiments on the combustion of a certain proportion of sludge.

Figure 2 shows an experimental installation and its scheme for studying the combustion of a single solid fuel particle. The installation includes a grate fuel holder 2 mounted on rack 1 and a camera 3 for photo and video recording of the combustion process of a separate fuel particle located on the grate holder (Fig. 2). The Sony DSC-W130 camera (Sony, China) with the following characteristics was used: focal length (mm) 5.35–21.4, focal ability 2.8–5.8. A thermocouple was also used to measure the temperature of combustion products. The grate fuel holder was made of a frame on which the wire – the grate – is wound (Fig. 2). The frame was made of copper wire with a diameter of 0.15 mm; the grate, to reduce heat dissipation from the fuel particles during combustion, was made of constantan wire with a diameter of 0.1 mm, which had a lower thermal conductivity than copper.

Table 1. **Technical analysis of sludge**

Component	Moisture W^w, %	Ash content A^w, %	Combustible mass, %	The yield of volatiles	
				V^a, %	V^c, %
Sludge	2.53	38.98	58.49	39.11	66.86

Table 2. **Heat of combustion of obsolete sludge**

Characteristic	Obsolete sludge
	MJ/kg
Higher heat of combustion of the analytical sample	12.678
Higher heat of combustion in the dry state	13.124
Higher heat of combustion in the state of delivery	12.792
Lower heat of combustion of the analytical sample	11.835
Lower heat of combustion in the dry state	11.814
Lower heat of combustion in the state of delivery	11.964

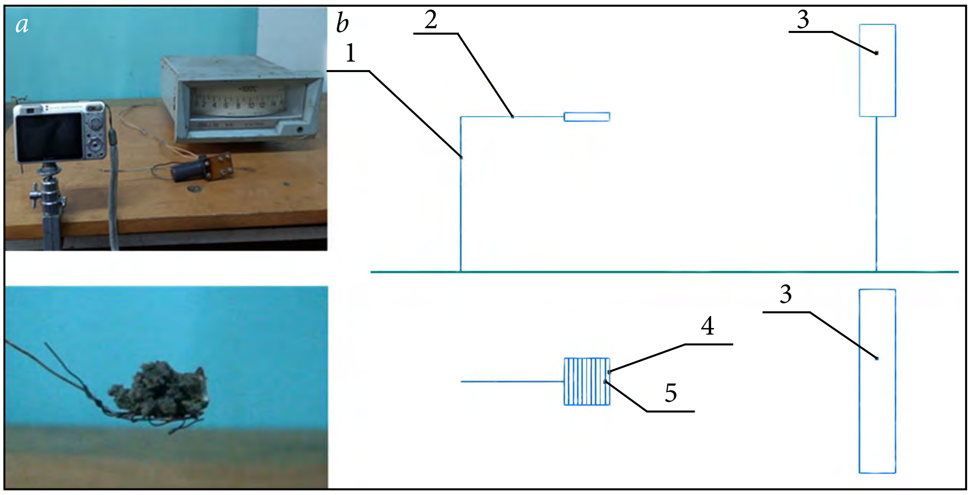

Fig. 2. Experimental installation and scheme for the study of the combustion process of a single particle of solid fuel: 1 – rack; 2 – grate fuel holder; 3 – camera; 4 – a frame; 5 – grate

Investigation into the combustion of individual sludge deposits included fuel ignition, flame structure, fuel combustion, and attenuation. In addition, the effect of heat dissipation on the combustion process was studied.

A video recording of the process determined the burning time of the particle. The temperature of the combustion products was measured directly near the front of the torch (Fig. 3) with an armoured chromel-alumel thermocouple (Ukraine) with a joint diameter of 0.1 mm. The thermocouple is attached to an M-64 millivoltmeter (Armenia). The mass of sludge particles in the experimental study ranged from 0.02 g to 0.25 g. The weight of the material was measured on scales VLR-200 and VLR-20 (Ukraine).

A burner device for two-stage fuel combustion is shown in Fig. 4. The combustion process in the burner device was the following: the fuel burned partially, heated up to spontaneous combustion temperature, and burned in the torch when in contact with the oxidant. The combustion process was stable and did not depend on the ratio of fuel and oxidant.

Fig. 3. Measurement of the torch temperature

RESULTS AND DISCUSSION

Investigation of the combustion process. Ignition of a separate particle of sludge was carried out by its intensive heating by an external heat source (Fig. 5). This led to the release of volatiles, which created a flame front around the particle of the zone in which the chemical reaction of the oxidant and fuel with the release of heat and combustion products, which diffused to the surface of the particle, supported its heating and ignited the particle. As presented, due to the combustion of volatiles, the complete ignition of a particle weighing 0.12225 g took 1.85 s. Experiments showed that the latter depended on the particle mass: with increasing mass, time increased.

A study of a certain burning particle of sludge revealed that the combustion process occurred in the ascending convective oxidant flow behind the double boundary layer. As presented in Fig. 6,

