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## Multicomponent Solid Fuel Production Technology Using Waste Water

A. N. Pekhota<sup>1</sup>, B. M. Khroustalev<sup>2</sup>, Vu Minh Phap<sup>3</sup>, V. N. Romaniuk<sup>2</sup>,  
E. A. Pekhota<sup>1</sup>, R. N. Vostrova<sup>1</sup>, Nguyen Thuy Nga<sup>3</sup>

<sup>1</sup>Belarusian State University of Transport (Gomel, Republic of Belarus),

<sup>2</sup>Belarusian National Technical University (Minsk, Republic of Belarus),

<sup>3</sup>Institute of Energy Science, Vietnam Academy of Science and Technology (Hanoi, Socialist Republic of Vietnam)

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**Abstract.** An assessment is given to the problems of urban wastewater sludge utilization in our country and abroad, with determination of formation and usage level. Global trends in the reduction of carbon dioxide emissions exacerbate the urgency of solving the designated tasks. At the same time, recently, in connection with the EU's plans to introduce a cross-border carbon levy, it has become necessary to reduce the carbon footprint from burning traditional fuels, which is an urgent problem of modern society. One of the directions that provide a solution to this problem is the replacement of part of the hydrocarbon fuel by the consumption of multicomponent solid fuel based on the use of combustible waste that is part of the multicomponent fuel. This solid fuel can be used to meet the needs of small consumers, for example, in the autumn-summer period to generate a drying agent for the preparation of grain on the threshing-floor, in small boiler houses, in sand drying plants of locomotive depots, heat installations of hangars and workshops, as well as in other heat-generating installations operating on solid fuels. At the same time, solving the problem of reducing the carbon footprint for Belarus is closely related to another urgent task – reducing the energy component of industrial products and the environmental consequences of storing accumulated and generated waste. The paper presents the results of joint scientific research in the field of application of modern technologies and equipment using electrohydraulic treatment to reduce and minimize the level of anthropogenic and polluting substances in wastewater sludge. The described technological equipment, technology and post-treatment modes reduce the content of harmful substances in the wastewater sludge composition even with short-term treatment. An assessment of the effectiveness of the developed technology for the use of sewage sludge is given, using the method of wet multicomponent briquetting to obtain a multicomponent fuel. The presented process flow diagram of multicomponent briquetting using sewage sludge and plant-wood waste directly shows the undeniable advantages of using watered wastewater sludge as a raw material for the production of solid fuel. At the same time, the optimally selected ratio of components and moisture content of the briquetted composition solves a number of technologically difficult problems that cannot be realized using traditional briquetting technologies.

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### Адрес для переписки

Хрусталеv Борис Михайлович  
Белорусский национальный технический университет  
просп. Независимости, 65,  
220013, г. Минск, Республика Беларусь  
Тел.: +375 17 293-93-52  
tg\_v\_fes@bntu.by

### Address for correspondence

Khroustalev Boris M.  
Belarusian National Technical University  
65, Nezavisimosty Ave.,  
220013, Minsk, Republic of Belarus  
Tel.: +375 17 293-93-52  
tg\_v\_fes@bntu.by

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The presented data of the conducted research and the developed technology make it possible to expand the area of using wastewater sludge as a secondary renewable material resource.

**Keywords:** waste, combustible secondary energy resources, wastewater sludge, municipal waste of the city, industrial waste, ecology, fuel, briquette, multicomponent solid fuel, carbon tax, volume of waste generation, electrohydraulic treatment

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## Технология производства многокомпонентного твердого топлива с использованием отходов сточных вод

А. Н. Пехота<sup>1)</sup>, Б. Н. Хрусталеv<sup>2)</sup>, Ву Минь Фап<sup>3)</sup>, В. Н. Романюк<sup>2)</sup>,  
Е. А. Пехота<sup>1)</sup>, Р. Н. Вострова<sup>2)</sup>, Нгуен Тху Нга<sup>3)</sup>

<sup>1)</sup>Белорусский государственный университет транспорта (Гомель, Республика Беларусь),

<sup>2)</sup>Белорусский национальный технический университет (Минск, Республика Беларусь),

<sup>3)</sup>Научный институт энергетики Вьетнамской академии наук и технологий  
(Ханой, Социалистическая Республика Вьетнам)

