INVESTIGATION OF THE COMBUSTION PROCESS OF THE DEVELOPED COMPOSITE GRANULES

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The urgent task of each country is to achieve energy independence through the transition from traditional energy sources to alternative ones. Sewage treatment plants can be considered a potential source of additional raw materials. In Ukraine, one of the problems is the disposal of sludge that are more than 30 years old and to which activated sludge has not been added. This sludge has a low content of organic components, which are not suitable for combustion in pure form and fertilizers. Since the old sludge have a small content of organic components, for their better utilization it is proposed to create composite granules, their subsequent drying and combustion, during which the resulting ash will be used for the production of building materials. The aim of the work is to study the combustion of composite granules based on sludge, peat and biomass. The determined specific heat of combustion of composite granules exceeds this index of peat by 1.2 times. The study of the combustion process of composite granules showed that the obtained results can be used in fuel combustion in different ways. The combustion rate of granules is much lower than the combustion rate of the original biomass, but the combustion rate of a separate part of sludge prevails. The combustion rate of granules is much lower than the combustion rate of the original biomass, but the combustion rate of a separate part of sludge prevails. The conducted experiments showed the possibility of decontamination of sludge and its disposal as an alternative fuel.

Keywords: sludge, peat, biomass, combustion, heat of combustion

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1. Introduction

In connection with the food problem, the whole world needs to free up land areas as much as possible and to carry out their reclamation, which were under technical use, for agricultural land.

Sewage treatment plants can be considered a potential source of additional raw materials. After wastewater treatment, not only treated water is formed, but also a group of substances called sludge. To treat large volumes of wastewater, treatment systems are used, based on the formation of activated sludge, which remains for years in landfills that need to be recycled [1].

The main methods of wastewater disposal in the world are through use in agriculture, landfills, ocean discharges, combustion [2].

The most commonly used method of sludge disposal is landfilling. But in the future, most countries plan to reduce landfill disposal [3 - 5].

Aerobic and anaerobic treatment of sewage sludge is popular in the countries of the European Union [6]. Studies have shown that a large number of humic acids is formed during aerobic transformation in sewage sludge, during anaerobic transformation - proteins and aromatic amino acids, which are part of organic mineral fertilizers in agriculture [7].

In developed countries, the main method of disposal of sludge is combustion. The advantage of this method is the independence of climate and time of year, the ash obtained after combustion can be used in road construction.

In Japan, the treatment of activated sludge by combustion, gasification, drying and carbonization is preferred [8].

There are also known technologies for the use of low-temperature pyrolysis in the process of combustion of sludge. The largest number of low-temperature pyrolysis plants is aimed at processing mixtures of household waste and sewage sludge, which is implemented in Japan, Italy, Germany and other countries. Processing of such mixtures takes place at the rate of 70 to 30 %. Pyrolysis of waste takes place at a temperature of 250 - 400ºC. A feature of low-temperature pyrolysis is that the processed sludge is converted into hydrocarbons initially in a gaseous state, and after condensation, the main product "crude oil" is obtained [9]. A positive point of the low temperature of pyrolysis is that it eliminates the possibility of evaporation of toxic salts of heavy metals.

The production of biogas and electricity through anaerobic treatment and dehydration is promising behind China data [10]. Simultaneous combustion of sludge and coal is used as an additional fuel in brick and cement kilns [9,11]. Also, in China, sludge is used to make building materials such as cement, brick and others [10].

One of the ways to process sludge is to create compositions with household waste and biomass. However, the sludge must have a solids content of 40 % or more and a total moisture content of 60 %. It must be dehydrated and dried before combustion.

In Europe, the technology of production of granules from biochar or ACB granules (Accelerated Carbonized Biomass) is becoming increasingly popular. The use of this technology for biomass, including organic waste, increases the heat of combustion, energy consumption and improves combustion parameters. From this point of view, the process of carbonization of sewage sludge is interesting, and in this regard, heat treatment at the sludge site not only reduces the accumulation, but also allows further use of sludge as an alternative fuel [13].

