ГІДРОТЕХНІЧНЕ БУДІВНИЦТВО, ВОДНА ІНЖЕНЕРІЯ ТА ВОДНІ ТЕХНОЛОГІЇ

HYDRAULIC CONSTRUCTION, WATER ENGINEERING AND WATER TECHNOLOGIES

UDC 628.38
DOI https://doi.org/10.32782/tnv-tech.2024.6.26

RESEARCH INTO THE THERMAL CHARACTERISTICS OF GRANULAR FUEL MADE FROM SEWAGE SLUDGE

Kravchenko V. I. *– Ph.D. in Technical Sciences, Associate Professor,*
Associate Professor at the Department of Hydraulic Construction,
Water and Electrical Engineering of the Kherson State Agrarian and Economic University
ORCID ID: 0000-0002-4989-1591

Kravchenko V. P. *– Ph.D. in Economic Sciences, Associate Professor,*
Associate Professor at the Department of Finance, Banking and Insurance
of the Central Ukrainian National Technical University
ORCID ID: 0000-0003-4343-6296

Today, the scale of the formation and accumulation of various wastes, in particular sewage sludge (SS) at sewage treatment plants in settlements, continues to grow. This situation leads to the alienation of productive agricultural lands by sludge and environmental pollution, which requires their immediate processing and disposal. One of the effective ways to process SS can be to produce granulated biofuel from it. The paper considers the issue of utilizing SS by producing biofuel pellets from them. For experiments on the production of pellets, samples of sewage sludge from the treatment facilities of regional municipal production enterprise "Dnipro-Kirovograd" in the city of Kropyvnytskyi after centrifugation with 75–80% humidity of two types: raw sediment and excess activated sludge. The experiments were carried out according to the developed research methodology on a specially designed laboratory press device. Due to the high humidity of the sludge sediment samples (75–78%), before making pellets from them, their preliminary preparation was carried out by thermal (drying) and mechanical (grinding) treatment. From the prepared sludge sediments with a humidity of 12–15%, when compressed to final pressures of 130.5…217.5 MPa in a press device with a vertical punch and a closed matrix, pellet samples with a high-quality texture and a density of 1150–1260 kg/m³ are formed, which meets the requirements of European standards ρ ≥1.0 g/cm3. The determined ash content of the manufactured samples of biofuel pellets on dry weight was 24–41%, and the calorific value calculated by the D. Mendeleev formula was 16–20 MJ/kg, which is comparable to the calorific value of briquettes made of wood waste, brown coal, and peat. The obtained results of the conducted experimental studies can be considered as estimative. In general, they confirm the prospect of further research and development in the direction of technologies and equipment for the production of biofuel pellets from sewage sludge and their further utilization through use in thermal power plants.

Key words: *sewage sludge, utilization, experimental press installation, biofuel, density, heat of combustion, ash content.*

Кравченко В. І., Кравченко В. П. Дослідження теплотехнічних характеристик гранульованого палива, виготовленого з осадів стічних вод

На сьогодні продовжують зростати масштаби утворення та накопичення різноманітних відходів, зокрема осадів стічних вод (ОСВ) на каналізаційних очисних спорудах населених пунктів. Такий стан призводить до відчуження осадами продуктивних сільськогосподарських земель та забруднення довкілля, що потребує їх негайної обробки та утилізації. Одним із ефективних способів переробки ОСВ може бути виготовлення з нього гранульованого біопалива. В роботі розглянуто питання утилізації ОСВ шляхом виготовлення з них біопаливних пелет. Для експериментів з виготовлення пелет використовувалися зразки мулових осадів з очисних споруд ОКВП «Дніпро-Кіровоград» у м. Кропивницький після центрифугування вологістю 75–80% двох видів: сирий осад та надлишковий активний мул. Експерименти здійснювалися за розробленою методикою досліджень на спеціально розробленому лабораторному пресовому пристрої. Через високу вологість зразків мулових осадів (75–78%), перед виготовленням з них пелет здійснювалась попередня їх підготовка шляхом термічної (підсушування) та механічної (подрібнення) обробки. З підготовлених мулових осадів вологістю 12–15% при стискуванні до кінцевих тисків 130,5…217,5 МПа у пресовому пристрої з вертикальним пуансоном і закритою матрицею утворюються зразки пелет з якісною фактурою і густиною 1150–1260 кг/м^3, що відповідає вимогам європейських стандартів ρ ≥1,0 г/см^3. Визначена зольність виготовлених зразків біопаливних пелет на суху масу складала 24–41%, а розрахована за формулою Д. Мендєлєєва теплота згоряння складала 16–20 МДж/кг, що порівняно з теплотою згоряння брикетів з дерев'яних відходів, бурого вугілля, торфу. Отримані результати проведених експериментальних досліджень можна розглядати як оціночні. Загалом вони підтверджують перспективу подальших досліджень і розробок в напрямку технологій і обладнання для виготовлення біопаливних пелет з осадів стічних вод та подальшої їх утилізації шляхом використання в теплоенергетичних установках.