**Реферат.** Дана оценка проблемам утилизации осадков городских сточных вод в Беларуси и за рубежом с определением уровня их образования и использования. Мировые тенденции сокращения выбросов диоксида углерода обостряют актуальность решения указанных задач. В связи с планами Европейского союза по введению трансграничного углеродного сбора возникла необходимость снижения углеродного следа от сжигания традиционных видов топлива, что является актуальной проблемой для современного общества. Одно из направлений ее решения – замещение части углеводородного топлива многокомпонентным твердым на основе горючих отходов. Твердое топливо можно использовать для обеспечения нужд мелких потребителей, например в осенне-летний период для генерации сушильного агента при подготовке зерна на токах, на мелких котельных, в сушильных установках песка локомотивных депо, теплоустановках ангаров и мастерских, а также в иных теплогенерирующих установках. При этом для Беларуси снижение углеродного следа тесно связано с другой актуальной задачей – уменьшением энергетической составляющей промышленной продукции и экологических последствий хранения накопленных и образующихся отходов. В статье представлены результаты совместных научных исследований в области применения современных технологий и оборудования, использующих электрогидравлическую обработку для снижения и минимизации уровня содержания антропогенных и загрязняющих веществ в осадке сточных вод. Описанное технологическое оборудование, технология и режимы доочистки позволяют снизить содержание вредных веществ в осадке сточных вод даже при кратковременной обработке. Дана оценка эффективности разработанной технологии использования осадка сточных вод с применением метода влажного многокомпонентного брикетирования для получения многокомпонентного топлива. Представленная принципиальная технологическая схема многокомпонентного брикетирования с использованием осадка сточных вод и растительно-древесных отходов показывает неоспоримые преимущества применения обводненного осадка сточных вод в качестве сырья для производства твердого топлива. При этом оптимально подобранное соотношение компонентов и влажности брикетируемого состава решает ряд технологически трудных задач, не реализуемых с помощью традиционных технологий брикетирования. Проведенные исследования и раз-

рабочая технология позволяют расширить область использования осадков сточных вод в качестве вторичного возобновляемого материального ресурса.

**Ключевые слова:** отходы, горючие вторичные энергетические ресурсы, осадок сточных вод, коммунальные отходы города, промышленные отходы, экология, топливо, брикет, многокомпонентное твердое топливо, углеродный сбор, объем образования отходов, электрогидравлическая обработка

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In the complex of problems pertaining to housing and communal services of the Republic of Belarus, one of the most important problems continues to be – the choice of directions for the disposal of sewage sludge. The problem of utilization of urban wastewater sludge is an important environmental challenge for the cities of our country, as well as the cities of our border neighbors and the CIS countries. The amount of precipitation released during wastewater treatment at modern wastewater treatment plants ranges from 2 to 10 % of the flow rate of incoming water. At the same time, 4–5 % of the total volume of them is used in the national economy, as a rule, in the field of soil-improving compositions, in connection with which, in significant volumes, sediments are stored on the territory of treatment facilities, that creates an unfavorable environmental situation near the city limits. The main reason for this situation is the fact that the problem under consideration has not been formulated initially in all aspects, the question was not considered in such a way that the accumulation of waste in a limited area in the future would lead to the need to solve the problem at significantly higher costs. It should be borne in mind that a wastewater treatment technology can be considered as a waste-free one only when it, at the end of the process, has effective and environmentally friendly ways for using or disposing of sludge.

All of the above is of particular importance because over the past decades, many countries, as part of the development of the concept of national sustainable development strategies, have been making a rapid transition to the efficient use of industrial, municipal waste and biomass using combustion and fuel production technologies. For example, the countries of the European Union declare, by 2030, the replacement of a quarter of the fuel consumed for transport by liquid types of biofuels, the production of which will be carried out using technologies for processing various waste and biomass.

Reducing the carbon footprint, in line with the global trend to reduce carbon dioxide emissions, exacerbates the urgency of solving the designated tasks. Naturally, the carbon footprint of waste disposal remains, but there is a reduction in CO<sub>2</sub> emissions associated with the replacement of a part of natural gas by the consumption of anthropogenic waste included in the multicomponent fuel. The latter can be used to meet the needs of small consumers, for example, in the autumn-summer period to generate a drying agent for the preparation of grain on the threshing-floor, in small boiler houses, in sand drying plants of locomotive

depots, heat installations of hangars and workshops, as well as in other heat-generating installations operating on solid fuels.