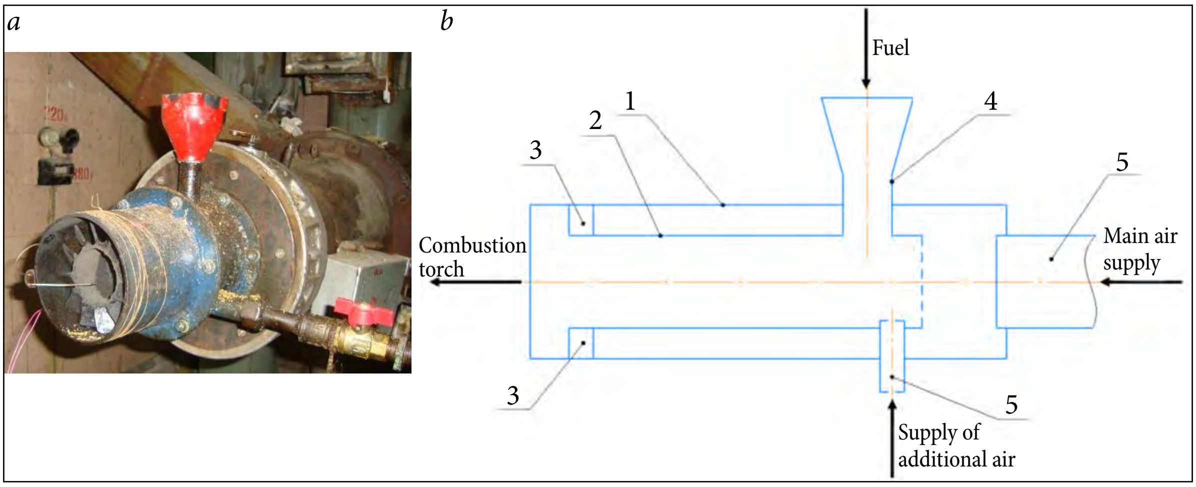

Fig. 4. Burner device for two-stage fuel combustion: 1 – outer casing; 2 – internal casing; 3 – vanes; 4 – fuel supply; 5 – air supply connection

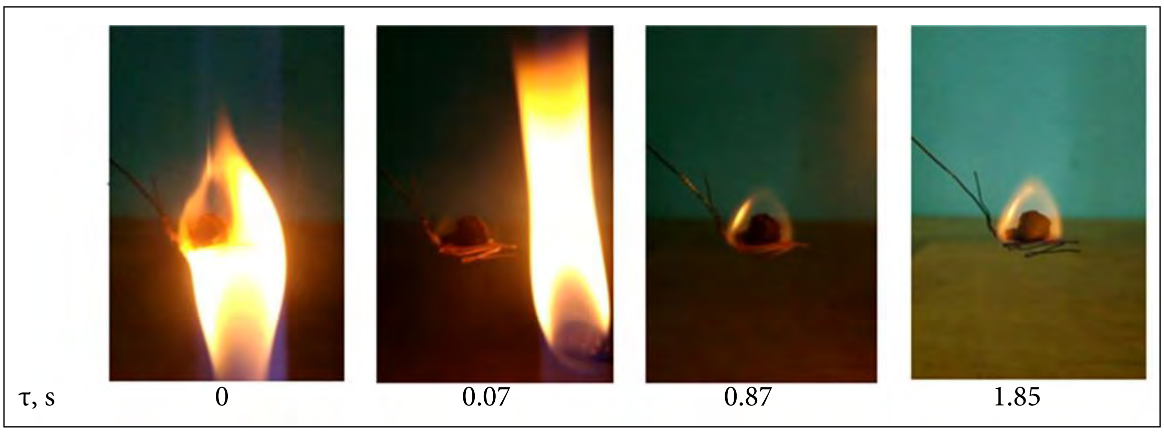

Fig. 5. The process of ignition of a separate particle of sludge (particle weight 0.11225 g)

there is a high-temperature zone around the particle of sludge, in which the combustion of the gas phase is the flame front (shown in dotted lines). It occurs when the particle ignites due to the combustion of volatiles 3, which move from the fuel to the flame front, to which the oxidant moves outside oxygen 1. The flame front is set in the stoichiometric ratio of the oxidant and fuel [25], and the temperature in the combustion reaction zone is determined by the heat of combustion of the fuel. Thus, there is a normal combustion process, deflagration.

Combustion products 2 (Fig. 6) diffuse from the flame front in both directions. Their main component is carbon dioxide CO_2. The combustion process at the flame front takes place between the gas phases oxidizer and fuel and is homogeneous.

After the sludge particle heats up, CO_2 that diffuses toward the fuel particle interacts with

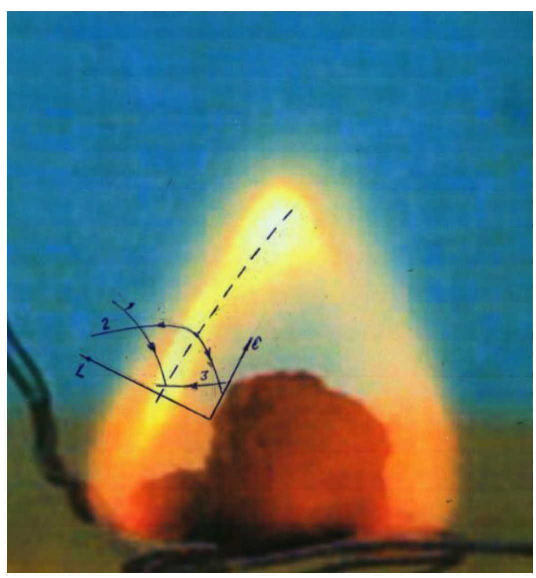

Fig. 6. The process of burning a particle of sludge on the double boundary layer

the carbon surface, resulting in carbon gasification and carbon monoxide CO, which diffuses to the flame front and burns out instead of volatiles.

The formation of CO occurs during the interaction of the gas phase and the surface of the particle. As a result, the process is heterogeneous, and, in general, the combustion process occurs in the double boundary layer [26].

As clearly seen in Fig. 6, during combustion, the flame front expands and intensifies the combustion process due to autoturbulation. The area between the solid phase and the flame front is eventually filled with combustion and gasification products (Fig. 7), the excess of which moves upward, contacts oxygen, and creates a sharp flame tail.