In Ukraine, unlike other developed countries of the world, the Soviet Union inherited old sludge collectors on hundreds of hectares of land that are not suitable for agriculture, with sludge after treatment facilities.

In connection with the energy crisis worldwide, it is possible to use them to create fuel based on old sludge, peat and biomass to solve this problem.

In Ukraine, unlike other countries, there is a problem of so-called sludge sites with "obsolete" sludge, which has been stored for many years and almost completely removed organic impurities, which greatly complicates the cleaning process. These are obsolete sludge sites to which no sludge was added, they have not been operated for 25-30 years. In the "active" sludge - about 80 % of organic and 20 % of mineral impurities [14].

The problem of disposal of "outdated" sludge has not been completely solved. Previously, it was allowed to use sludge as organic fertilizers due to the high concentration of phosphorus and nitrogen, but at the same time it is a source of pollution, as it contains an extremely high content of heavy metals and cannot be used in agriculture.

To solve this problem, combustion of sediments has become more and more common in recent times. The named process also makes it possible to obtain a positive energy balance and effectively use the calorific value of sediments [15].

Therefore, it is most expedient to solve the technological task of processing "outdated" sludge by developing composite fuel granules. The purpose of the work is to study the process of combustion composite granules based on sludge, peat and biomass, the technology of which was previously developed by us.

2. Materials and methods

The aim of the work is to study the process of combustion composite granules based on sludge, peat and biomass, the technology of which was previously developed by us.

To create the compositions, aged sludge from sewage treatment plants (Fastiv), peat from the Chernihiv torf deposit and biomass in different proportions were used. Biomass was added on the example of sawdust and buckwheat husks [16].

Compositions for granulation were mixed in 3 ratios: 1 – two-component composition based on 50 % sludge and 50 % peat; 2 – a three-component composition based on 45 % sludge, 45 % peat and 10 % sawdust; 3 – a three-component composition based on 45 % sludge, 45 % peat and 10 % buckwheat husk.

Fig. 1 shows that the ash content of the sludge is 47.3 %, which is unacceptable for combustion.

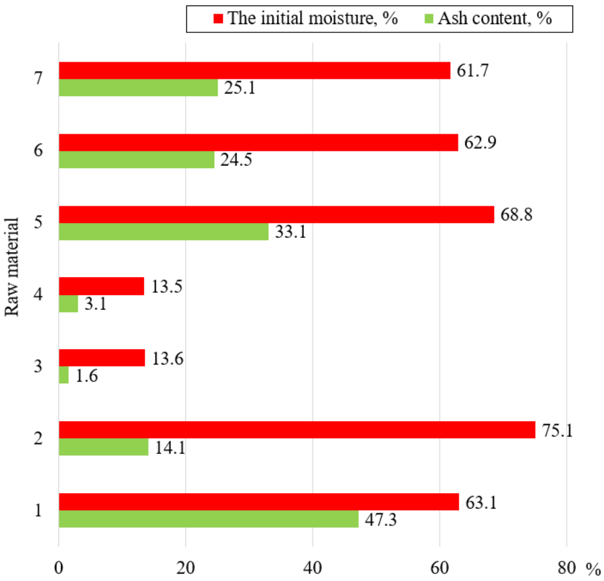

Fig 1 Ash and moisture content of raw materials: 1 – sludge, 2 – milled peat, 3 – buckwheat husk, 4 – sawdust, 5 – two-component composition based on sludge and peat, 6 – three-component composition based on sludge, peat and husk buckwheat, 7 – a three-component composition based on sludge, peat and sawdust

Table 1 Analysis of composite granules

Component	Working moisture W^w, (%)	Ash content A^w, (%)	Combustible mass, (%)	Volatiles	
				V^a (%)	V^c (%)
Two-component granules based on sludge and peat	6.1	32.35	61.55	40.51	65.82
Three-component granules based on sludge, peat and sawdust	4.35	24.86	70.79	51.66	72.97
Three-component granules based on deposits, peat and buckwheat husks	4.36	23.08	72.56	46.18	63.64

Peat of the Chernihiv region has a fairly low ash content of 14.1 %. When these materials are combined, the ash content of the composition is 33.1 %. Ash content of biomass: sawdust – 3.1 %, buckwheat husk – 1.6 %. To improve the quality and reduce the ash content of sludge-peat tablets, it is advisable to add sawdust and buckwheat husks. Ash content of three-component compositions is 25 %.