The topic of carbon regulation has become aggravated in connection with the EU plans to introduce a cross-border carbon levy which directly affects the tax on the export of chemical and paper products, nitrogen and potash fertilizers, the oil and gas industry and metallurgy are directly subject to the tax. The prospect of transboundary carbon charges and trade in carbon dioxide emissions provided for by the Paris Agreements, taking into account the current geopolitical situation which affects the interests of not only the Republic of Belarus, but also other European countries. Finally, solving the problem of reducing the carbon footprint for Belarus is closely related to another urgent task of dramatically reducing the energy component of industrial products.

The required achievements in the use of non-conventional and renewable energy sources in the energy sector, which meet the challenges of the current moment, are possible only through the use of all the accumulated research, technological and practical experience in the involvement of combustible industrial and household waste, as well as biomass as a source of chemical energy. The development of this direction of using combustible waste as non-conventional and renewable energy sources in the energy sector is primarily associated with the increasing world consumption, provided by the growth of both national and world Gross Domestic Product in recent decades. So, according to the Institute of Economics of the National Academy of Sciences of Belarus (Minsk) [1], presented in Tab. 1, the population on our planet has been increasing by 1 billion people over the past 60 years, with dynamics every 13 years. In the short term, this period will decrease to 8–11 years, which is inextricably linked with the growing need to use waste from human life and production.

Table 1

**Dynamics of population growth on planet Earth**

Years in which it is possible to perform calculation of population	Population of planet Earth, people	Period between years, in years
1805	1 000 000 000	555 (from 1250)
1927	2 000 000 000	122
1959	3 000 000 000	32
1974	4 000 000 000	15
1987, July 11	5000 000 000	13
1999, December 31	6 026 548 295*	12
2011, December 31	7 001 071 861*	12
2020, December 31	7 851 163 856*	9
*Revised data – according to UN fund estimates number of population for 31.12.2020 ( <a href="https://countrysmeters.info/ru/World">https://countrysmeters.info/ru/World</a> ).		

Comprehensive analysis of the data shows that the world's population has increased by about 110 % per year over the past three years, with an average annual population growth of 81 million.

All this suggests that the development and implementation of technologies for the use of various wastes of human life is the most important strategic task for the entire civilized world community, to which we also count ourselves.

At the same time, at the present stage, based on the numerous results of scientific research and developed available and effective technologies, they prove that sewage sludge is a demanded secondary resource that can and should be used in various areas of the national economy.

The relevance of using briquetted fuel from wastewater sludge (WWS) is based on the fact that the main component is renewable, and its volume increases annually in proportion to the growth of population and production [2]. The use of secondary energy resources is acquiring additional relevance, also in connection with a decrease in reserves of fossil fuels, the need to strengthen energy security, as well as the economic and environmental need to increase the level of waste use. At the same time, for example, the use of wood waste in conjunction with other renewable fuels can reduce carbon dioxide emissions into the atmosphere [3]. This does not completely solve the problem of climate change – but in combination with other actions can mitigate its catastrophic changes.

At this stage, one of the limiting factors for the widespread use of WWS in various developed technologies are high humidity, the presence of mineral (mechanical) impurities and an increased content of heavy metals in the fuel.

One of the solutions to these constraining factors is the use of electrohydraulic treatment of this type of waste, as a result of which, according to the conducted studies, a decrease in the quantitative content of sulfur, zinc, nickel, chromium, copper, manganese and lead has been noted. On the whole, this makes it possible to regulate and ensure the permissible content of these elements in the physicochemical composition of the used WWS at an environmentally safe or normatively required level. The external view of the installation assembled using the device “ZEVS Profi” of the “UChT-220P” type, which converts energy into current pulses of microsecond duration for electrohydraulic treatment of wastewater sludge of urban facilities, is shown in Fig. 1.

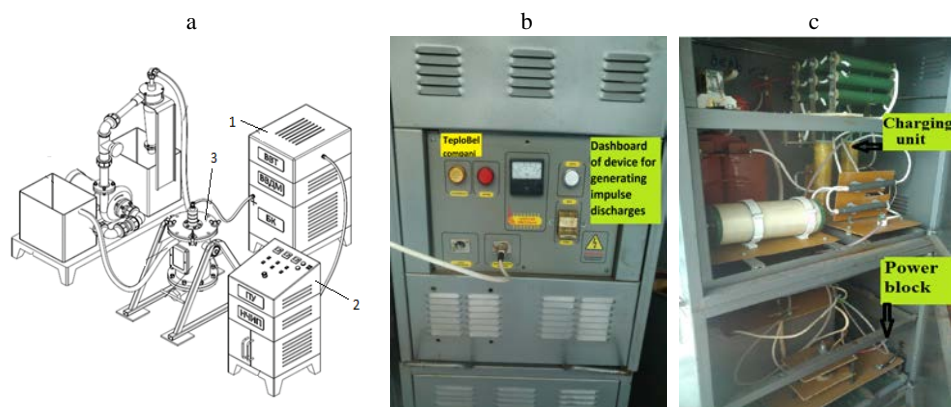


Fig. 1. Scheme and device of electrohydraulic plant for treatment of wastewater sludge of urban facilities: a – general view of the plant; b – dashboard for electrohydraulic impulses control; c – type of charging and power units generating electrohydraulic impulses