As the measurements show, the temperature of the combustion products of individual particles of sludge was in the range of 690–750°C. This temperature does not correspond to the heat of combustion of sludge; it is low due to heat loss into space. In the case of group combustion of sludge particles (in a torch), the temperature of combustion products must be higher.

Figure 8 shows the temporal process of extinguishing the flame of the sludge deposits, which occurs due to the burning of the combustible

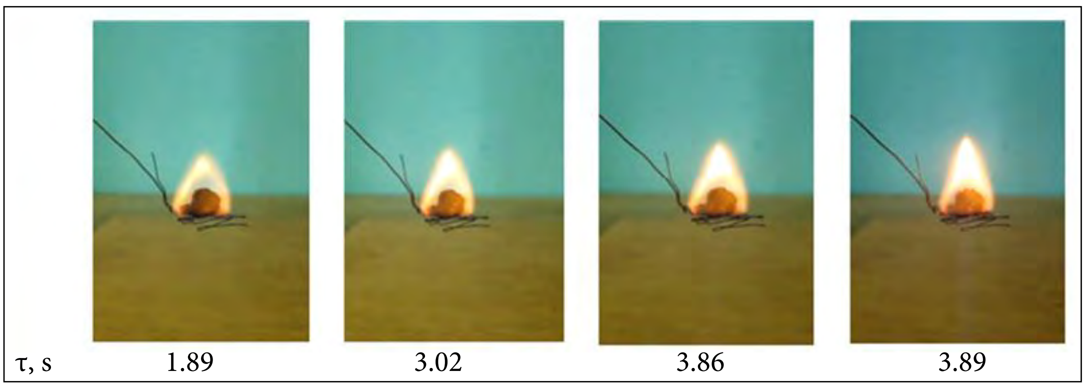

Fig. 7. Combustion of a particle of sludge

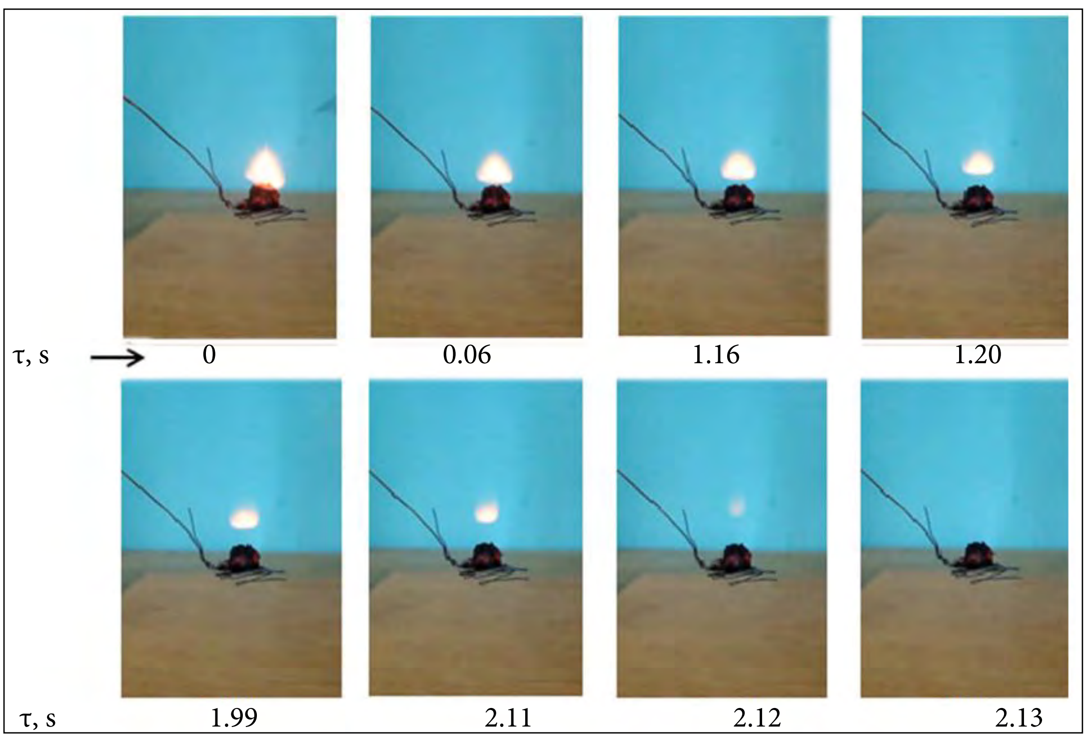

Fig. 8. Extinguishing the flame of burning of a particle of sludge

mass. At the same time, heat release at constant heat losses decreases, temperature decreases, and the speed of chemical reactions of the interaction of components, according to Arrhenius's law, decreases accordingly.

Given that the process of combustion of sludge occurs in the double boundary layer, the attenuation of combustion of the particle occurs when reducing the speed of the heterogeneous process. The latter is due to the loss of heat to the environment and the reduction of heat supply from the flame front – a homogeneous process. This slows down the gasification reaction on the surface of the particle, which gradually attenuates, reducing the flame size and attenuation. As shown in Fig. 8, the combustion zone decreases over time and finally disappears when the fuel is extinguished.

Experiments were conducted on the effect of heat on fuel burnout during combustion. For this purpose, the fuel was burned on a grate holder covered with aluminium foil (Fig. 9) and without it (Fig. 10).

The results of the experiment are presented in Table 3. They show that fuel particles differ in weight; despite the heat dissipation through the aluminium foil, they burn at almost the same rate.

According to the mass ratios, the fuel on the aluminium foil had to burn longer. However, the combustion process was completed earlier as a result of heat dissipation, which led to the mechanical underburning of fuel by almost 20%, while fuel burned completely when burned on a grate without aluminium foil.

It is evident that the temperature of the combustion products during the combustion of a particle of sludge deposits with increased heat dissipation is lower by almost 30°C.