The created compositions were granulated on a screw mechanical device with a diameter of 6 mm and a length of 15 mm. The composite granules were dried on a research and industrial drying unit at a coolant temperature of 80 °C.

For the analysis of composite granules, a technique was used that allows determining hygroscopic moisture, ash content and volatile content [17].

The results of the analysis are presented in Table 1. At low humidity and relatively low ash content, granules have high fuel characteristics in the presence of 60 % - 70 % combustible mass. The high content of volatiles provides easy flammability of the obtained granules.

The results of the technical analysis are presented in Table 1. As you can see, the granules have, at low humidity and relatively low ash content, high fuel characteristics in the presence of a combustible mass of 60 % - 70 %. The high content of volatiles provides easy flammability of the obtained granules.

To determine the heat of combustion, the calorimetric complex KTS-4 was used to conduct a large number of experiments to determine the calorific value of biofuel samples of different physical state [18-24].

Biofuels created by us on the basis of obsolete sludge, peat and biomass have not been previously studied in contrast to traditional fuels.

Heat of combustion was determined according to the standard method for solid fuel DSTU ISO 1928:2006 and the European standard ISO 18125:2017 "Solid biofuels - Determination of calorific value" [25,26]. According to this standard, two or more experiments are performed to measure the heat of combustion, and if the difference between the results of the experiment exceeds a certain level, a third experiment is performed, the result of which is the average of the next two measurements. In the processing of experimental data, the values of hydrogen and nitrogen content were used to determine the correction, as recommended in [27] and in the technical literature [25].

The study of the combustion of composite fuel was carried out on an experimental installation, which allows fuel to be burned in a high-speed (clamped) layer at different pressure drops on it. At the same time, combustion at low pressure drops makes it possible to simulate fuel combustion in a conventional layer.

The experimental setup is shown in Fig. 2. It is a rectangular channel with a cross section of 40 mm x 80 mm, one of the side walls measuring 80 mm x 170 mm is made of quartz glass (1) 15 mm thick. Titanium grilles with a 40mm x 80mm combustion mirror (2) are installed in the middle of the channel as grate.

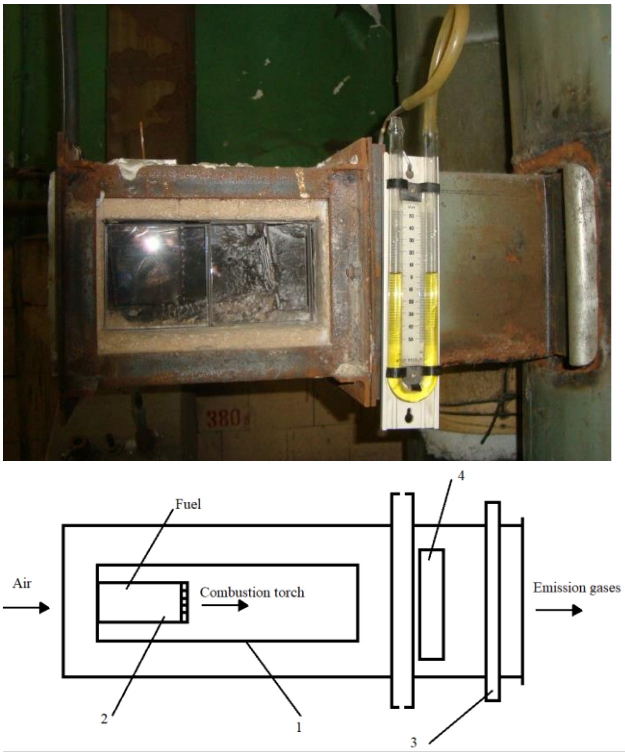

Fig 2 Experimental installation for the study of fuel combustion in the high-speed (clamped) layer:
1 – quartz glass wall; 2 – grills made of titanium with a combustion mirror; 3 – gate valve; 4 – pressure gauge

The installation works under vacuum. Oxidizer - air is sucked in by a smoke extractor. The gate valve (3) at the outlet of the installation allows you to set the necessary rarefaction on the layer. The pressure gauge (4) adjusts the value of the rarefaction pressure on the layer.