A schematic view of the equipment included in this device, which provides preparation and disposal of waste, is shown in Fig. 1a. The effect is achieved due to the fact that electric discharges occur in a humid environment of sewage sludge, creating an ultra-high pulsed hydraulic pressure, while hydrodynamic effects lead to the appearance of shock waves with sonic and supersonic speeds, which form a block of high voltage transformer 1, having a high-voltage diode bridge and a battery of storage capacitors, controlled by a control panel unit 2, equipped with a low-voltage part of the power supply, the appearance of which is shown in Fig. 1b, c. In reactor 3, as a result of a specially formed pulsed (spark, brush) high voltage electric discharge between the electrodes, powerful pulsed cavitation processes are created, which, depending on the duration, frequency, power and duration of the electric pulse of the discharge current, trigger mechanical resonance phenomena allowing material processing.

All of these factors have a variety of physical and chemical effects on the liquid and objects placed in it. Shock displacements of the liquid near the discharge zone, arising from the development and collapse of cavitation cavities, can destroy non-metallic materials and cause plastic deformation of metallic objects. At the same time, electrohydraulic waste treatment, performed without intermediate mechanical links, is accompanied by a wide range of physical and chemical phenomena such as: infra- and ultrasonic radiation, intense pulsed light, thermal, ultraviolet radiation, multiple ionization of compounds and elements contained in the processed waste [4].

All these phenomena, in combination, acting on the processed waste composition, make it possible to reduce the content of such chemical elements as Zn, Ni, Cr, Cu, Mn, Pb, S affecting the formation, for example, of emissions of harmful substances during the combustion of multicomponent fuel with using WWS, as well as with direct combustion of sewage sludge as a single-component fuel composition [5].

Tab. 2 presents the data obtained in the study of WWS of urban wastewater treatment plants in the city of Gomel for the content of various metals in liquid samples. Laboratory studies have been executed on an atomic absorption spectrometer "МГА-915М" (MGA-915M). The studies have been carried out in accordance with the methodology developed by Republican Unitary Enterprise "Central Research Institute for Complex Use of Water Resources" (Minsk, Republic of Belarus) and approved in accordance with the established procedure by "Methodology for measuring the content of metals in liquid and solid matrices by method of atomic absorption spectrometry. MVI. MN 33-69-2010".

Thus, the use of electrohydraulic treatment of sewage sludge with a high-voltage short-pulse (at the level of 10–20  $\mu$ s) electrohydraulic discharge for 3 min allows to reduce the concentration of some chemical elements in the working composition of the WWS. There is a change in the concentration of such elements as Zn, Cu, Ni (Fig. 2a, d, e) within 2.277–2.474 times, respectively, and the concentration of Mn, Cr, Pb (Fig. 2b, c, f) decreases within 1.412–1.567 times, respectively.

Table 2

**Comparisons in degree of concentration change after electrohydraulic treatment of wastewater sludge**

Serial number	Metal type	Volume, cm <sup>3</sup>	Degree of concentration change
1	Zn	50.0	2.277
2	Ni	50.0	2.474
3	Cr	50.0	1.497
4	Cu	50.0	2.467
5	Mn	50.0	1.567
6	Pb	50.0	1.412