In the complete combustion of sludge, the ash residue consists of oxides of calcium, magnesium, silicon and other mineral components (Fig. 10b), and in the case of incineration of many coke residues, as seen in the ash (Fig. 10b).

Experiments on the combustion of a single particle of sludge showed that as a result of burning sludge in the double boundary layer,

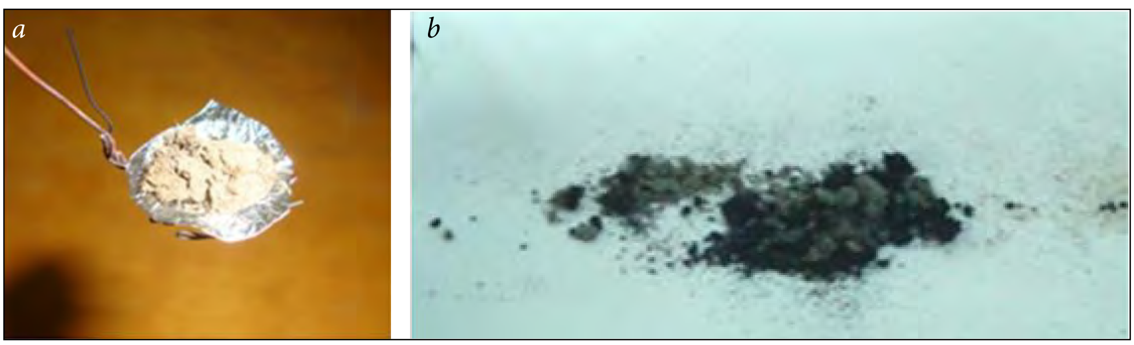

Fig. 9. Fuel on the grate covered: a – aluminium foil, b – ash residue

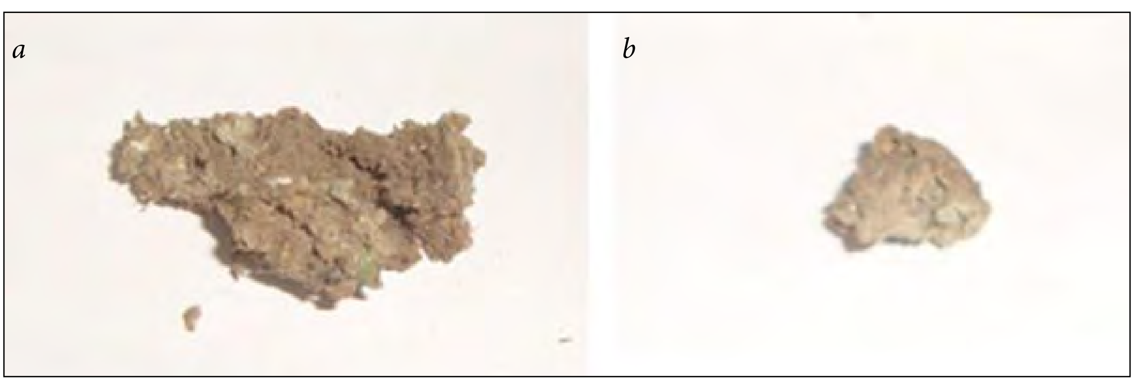

Fig. 10. Fuel for combustion on the grate: a – without aluminium foil; b – ash residue

Table 3. **The effect of heat dissipation on fuel combustion**

Fuel holder	Initial mass *M*, g	Mechanical incomplete combustion q^4, %	Burning speed *u*, kg/hour	The temperature of combustion products, °C	Burning time τ, s
Aluminium substrate	0.04455	19.94	7.2	690	11
Grids	0.08825	0	7.43	720	28

the burning rate per unit surface area of the particle is the same, regardless of its size. This can be seen from the graph (Fig. 11), where particles of different masses burn at the same rate, and confirmed by the burning time of particles (Fig. 12): larger particles burn for a longer time.

Mechanical afterburning of fuel is greater in larger particles (Fig. 13). This is because the size of the surface on which the heterogeneous combustion process takes place per unit of mass decreases with increasing particle mass.