Ключові слова: *осади стічних вод, утилізація, експериментальна пресова установка, біопаливо, щільність, теплота згоряння, зольність.*

Introduction. Among the current environmental problems in Ukraine and around the world, the disposal of industrial waste stands out, which, in particular, is related to the issues of sewage treatment plant waste. Waste in the form of sewage sludge, consisting of household, industrial and storm water, is discharged into the sewer and is a source of pollution of urban areas.

To treat large volumes of wastewater, treatment systems are used that are based on the formation of sludge, which remains in sludge ponds for years [1]. The use of such sites for the disposal of SS is a traditional, but outdated and irrational method of sediment management, as it takes significant areas of land out of circulation and leads to pollution of air, soil, and groundwater with toxic components that are part of the sediments [2, 3].

Currently, stricter EU rules regarding the management of local sewage sludge, as well as the Law of Ukraine "On Water Disposal and Wastewater Treatment" of January 12, 2023, pose new challenges for the country, one of which is to find areas of effective technologies and methods of their utilization.

Analysis of recent research and publications. The feasibility of using a certain technology for the utilization of wastewater depends on several factors: the productivity of the wastewater treatment plant, the composition and methods of wastewater and sludge treatment, the efficiency of treatment facilities, etc. [4]. Thus, in Germany, Great Britain, Sweden and Finland, silt sediments are used for land reclamation and reclamation of lands disturbed by industrial developments, as well as for combustion to obtain thermal energy and ash, which is a valuable product for the production of building materials [5]. In France, 50–60% of SS is used as organic fertilizer; 20–25% is taken to solid waste landfills; and 15–20% is burned in incinerators [6].

In Ukraine, the use of SS as fertilizer is limited to 5% due to a number of circumstances, including the presence of bacterial contamination, toxic compounds, and a high

content of trace elements, which have a negative impact on plants and the quality of agricultural products. Therefore, the burial of SS is the main method of their storage for decades [5].

One of the methods of disposal that is guaranteed to eliminate harmful organic substances and significantly reduce the volume of sludge waste is incineration [6]. The heat of combustion of SS per dry mass is 14.5–16.0 MJ/kg [7] and is not inferior to wood, peat and brown coal.

However, the process of spreading the method of burning sludge in Ukraine and the world is primarily hindered by their high humidity, which is not less than 70% [2]. Studies have shown that it is advisable to use them in the energy combustion process only after they reach a moisture content of 10% [8].

For preliminary drying of SS before incineration, efficient drying equipment can be used, which will ensure the preparation of raw materials for thermochemical processing with an initial humidity of 60–70% [2]. At the same time, after treatment of SS in sewage treatment plants, they are also characterized by variability in composition, size and shape, which worsens the process of their incineration [1]. Therefore, it is more expedient to use SS as fuel in the form of pellets, which will also make it possible to increase the efficiency of energy use.

The aim of the study. The aim of the work is the experimental testing of pilot samples of biofuel pellets made from wastewater sludge of the “Dnipro-Kirovograd” Wastewater Treatment Plant.

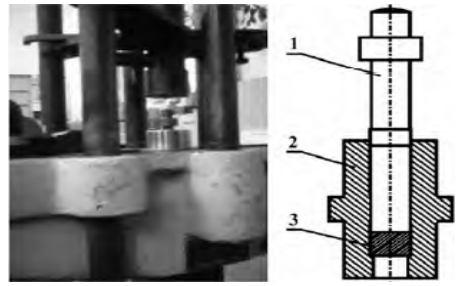
Presenting main material. The collection of formed sludge from wastewater, as well as their neutralization and preparation for disposal, takes place in a complex of engineering structures used in treatment plants using biological treatment technology in aeration tanks. The technological scheme for the treatment and processing of wastewater sludge is given in [1]. This technological process is currently one of the easiest to implement, basic in Ukraine, used at most existing treatment plants and allows for the removal of organic pollutants by 95–97%.