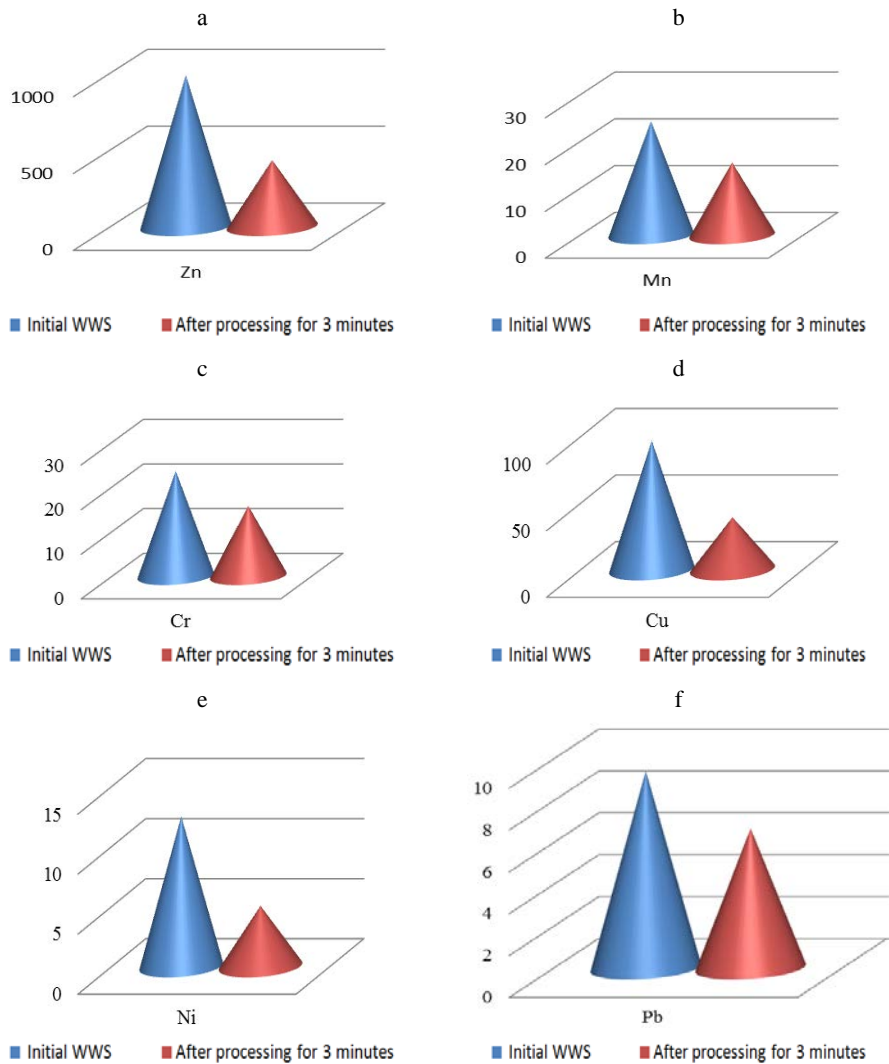


Fig. 2. Diagram of changes in the content of heavy metals in wastewater sludge: a – zinc; b – manganese; c – chrome; d – copper; e – nickel; f – lead

The analysis of the results obtained shows that the use of an industrial installation, which provides, in certain operating modes, the conversion of electrical energy into mechanical energy, obtaining a highly effective effect on the processed material in the form of electrohydraulic treatment of the sludge, which subsequently can find a wider technological application.

One of the directions of the integrated WWS management scheme is the energy-saving technology of sludge briquetting to obtain fuel briquettes, while WWS can be considered as a secondary energy resource that can be further burned in boiler houses.

The problems of its use to obtain solid fuel, using typical widespread technologies (RUF, C. F. Nielsen, Pini Kei, etc.) are high humidity and impurity content. However, when using the developed technology for briquetting multicomponent solid fuel [6], such a disadvantage as high humidity, is a technological necessity, which is more an advantage when using this technology than a technological disadvantage. In this case, sewage sludge is a dispersed system. The degree of dispersion, which ranges from 10 to 107 cm<sup>-1</sup>, allows the sediments to be considered as colloids with increased viscosity. The viscosity of heterogeneous masses, in particular sewage sludge, has not yet been studied due to the exceptional variety of phenomena and the complexity of the issue. However, it can be argued that on the basis of the data obtained from the complex of studies carried out by the authors, during which it has been revealed that WWS, having a high viscosity and high heat of combustion [7, 8] can be effectively applied in multicomponent briquetting. At the same time, its physical state and characteristics allow the sludge to be used both as a binder component and as a filler in fuel.

Mechanically dewatered sludge contains 65–80 % water. After thermal drying, the calorific value can reach 9–6 MJ/kg, and the processing of 1 ton of WWS (calculated on dry weight) makes it possible to obtain, depending on the composition, 531–556 kg of standard fuel [7]. Taking into account the Republic-wide volume of previously accumulated sewage sludge and the growing need for their processing, one of the ways to utilize this waste may be the production of boiler and furnace fuel for local heat supply systems.