3. Results and discussion

This chapter summarizes the results of determining the heat of combustion and the study of the combustion process of composite granules.

At least two experiments are conducted to measure the heat of combustion, and if the discrepancy between the results of the experiments exceeds the specified level, a third experiment is conducted, and the average of the two closest measurements is taken as the result behind standards data. This is how the results were obtained for three-component granules based on sludge, peat and buckwheat husk.

The reason for the noticeable discrepancy between individual results is the heterogeneity of the tested samples and the presence of pieces of micoplastic in them. When processing experimental data, the values of hydrogen, sulfur, and nitrogen content were used to determine corrections, which are average in the range given in the literature, namely hydrogen content H=6.0 %, sulfur content S=0.8 %.

The generalized results of measurements and calculations of the properties of the studied granules in the analytical air-dry state, in the delivery state and in the dry state are shown in Table 2.

Table 2 The results of calorimetric analysis of composite granules

Characteristic	Two-component granules (sludge and peat)	Three-component granules (sludge, peat, and buckwheat husk)	Three-component granules (sludge, peat and buckwheat husks)
Higher heat of combustion of the analytical sample (MJ/kg)	13.87	15.08	15.71
Higher heat of combustion in the dry state (MJ/kg)	14.70	15.95	16.53
Higher heat of combustion in the state of delivery (MJ/kg)	13.51	15.44	15.97
Lower heat of combustion of the analytical sample (MJ/kg)	12.94	14.03	14.67
Lower heat of combustion in the dry state (MJ/kg)	13.39	14.64	15.22
Lower heat of combustion in the state of delivery (MJ/kg)	12.54	14.43	14.95

The heat of combustion of old sludge is in the range of 11.81 - 13.12 MJ/kg, and is close to the fuel close to it - peat. The average specific heat of combustion of peat is 14.44 MJ/kg.

It can be seen from Table 2 that two-component granules based on sludge and peat have almost the same calorific value as peat. With the creation of three-component granules based on sludge, peat and biomass, the heat of combustion is already beginning to exceed that of peat. The energy indicators of granules based on sludge are quite high (Table 2), which allows them to be used as an alternative fuel in household and communal energy.

Combustion studies of composite fuel were performed at 100, 250 and 500 Pa dilutions on an experimental plant, which allows combustion fuel in a high-speed (clamped) layer at different pressure drops. Figures 3, 4, 5 show combustion torches of two-component granules based on sludge and peat; three-component granules based on sludge, peat and sawdust; three-component granules based on sludge, peat and buckwheat husks.

Combustion torch two-component granules based on sludge and peat (Fig. 3) has a high-temperature core in the initial section and a sufficiently long tail, in which the particles of fuel carry-out burn out. In contrast, the combustion torch three-component granules based on sludge, peat and buckwheat husk (Fig. 4) has almost no tail, all the fuel burns in the core of the torch. Both types of granules burn at the same rarefaction, which excludes the influence of the air velocity gradient on the comparison of torches. The difference is determined by the content of combustible mass, which is more in three-component granules based on sludge, peat and buckwheat husk (see Table 1). The effect of the difference in pressure drop can be seen from Fig. 5, which shows the combustion torch of granules of three-component granules based on sludge, peat and sawdust.

Fig 3 Combustion torch of two-component granules based on sludge and peat: dilution 250 Pa

Fig 4 Combustion torch of three-component granules based on sludge, peat and buckwheat husks: dilution 250 Pa

Fig 5 Combustion torch of three-component granules based on sludge, peat and sawdust: dilution 500 Pa

Despite the fact that the granules have the highest content of volatile V^c, an increase in the pressure drop and, accordingly, the air velocity gradient leads to an increase in the fuel combustion rate and a shortening of the flame.