In experimental studies on the production of pellets, samples of sludge from the treatment facilities of the regional municipal production enterprise "Dnipro-Kirovograd" in Kropyvnytskyi were used. Samples of two types were provided after centrifugation with a humidity of 75–80%: raw sludge (SS-1) and excess activated sludge (SS-2). Since the provided samples of sewage sludge had high humidity, before making fuel from them, they were prepared by thermal and mechanical treatment. After treatment, the samples were destroyed with the formation of individual particles, of which the majority (60–70%) had dimensions of 3–5 mm and humidity of 16%.

To produce pellets from sludge SS in a closed matrix, an experimental press installation was used, the scheme of which is shown in Fig. 1a, and a press device with a mold and a punch d = 16 mm, the general view of which is shown in Fig. 1b.

For fractographic study of the surface structure of biofuel granules made from sludge SS, an optical-digital unit was used, consisting of: a stereoscopic microscope model MBC-9, a Web camera and a laptop.

The ash content was assessed using a muffle furnace. The crucible with the installed sample was placed in a muffle furnace and ashed with subsequent holding in it at a temperature of 800 °C for 1 hour (until the carbon was completely burned out).



a *b*

Fig. 1. Working part of the УВМ-50 machine with installed press device (a), press device (b)

The results of experimental studies are given in Table 1.

Table 1

Main results of experimental studies

Raw	Bulk density, g/cm^3	Pellet density, g/cm^3		Heat of combustion, MJ/kg	Ash content, %
		Pressure 130.5 MPa	Pressure 217.5 MPa		
SS-1	0.42	1.18	1.26	16.54	41.0
SS-2	0.413	1.15	1.22	20.15	24.5

The general appearance of pellets made from samples SS-1 and SS-2 is shown in Figure 2.

Pellet samples made from sewage sludge had a sufficiently smooth surface (Fig. 2a, 2b) and a high density: 1.15…1.26 g/cm3 (Table 1), which meets the requirements of European standards $\rho \geq 1.0$ g/cm^3 [9].

The nature of the surface structure of the pellets and the density of the gaps between the particles of the raw material after pressing are shown in Figure 3.

a *b*

Fig. 2. General view of pellets and their ash residues after combustion made from: a – raw sludge SS-1; b – activated sludge SS-2

a *b*

Fig. 3. Character of the surface structure of pellets and the density of gaps between the particles of raw material after pressing: a – outer surface of the SS-1 sample with a final pressure of 130.5 MPa; b – the same with a final pressure of 217.5 MPa

The results of fractographic studies showed that with increasing pellet density (at final pressures of 130.5 and 217.5 MPa), the distance between particles on the surface decreases from 0.075 mm (Fig. 3 a) to 0.02 mm (Fig. 3 b).

To determine the higher heat of combustion of sewage sludge per dry mass, which was carried out based on the average values of the elemental composition of the raw material, D. Mendeleev's formula was used to calculate the higher heat of combustion per working mass [10]:

$$Q_в^p = 4{,}187(81C^p + 300H^p - 26(O^p - S)),$$

where C^p, H^p, O^p, S^p – elemental composition of fuel per working mass.

Recalculation of the higher heat of combustion from the working mass to the dry mass was carried out according to the expression:

$$Q^d_s = Q_в^p \frac{100}{100 - W^p}$$

where W^p is the moisture content of sludge before pressing.

The values of the higher calorific value per dry mass of the manufactured pellet samples are given in Table 1.

The obtained values of the heat of combustion of pellets from sewage sludge (16.54…20.15 MJ/kg) are in satisfactory agreement with the average values of the heat of combustion: 16.8…27.4 MJ/kg, given in [11] for domestic sewage sludge.

The general appearance of ash residues after burning pellets made from sewage sludge is shown in Figure 2. The ash residue per dry mass of SS-1 almost twice exceeded the value of SS-2 and was 46.0 and 24.5%, respectively. Significantly different quantitative data of the obtained ash content values of pellets from sludge waste SS-1 and SS-2 may be due to their slightly different initial compositions. At the same time, it should be noted that, in general, the results obtained on ash content are in satisfactory agreement with the data given in works [12].