The production of such fuel is achieved by using the developed technologies of multicomponent briquetting, which is called multicomponent solid fuel (MSF) [5–7, 9, 10].

Fig. 3 shows a schematic process flow diagram of multicomponent briquetting using sewage sludge and plant-wood waste.

The technology for producing MSF is based on wet briquetting of multicomponent mixtures with the use of binding components or materials that provide, in the composition of the briquetted mixture, the processes of combining small uncoupled particles into large structural compounds with the required geometric and mechanical parameters and the necessary energy properties. In this case, the wastewater sludge in MSF briquetting acts as a binder, but if necessary, a specialized binder can be used to provide additional physical characteristics specified during briquetting.



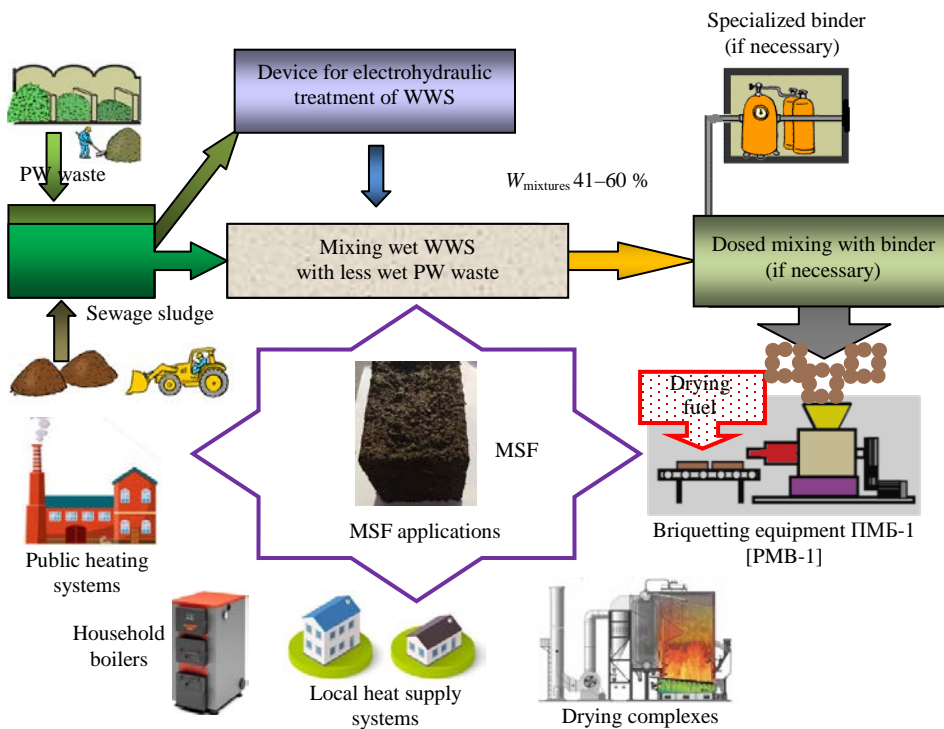


Fig. 3. Principal technological scheme of multicomponent solid fuel production using sewage sludge by the method of continuous briquetting of wet multicomponent compositions

The principal technological scheme of multicomponent briquetting is the use of various crushed combustible waste of plant and wood origin. These, as a rule, include waste of woodworking, logging, husk, fire, etc. In most of the developed multicomponent compositions, they are both the basic component, to which other types of combustible waste can be added in a certain (investigated) ratio, and auxiliary, i.e. its addition provides a reduction in certain indicators in the fuel in general. For example, ash content, sulfur content, etc. decreases. At the same time, it is possible to add in the developed compositions of multicomponent fuel, such combustible components that have not found technological application, such as spent oil-containing sorbents, fuel and oil filter elements, sawdust and rags saturated with oil products, sewage sludge from treatment facilities, animal and poultry waste, municipal waste, etc. An important condition for their use is a certain technological cycle for the preparation of these materials, which we will consider separately.

Depending on the composition, morphological state and moisture content of the waste entering for processing, as well as taking into account their priority ratio in the prepared briquetted mixture, the most technically simple and economically justified system for obtaining the required moisture content of the mixed components of the mixture is used [11]. The moisture content after the preparation process is the most critical technological cycle, which further ensures the maximum productivity of the briquetting equipment and the formation of a static wet frame of the fuel supplied for drying. At the same time,

the optimally selected ratio of components and the moisture content of the composition solves many technological problems, the main of which are:

- the intensity of adsorption of wet components with briquetted particles with the formation of a thin film of the binder on the surface;
- high-quality formation of the surface, shape, density and required standard sizes of briquettes;
- the ability to regulate the heat of combustion (using oil-containing components, organic and combined binders);
- creation of the required intensity of hardening and strength of the briquette during drying.