The combustion speed in the high-speed (clamped) layer (Table 3 and Fig. 6) of composite fuel granules was also determined: a two-component composition based on sludge and peat; three-component composition based on sludge, peat and sawdust; three-component composition based on sludge, peat and buckwheat husk. The combustion speed in a direct flow layer depends both on the pressure drop across the layer (velocity gradient in the layer) and on the type of fuel. The rate of combustion is also affected by the content of volatile compounds.

As can be seen, the fuel characteristics of the granules are significantly different from the fuel characteristics of the raw material. Combustion rate of granules: two-component composition based on sludge and peat - 1, three-component composition based on sludge, peat and sawdust - three-component composition based on sludge, peat and buckwheat husk - 3, much lower than the combustion rate of the original biomass: wood - 4 and peat 5 [28]. This is explained by the reduction of the reaction surface and compaction of granules during pressing of the raw material. However, the rate of combustion of granules is much higher than the rate of combustion of an individual particle of sludge.

Fig. 7 shows histogram of the cost of obtaining 1 kWh of heat during combustion in boilers. As you can see, the highest cost of obtaining 1 kWh of heat during combustion in boilers is 0.046 $ for electric energy and 0.04 $ for wood granules. The cost of obtaining 1 kWh of heat during combustion in the created two-component granules based on sludge and peat is 0.01 $; for three-component granules based on sludge, peat and sawdust - 0.0079 $ and for three-component granules based on sludge, peat and buckwheat husk - 0.0011 $.

Table 3 The combustion rate of composite fuel granules in the high-speed (clamped) layer

Fuel	Combustion speed, U kg.m^{-2}h^{-1} ΔP=100 Pa	ΔP=250 Pa	ΔP=500 Pa
Peat	947.3	1292	-
Sawdust	662.85	712	786.44
Two-component granules (sludge and peat)	369.20	446.22	517.99
Three-component granules (sludge, peat and sawdust)	431.40	500.00	572.16
Three-component granules (sludge, peat and buckwheat husks)	442.36	526.12	628.37

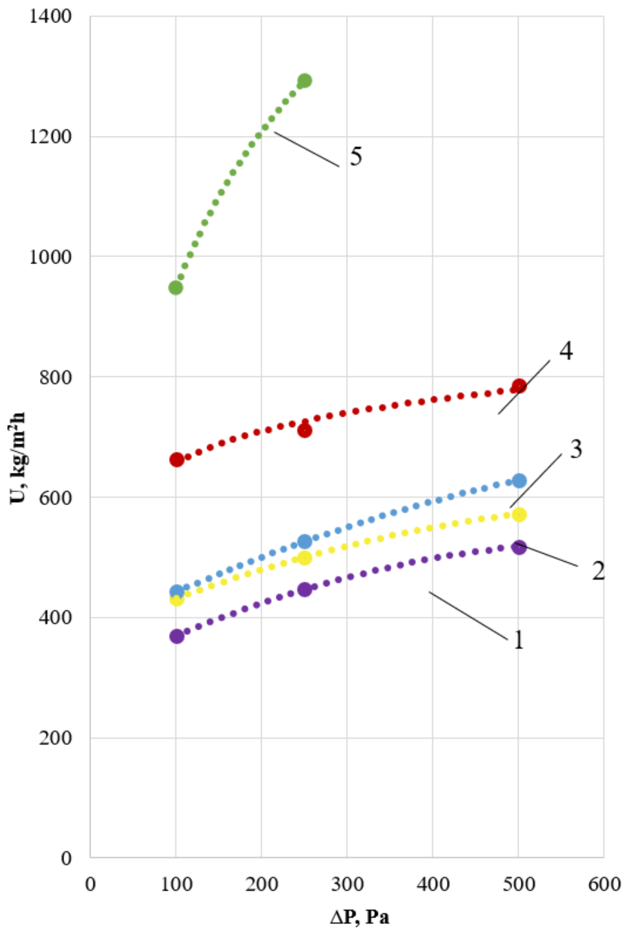

Fig 6 Combustion rate of composite fuel granules in the speed (clamped) layer: 1 - two-component composition (sludge and peat); 2 - three-component composition (sludge, peat and sawdust); 3 - three-component composition (sludge, peat and buckwheat husks); 4 - sawdust, 5 – peat

4. Conclusion

For the first time, the specific heat of combustion of composite granules was determined, which exceeds this indicator of peat by 1.2 times. The energy indicators of granules based on sludge deposits are high enough, so it is possible to use them as an alternative fuel in household and municipal energy.