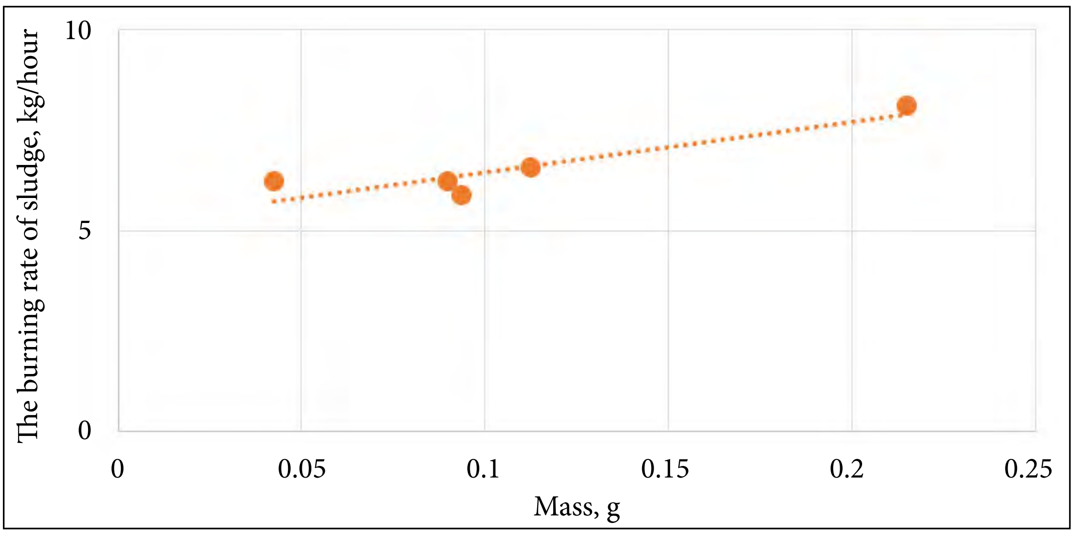

Fig. 11. The burning rate of sludge

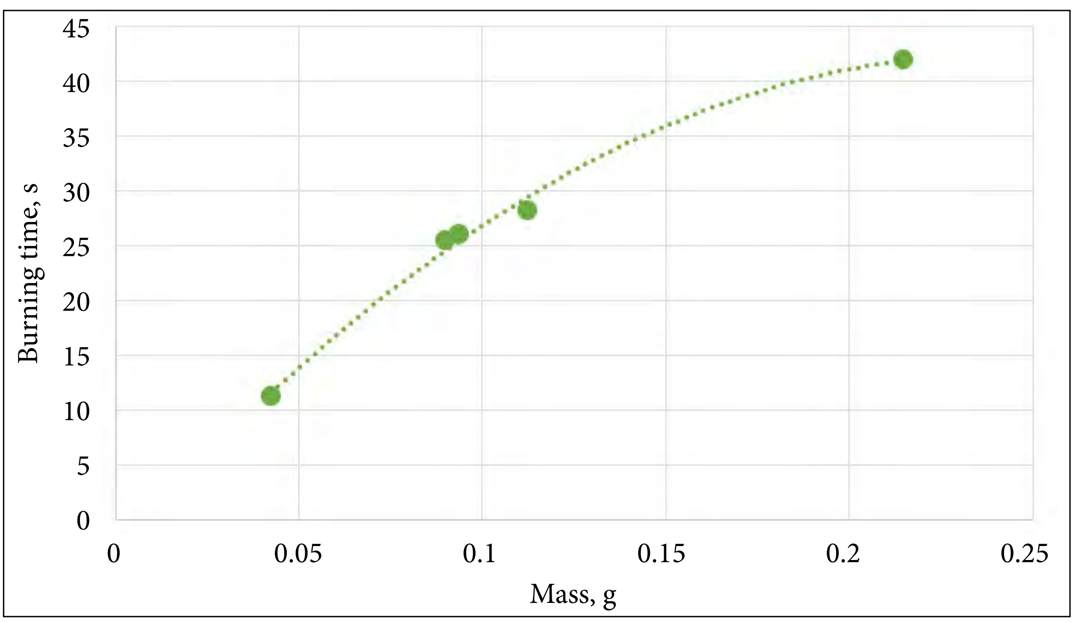

Fig. 12. The burning time of sludge particles

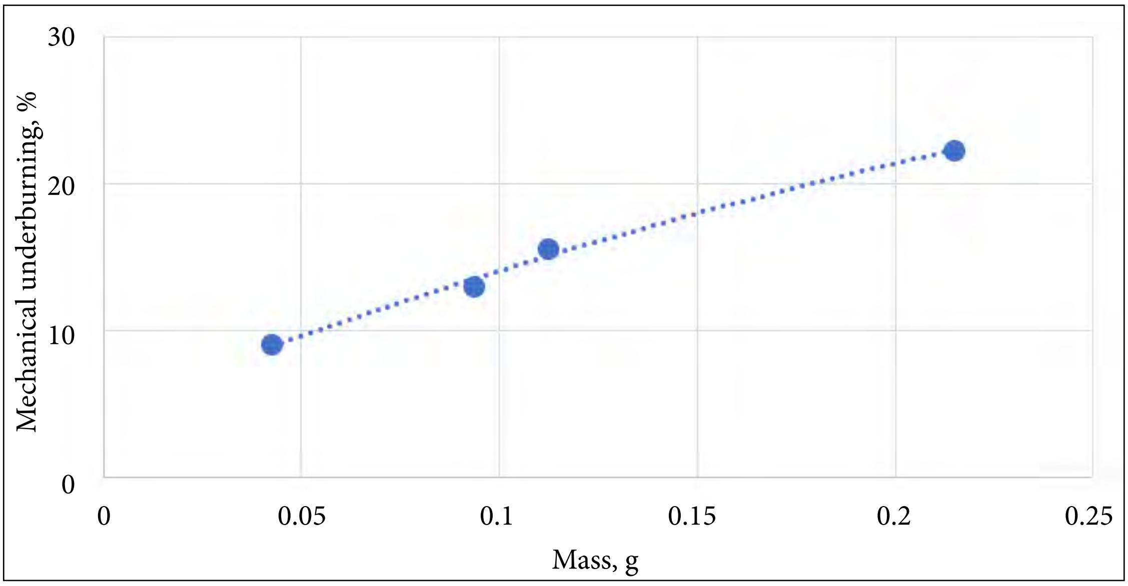

Fig. 13. Mechanical underburning of sludge particles

Torch burning of sludge. Taking into account the results of the experiments on the combustion of a certain particle of sludge, torch burning was carried out.

For torch burning, sludge deposits were ground to the state of dust. Then, the particle-size distribution of sludge was determined, which significantly affected fuel combustion according to the method described [27].

The particle-size distribution of fuel was determined by sieving the fuel on several standard sieves. For this purpose, sieves with hole sizes of 0.1, 0.315, 0.5, and 1.0 mm in diameter were used.

Quantitative characteristics of the particle-size distribution are the residues on sieves with different sizes of sludge particles. The total residue on the sieve with hole size x is denoted by R_x and is the ratio of the mass of fuel remaining on the sieve to the mass of the whole sample.