The multicomponent compositions of MSF developed to date with the use of various wastes ensure complete combustion of the combustible materials used in it with the release of specified thermal and technical characteristics. At the same time, the requirements of transportation and storage are met, ensuring the preservation of the properties and quality characteristics of the combustible mass [3, 5, 12].

Determination of the main physical and chemical indicators of the compositions of briquetted fuel in order to obtain the optimal component parameters have been carried out with the participation of the accredited laboratory “Scientific Research Institute of Physical and Chemical Problems” of the Belarusian State University.

Taking into account the problems of the need for the preferential use of sewage sludge and the determination of the optimal component composition of fuel briquettes with due account of the requirements that ensure the standardization of indicators for so-lid fuel, four intermediate compositions have been developed to determine the ranges and ratios of the chemical composition of the corresponding optimal quality, suitable for use in economic activities at Utility Production Unitary Enterprise “Gomelvodokanal” with the possibility of being burnt in boilers of the existing industrial boiler house.

The main results of experimental studies in accordance with the developed grades of briquetted fuel are summarized and in the form of a comparison in respect of indicators pertaining to the content of carbon, hydrogen, nitrogen, oxygen and sulfur in the working composition of the fuel are presented in Tab. 3.

Table 3

**Change in elemental composition of combustible mass of various fuel grades while using wastewater sludge**

Type of fuel	Working composition of fuel (by mass), %				
	C	O	H	N	S
MSF of WWS containing wood waste 50 %	40.3	34.0	5.3	1.77	0.62
MSF of WWS containing wood waste 25 %	39.4	24.6	5.4	2.24	1.09
MSF of WWS without wood waste	40.4	12.7	5.7	2.38	1.18
MSF of WWS containing wood waste 67 %	43.4	31.1	5.6	1.66	0.54

In addition, a study on the shape dependence of the briquetted component composition on the productivity of the installation has been carried out. In the

course of the experiment, the female die shapes of the press working channel have been changed in order to determine their influence on the productivity and quality indicators, as well as the optimal conditions for packing and transporting the resulting briquettes. In experimental studies, dies having the shape of a square, a circle and a square with rounded edges have been used.

In turn, tests and calculations have been also carried out to determine the density of dried samples of briquetted solid fuel, for which we used randomly selected briquettes-samples with a length of 200 mm, dried to a moisture content of 10.4 %. The error of instrumental dimension measurements of the samples was  $\pm 0.1$  mm.

One of the important performance indicators of fuel is its heat of combustion. A comparative analysis of the calorific value of solid fuels and multicomponent fuels using WWS of urban wastewater treatment plants is presented in the form of a diagram in Fig. 4.