Conclusions. 1. The paper deals with the issue of disposal of sewage sludge by making biofuel pellets from it.

2. A research methodology and a press device have been developed for experimental testing of the production of pilot samples of biofuel pellets from sewage sludge of the "Dnipro-Kirovograd" Wastewater Treatment Plant.

3. It has been determined that the production of pellets from sewage sludge, due to their high humidity (75–80%), requires their preliminary preparation by thermal (drying) and mechanical (grinding) treatment.

4. From the prepared sewage sludge with a humidity of 12–15%, when compressed to final pressures of 130.5…217.5 MPa in a press device with a vertical punch and a closed matrix, pellet samples with a high-quality texture and a density of 1150-1260 kg/m^3 are formed, which meets the requirements of European standards $\rho \geq 1.0$ g/cm^3

5. The determined ash content of the manufactured samples of pellets from sewage sludge was 24–41%, and the calculated heat of combustion per dry mass was 16–20 MJ/kg, which is comparable to the heat of combustion of briquettes from wood waste, brown coal, and peat.

6. The obtained quantitative results of the conducted experimental studies can be considered as evaluative, taking into account the wide range of initial characteristics of sewage sludge and the provision of methods for their preliminary preparation for the press production of biofuel pellets.

7. In general, the results obtained confirm the prospects for further research and development in the direction of technologies and equipment for the production of biofuel pellets from sewage sludge for the purpose of their utilization by use in thermal power plants.

BIBLIOGRAPHY:

1. Кравченко В.І., Білоус Ю.В., Кравченко В.П. Створення та обгрунтування композитного палива на основі осаду стічних вод. Технічні науки. Херсон: ХДАЕУ. 2023. Вип. 3. С. 88-94. URL: http://journals.ksauniv.ks.ua/index.php/tech/article/view/403

2. Бабаєв В.М., Панов В.В., Хайло Я.М., Волков В.М., Горох М.П. Альтернативні технологічні рішення проблеми повної утилізації мулового осаду стічних вод // Комунальне господарство міст. 2018. № 144. С. 32-42.

3. Syed Shatir A. Syed-Hassan, Yi Wang , Song Hu, Sheng Su, Jun Xiang. Thermochemical processing of sewage sludge to energy and fuel: Fundamentals, challenges and considerations. URL: https://www.sciencedirect.com/science/article/abs/pii/S1364032117309036

4. Зоріна О.В., Маврикін Є.О. Сучасні підходи до обробки та утилізації вторинних осадів господарсько-побутових стічних вод //Водні ресурси. Меліорація і водне господарство, 2021, № 2. С. 55-68.

5. Шквірко О. М., Тимчук І. С., Мальований М. С. Адаптація світового досвіду утилізації осадів стічних вод до екологічних умов України // Науковий вісник НЛТУ України. 2019. Т. 29. № 2. С.82-87.

6. Карп І. М., П'яних К. Є., Нікітін Є. Є. Проблема утилізації та знешкодження мулових осадів // Энерготехнологии и ресурсосбережение. – 2017. № 2. С. 35-48. URL: http://nbuv.gov.ua/UJRN/ETRS_2017_2_6

7. Пазюк В.М., Токарчук О.А. Основні характеристики осадів стічних вод. Техніка, енергетика, транспорт АПК. С.96-104. DOI: 10.37128/2520-6168-2022-1-11.

8. Malhozhata V. ta Mariush T. Production of solid biofuel from city sewage sludge. Technical and economic optimization. 2015. Vol. 33(8). URL: https://journals.sagepub.com/doi/full/10.1177/0734242X15588584

9. Сайт ukr bio: Пелети-стандарти. Пелети-стандарти. URL: https://bio.ukr.bio/ua/articles/1574/

10. Константінов С.М., Панов Є.М. Теоретичні основи теплотехніки: Підручник. К.: «Золоті ворота», 2012. 592 с.

11. Шаманський С.Й., Бойченко С. В. Енергоефективна та екологічно безпечна технологія стабілізації осадів стічних вод авіапідприємств. Восточно-Европейский журнал передовых технологий. 2015. № 5(8). С. 39-45. URL: http://nbuv.gov.ua/UJRN/Vejpte_2015_5%288%29__8

12. Бондар О.І., Лозовіцький П.С., Машков О.А., Лозовицький А.П. Екологічний стан накопичених осадів стічних вод м. Києва / Науково-практичний журнал Екологічні науки. 2015, №7. С. 38-53. URL: http://ecoj.dea.kiev.ua/archives/2015/7/5.pdf.