When burning solid fuel, depending on its type, it is crushed to a particle size of less than 90 microns, which makes up 95–75% of the total amount. As we can see from the curve of total residues, it shows heterogeneity in the composition of sludge; particles of the size of 0.1 mm are R_x = 12% (Fig. 14), while all others, coarser (up to 1 mm) are 88%.

The heterogeneity of crushed fuel from sludge is confirmed by the curve of fractional fuel residues (Fig. 15), where the position of the maximum of the differential curve relative to the abscissa determines the most characteristic values of the particle size: the sharper the maximum, the more homogeneous the particle-size distribution of the fuel.

The heterogeneity of the distribution of the particle size of the fuel affects its combustion process in the torch. It is known and shown in Fig. 15 that small particles burn out in the torch at the beginning when burning a separate particle of sludge. Gas was sampled from the flare with a cooling sampler, and further analysis was performed on a gas analyser chromatograph Gasochrome 3101 (Ukraine). At the same time, the amount of oxygen in the torch decreased, which complicated the process of burning large particles that burned out outside the torch, which could further lead to mechanical burnout.

Figure 16 shows a torch for burning sludge. The combustion process corresponds to the generally accepted process of burning solid fuel in a flare described above. In contrast, because sludge particles had a spontaneous combustion temperature, large particles that left the torch going beyond it burned completely. Fig. 16 shows the tracks of particles that burn completely. At the same time, mechanical underburning was absent.

The torch shown had a thermal power of 5 kW, the average temperature of combustion products was 860°C.