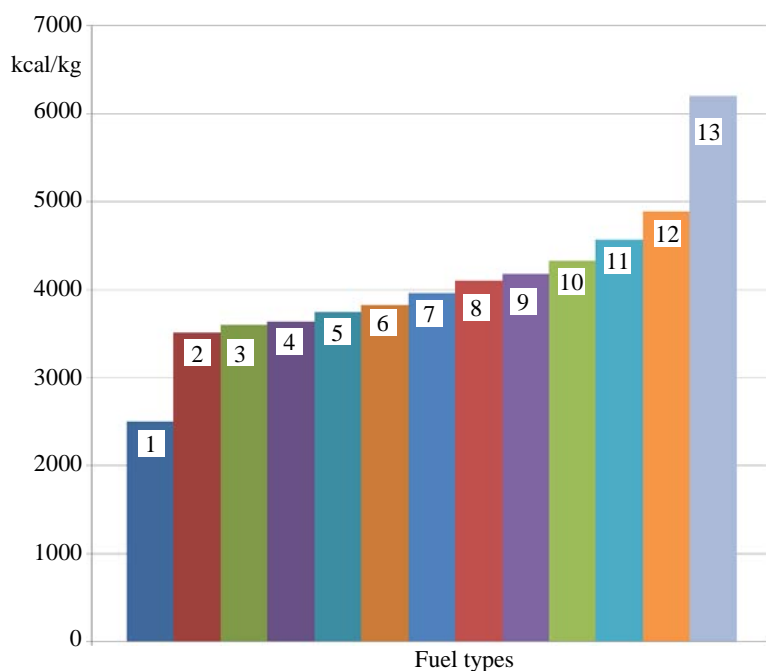


Fig. 4. Diagram comparing the calorific value of various solid fuels with multicomponent solid fuel using sewage sludge: 1 – fire wood (round timber), water content  $W = 15\%$ ; 2 – multicomponent solid fuel (with WWS 33 %),  $W = 15\%$ ; 3 – peat briquette with  $W$  not more than 16 %; 4 – multicomponent solid fuel (with WWS 25 %),  $W = 15\%$ ; 5 – multicomponent solid fuel (with WWS 50 %),  $W = 15\%$ ; 6 – multicomponent solid fuel (with WWS 25 %),  $W = 15\%$ ; 7 – wood chips,  $W = 10.4\%$ ; 8 – fuel briquette RUF,  $W = 12\%$ ; 9 – brown coal of B-2-rank,  $W = 15\%$ ; 10 – multicomponent solid fuel (with oil sludge 100 %),  $W = 15\%$ ; 11 – fuel pellets,  $W = 7.7\%$ ; 12 – fuel briquette Pinykey,  $W = 9\%$ ; 13 – coal anthracite of AM-rank

According to the data obtained, we note a clear advantage in terms of calorific value, since according to this characteristic, fuel obtained using sewage sludge, in various ratios, has a calorific value significantly higher than wood

fuel. Also, in terms of calorific value, fuel used in WWS in a ratio of 25, 50 and 100 % exceeds the calorific value of peat fuel. At the same time, the difference in the heat of fuel combustion using in the WWS composition in the ratio of 100 and 50 % is 135–350 kcal/kg, respectively, from fuel chips and fuel briquettes of the RUF type. Accordingly, the obtained values of the MSF combustion heat using WWS differ from the generally accepted compared fuels insignificantly, not exceeding the range of values within 3.3–8.5 %.

Taking into account the obtained results of comparing the heat of combustion, it can be concluded that there is a potential for obtaining alternative energy resources using waste in the form of wastewater sludge from urban structures, which is an urgent state task in solving the problems of waste use.

Comparative analysis of MSF samples has been also tested in other parameters, such as density, strength, water absorption, assessment of emissions of harmful substances from combustion, etc. In the tests, samples of various component compositions have been used, briquetted under the same pressure, but at different humidity, their appearance is shown in Fig. 5.

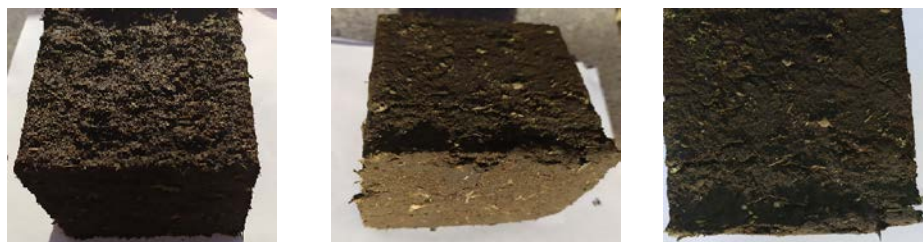


Fig. 5. Appearance of briquette samples using wastewater sludge

## CONCLUSIONS

1. The use of the developed specialized device in certain operating modes of the installation for short-term electrohydraulic treatment of sewage sludge makes it possible to improve the physicochemical characteristics of the composition in the terms of environmental parameters, which allows, after electrohydraulic treatment, to use wastewater sludge in other technologies, including thermal neutralization.

2. Research and comparative analysis of physical and thermotechnical characteristics, has made it possible to find the optimal ratio of components in the fuel composition and to determine that wastewater sludge has a significant energy potential and high energy efficiency indicators of this type of waste, even despite the increased ash content in the working composition of the fuel.

3. The use of optimal, environmentally sound ratios of working compositions of multicomponent solid fuel using wastewater sludge will make it possible to create a stable raw material base for the production of local energy resources with a high energy potential for replacing wood fuel sources, as well as to reduce the amount of wastewater sludge waste storage, which will reduce construction and maintenance costs of new sludge maps and undoubtedly improve the environmental situation in general.

4. The proposed directions for the utilization of wastewater sludge, in addition to the above, correspond to a low-carbohydrate strategy for the further development of the country's economic complex, which is implicitly formed in the context of solving the current tasks of increasing the competitiveness of products and preserving its export.

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