The combustion process of composite granules was studied, which showed that the obtained results can be used when combustion fuel in a different way or when creating new ways of combustion. The combustion rate of granules is much lower than the combustion rate of the original biomass, but the combustion rate of a separate part of sludge deposits prevails. Conducted experiments showed the possibility of decontamination of sludge deposits and its disposal as an alternative fuel for use at sewage treatment plants. A comparison of the cost of obtaining 1 kWh of heat during combustion in boilers showed that the efficiency and feasibility of using the fuel granules developed by us exceeds all existing ones.

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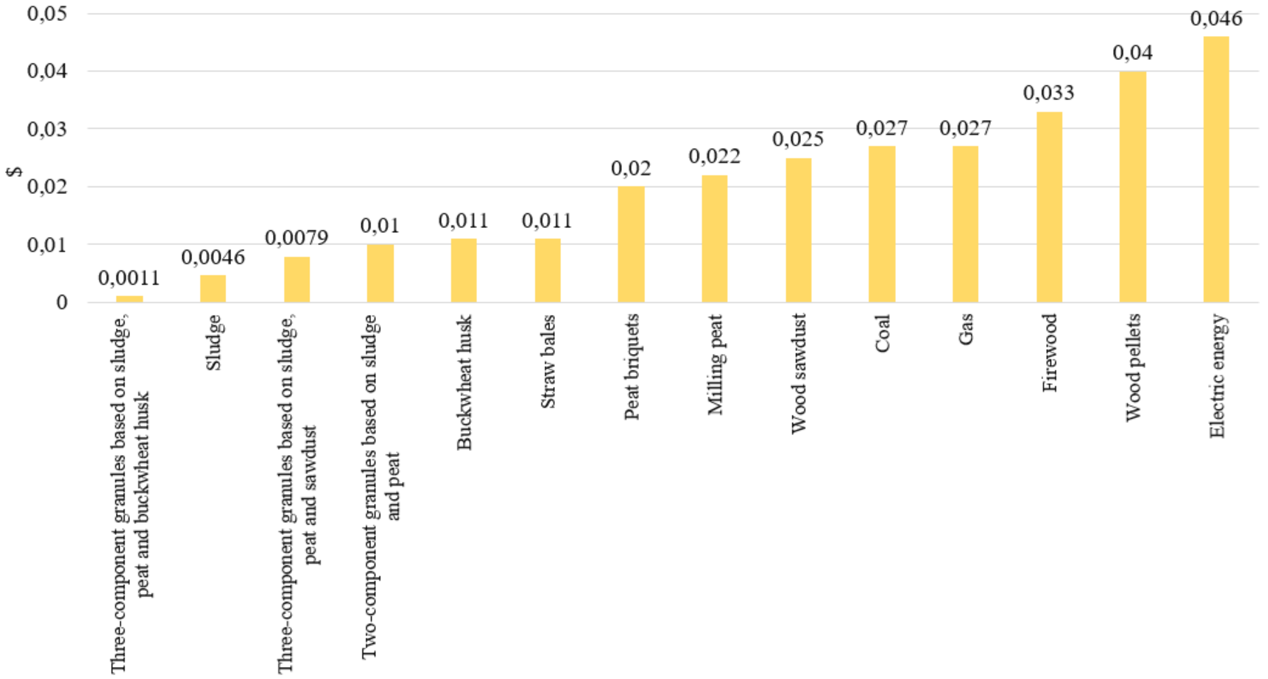

Fig 7 The cost of obtaining 1 kWh of heat during combustion in boilers

List of symbols and abbreviations

W^w	Working moisture (%)
A^w	Working ash content (%)
V^a	Analytical volatiles (%)
V^c	Volatiles of combustible mass (%)
U	Combustion speed (kg / m^2h)
ΔP	Dilution (Pa)

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