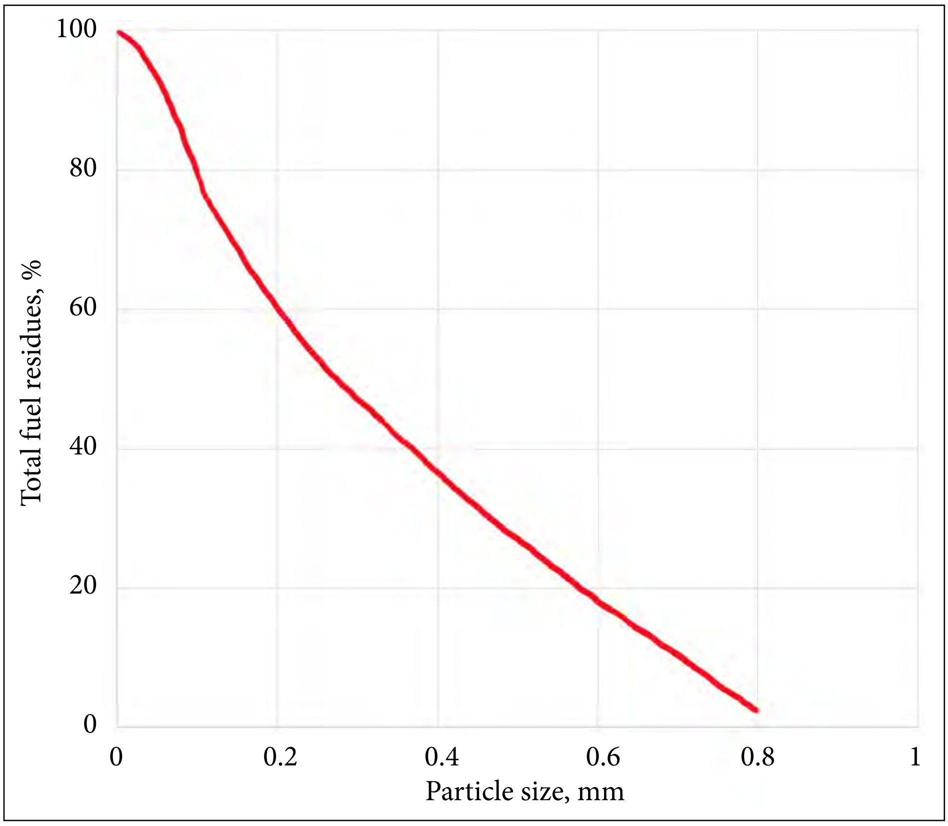

Fig. 14. The curve of total fuel residues

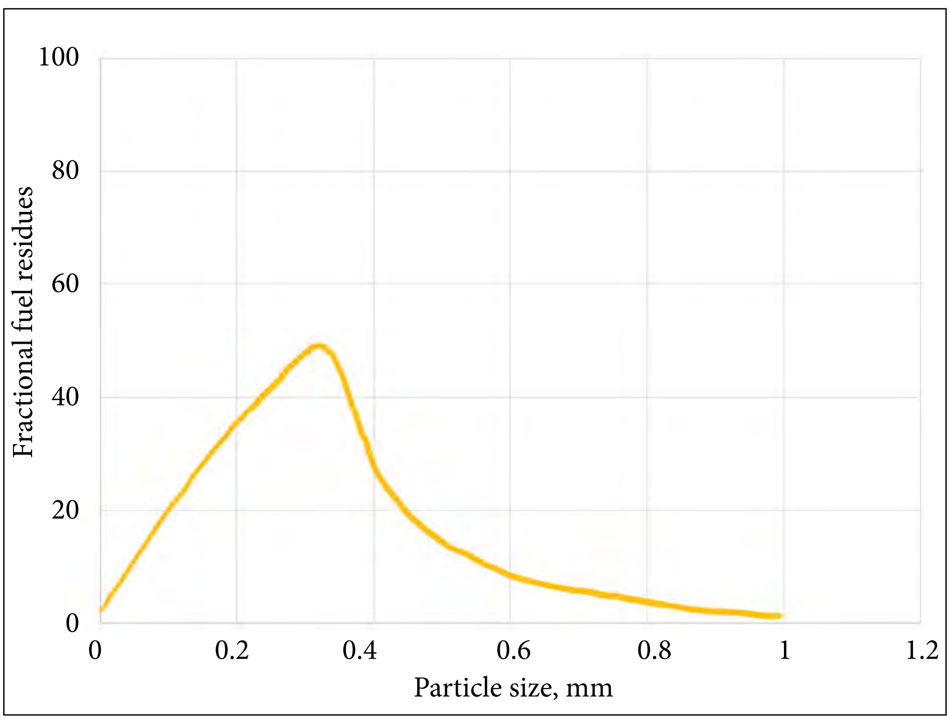

Fig. 15. The curve of fractional fuel residues

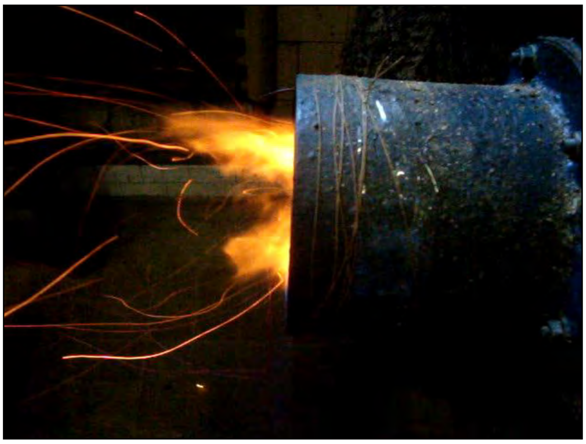

Fig. 16. Torch flame of sludge particles

CONCLUSIONS

Fuel characteristics of different types of sludge were determined and the combustion of sludge was studied. The heat of combustion of sludge was quite high and, in its indicators, was close to peat, the fuel close to it. Peat has an average lower calorific value of 15.00 MJ/kg, and silt has a calorific value of 11.964 MJ/kg, 1.26 times lower than peat. However, the similarity of fuel characteristics of silt and peat, as well as their structure, make it possible to create composite fuels.

Studies have shown that the burning process of sludge occurs behind a double boundary layer. The combustion process between the gas phases of the oxidizer – air oxygen and fuel – CO is homogeneous. That is, the combustion process takes place at the flame front, which is established in the zone of the stoichiometric ratio of the oxidizer and fuel. The formation of CO occurs during the interaction of the gas phase and the particle surface. As a result, the process is heterogeneous. The attenuation of sludge combustion is due to a decrease in the rate of the heterogeneous process.

The combustion of sludge particles in the flare corresponds to the generally accepted combustion of solid fuel in the flare. In contrast to solid fuels, because the particles of sludge had a spontaneous combustion temperature, large particles that left the torch going beyond it burned completely. At the same time, mechanical underburning was absent. The determined curve of total residuals shows heterogeneity in the composition of silt deposits: particles of 0.1 mm in size make up 12%, while all other coarser particles of up to 1 mm make up 88%.

Given the structure of sludge and the proximity of its fuel characteristics to peat, it will further create a composite fuel.

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References

1. Klius V., Chetveryk H. O., Masliukova Z. V. Technologies of sewage sludge recycling of treatment plant. *Vidnovluvana Energetika.* 2018. Vol. 52. No. 1. P. 78–84.
2. Ecosoft blog. Yak pratsiuie Bortnytska stantsiia aeratsii. https://ecosoft.ua/ua/blog/bortnicheskaya-stantsiya-aeratsii/
3. Kelessidis A., Stasinakis A. S. Comparative study of the methods used for treatment and final disposal of sewage sludge in European countries. *Waste Management*. 2012. Vol. 32. No. 6. P. 1186–1195. https://doi.org/10.1016/j.wasman.2012.01.012
4. Matsumiya Y. Green energy production from municipal sewage sludge in Japan. *Japan Sewage Works Association*. 2014.
5. Mininni G., Blanc A. R., Lucena F., Berselli S. EU policy on sewage sludge utilization and perspectives on new approaches of sludge management. *Environmental Science and Pollution Research*. 2014. Vol. 22. No. 10. P. 7361–7374. https://doi.org/10.1007/s11356-014-3132-0
6. Zhen G., Lu X., Kato H., Zhao Y., Li Y.-Y. Overview of pretreatment strategies for enhancing sewage sludge disintegration and subsequent anaerobic digestion: Current advances, full-scale application and future perspectives. *Renewable and Sustainable Energy Reviews*. 2017. Vol. 69. P. 559–577. https://doi.org/10.1016/j.rser.2016.11.187
7. Sniezhkin Yu., Petrova Z., Paziuk V., Novikova Y. State of wastewater treatment technologies in Ukraine and the world. *Thermophysics and Thermal Power Engineering*. 2021. Vol. 43. No. 1. P. 5–12.
8. Ahn Y. H., Choi H. C. Municipal sludge management and disposal in South Korea: status and a new sustainable approach. *Water Science and Technology.* 2004. Vol. 50. No. 9. P. 245–253.

9. Blagorazumova A. M. *Obrabotka i obezvozhivanie osadkov gorodskih stochnyih vod*. 2nd ed., rev. and expanded. Sankt-Peterburg: Izdatelstvo 'Lan', 2014. 208 s.

10. Suchkova N. G. Analiz sostoyaniya problemyi rekultivatsii ilovyikh ploschadok ochistnyikh sooruzheniy gorodov i perspektivyi dlya Harkovskogo regiona. *Sbornik dokladov mezhdunarodnogo kongressa 'ETEVK-2007', May 22–26, 2007, Yalta*. P. 279–284.

11. Petrova Z., Sniezhkin Y., Paziuk V., Novikova Y., Petrov A. Investigation of the kinetics of the drying process of composite pellets on a convective drying stand. *Journal of Ecological Engineering*. 2021. Vol. 22. No. 6. P. 159–166. https://doi.org/10.12911/22998993/137676

12. Sklyar M. G., Tyutyunnikov Yu. B. *Khimiya tverdyikh goryuchikh iskopaemyikh: laboratornyiy praktikum*. 2nd revised and expanded ed. Kyiv: Vyshcha shkola, 1985. 247 p.

13. DSTU ISO 1928: 2006, Palyva tverdi mineralni. Vyznachennia naivyshchoi teploty zghoriannia metodom spaliuvannia v kalorymetrychnii bombi ta obchyslennia nainyzhchoi teploty zghoriannia.

14. GOST 147-95, Mezhgosudarstvennyiy standart. Toplivo tverdoe mineralnoe. Opredelenie vyisshey teplotyi sgoraniya i vyichislenie nizshey teplotyi sgoraniya.

15. EN 14918:2009, Solid Biofuels – Method for the determination of calorific value.

16. DSTU EN 14774-2:2013, Tverde biopalyvo. Vyznachennia vmistu volohy. Metod vysushuvannia v sushylnii shafi. Chastyna 2. Zahalna voloha. Sproshchenyi metod.

17. Vorobev L. I., Grabov L. N., Dekusha L. V., Nazarenko O. A., Shmatok A. I. Opredelenie teplotvornoy sposobnosti biotoplivnyih smesey. *Promyishlennaya teplotekhnika*. 2011. Vol. 33. No. 4. P. 87–93.

18. Vorobiov L. I., Hrabov L. M., Dekusha L. V., Nazarenko O. O., Shmatok O. I. Teplota zghoriannia biopalyv ta biopalyvnykh sumishei. *Enerhetyka ta elektryfikatsiia*. 2011. No. 7. P. 54–59.

19. Burova Z. A., Vorobiov L. Y. Kalorymetrychnyi analiz tverdoho ta ridkoho biopalyva. *Naukovi trudy Sword*. 2016. Vol. 2. No. 1(41). P. 38–42.

20. Vorobiov L. Y., Dekusha L. V., Nazarenko O. O., Serhiienko R. V. Kontrol palyva za teplotoiu zghoriannia z vykorystanniam bombovoho kvazydyferentsialnoho kalorymetru teplovoho potoku. Neruinivnyi kontrol ta tekhnichna diahnostyka. *UkrNDT-2016: 8-a Natsionalna naukovo-tekhnichna konferentsiia, November 22–24, 2016, Kyiv*. P. 89–94.

21. Burova Z. A., Vorobiov L. Y., Nazarenko O. O. Pidvyshchennia tochnosti vymiriuvan teploty zghoriannia palyva. *Naukovi trudy Sword*. 2016. Vol. 1. No. 3(44). P. 93–97.

22. Roman T. O., Ivanchenko M. H., Kolomiiets D. P., Mazurenko O. H., Dolhonenko I. V., Soia H. R., Sydorenko O. H., Vorobiov L. Y. Kharchova tsinnist ta rezultaty vyznachennia enerhetychnoi tsinnosti hryba shampiniona. *Kharchova promyslovist*. 2016. No. 19. P. 79–86.

23. Sniezhkin Yu. F., Korinchuk D. M., Vorobiov L. Y., Khavin O. O. Rozrobka enerhoefektyvnoho palyva na torfianii osnovi. *Promyishlennaya teplotehnika*. 2006. Vol. 28. No. 2. P. 41–45.

24. Chmel V. M., Novikova I. P. Doslidzhennia palyvnykh kharakterystyk vidkhodiv biomasy. *Vidnovliuvana enerhetyka*. 2006. Vol. 7. No. 4. P. 107–113.

25. Zeldovich Ya. B. K teorii goreniya ne peremeshanyih gazov. *Zhurnal tekhnicheskoy fiziki*. 1949. Vol. 5. No. 10. P. 260–272.

26. Gausorn V., Uiduel D., Hottel G. Smeshenie i gorenie v turbulentnyikh gazovyikh struyakh. *Sbornik 'Voprosyi goreniya'*. 1953. Vol. 1. P. 146–193.

27. Beloselskiy B. S., Solyakov V. K. *Energeticheskoe toplivo*. Moskva: Energiya, 1980. 168 p.

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PASENUSIO NUOTEKŲ DUMBLO DEGINIMO PROCESO TYRIMAS

Santrauka

Gamtos išteklių tvarus panaudojimas ir aplinkos apsaugos užtikrinimas yra neatidėliotinas žmonijos vystymosi uždavinys. Ukrainoje susiduriama su sukaupto nuotekų dumblo problema – jis neigiamai veikia aplinką, užteršdamas požeminį vandenį ir dirvožemį toksinėmis medžiagomis. Daugumoje dumblo saugojimo vietų yra daugiau kaip 30 metų senumo dumblas, kuris vadinamas pasenusiu. Todėl šio darbo tikslas yra ištirti pasenusio dumblo deginimo procesą ir nustatyti šio kuro charakteristikas. Gautas dumblo savitosios degimo šilumos rodiklis yra artimas durpėms ir gali būti naudojamas alternatyviajam kurui. Taip pat ištirtas atskirų dumblo frakcijų degimo procesas, kuris lėmė degimo trukmę ir greitį. Atsižvelgiant į gautus tam tikros dumblo dalies teigiamus degimo eksperimentų rezultatus, buvo atliktas papildomas degimo tyrimas išpurškiant smulkintą dumblą degiklyje. Tyrimų rezultatai parodė, kad dumblo dalelių degimo fakele procesas atitinka visuotinai pripažintą kietojo kuro degimo fakele procesą.

Raktažodžiai: dumblas, deginimas, alternatyvusis kuras