REFERENCES:

1. Kravchenko V. I., Bilous Yu. V., Kravchenko V. P. (2023) Stvorennia ta obhruntuvannia kompozytnoho palyva na osnovi osadu stichnykh vod [Creation and justification of composite fuel based on sewage sludge] *Tavriiskyi naukovyi visnyk* [Tavrii scientific university] (electronic journal), no. 3. pp. 88-94. Retrieved from: http://journals.ksauniv.ks.ua/index.php/tech/article/view/403 (accessed 15 December 2024).

2. Babaiev V.M., Panov V.V., Khailo Ya.M., Volkov V.M., Horokh M.P. (2018). *Alternatyvni tekhnolohichni rishennia problemy povnoi utylizatsii mulovoho osadu stichnykh vod* [Alternative technological solutions to the problem of complete utilization of sewage sludge]. *Komunalne hospodarstvo mist* [Municipal utilities]. Kharkiv, Kharkiv: National University of Urban Economy named after O.M. Beketov, no. 144, pp. 32-42.

3. Syed Shatir A. Syed-Hassan, Sheng Su, Jun Xiang (2017) [Thermochemical processing of sewage sludge to energy and fuel: Fundamentals, challenges and considerations]. *Oglyadi vidnovlyuvanoyi ta staloyi energetiki* [Renewable and Sustainable Energy Reviews]. *Agricultural sciences* (electronic journal), vol. 80, pp. 888-913. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S1364032117309036 (accessed 19 December 2024).

4. Zorina O.V., Mavrykin Ye.O. (2021) Suchasni pidkhody do obrobky ta utylizatsii vtorynnykh osadiv hospodarsko-pobutovykh stichnykh vod. [Modern approaches to the treatment and disposal of secondary sludge from domestic wastewater] *Vodni resursy. Melioratsiia i vodne hospodarstvo*. [Water resources. Land reclamation and water management]. Kyiv: pp. 55-68.

5. Shkvirko O. M., Tymchuk I. S., Malovanyi M. S. (2019). Adaptatsiia svitovoho dosvidu utylizatsii osadiv stichnykh vod do ekolohichnykh umov Ukrainy. [Adaptation of world experience in wastewater sludge utilization to the environmental conditions of Ukraine]. *Naukovyi visnyk NLTU Ukrainy* [Scientific Bulletin of the National Technical University of Ukraine], Lviv: Natsionalnyi lisotekhnichnyi universytet ukrainy, pp. 82-87.

6. Karp I. M., Pianykh K. Ye., Nikitin Ye. Ye. (2017) Problema utylizatsii ta zneshkodzhennia mulovykh osadiv [The problem of utilization and neutralization of sludge sediments] *Энerhotekhnolohyy y resursosberezhenye.* [Energy technologies and resource conservation]. *Энerhotekhnolohyy* (electronic journal) no. 2, pp. 35-48. Retrieved from: http://nbuv.gov.ua/UJRN/ETRS_2017_2_6 (accessed 20 December 2024).

7. Paziuk V.M., Tokarchuk O.A. Osnovni kharakterystyky osadiv stichnykh vod. [Main characteristics of sewage sludge]. *Tekhnika, enerhetyka, transport APK* [Machinery, energy, transport, agro-industrial complex] *Engineering, Energy, Transport AIC* (electronic journal), vol. 3, no. 126, pp. 96-104. Retrieved from: DOI: 10.37128/2520-6168-2022-1-11 (accessed 22 December 2024).

8. Malhozhata V. ta Mariush T. (2015) Tekhniko-ekonomichna optymizatsiia [Production of solid biofuel from municipal wastewater sludge] *Tekhniko-ekonomichna optymizatsiia* [Technical and economic optimization]. *Agriculture* (electronic journal), vol. 33, no. 8, pp. 36-42. Retrieved from: https://journals.sagepub.com/doi/full/10.1177/0734242X15588584 (accessed 15 December 2024).

9. Sait ukr bio: Pelety-standarty. Retrieved from: https://bio.ukr.bio/ua/articles/1574/ (accessed 18 December 2024).

10. Konstantinov S.M., Panov Ye.M. (2012) Teoretychni osnovy teplotekhniky [Theoretical foundations of heat engineering]. Kyiv. Zoloti vorota. (in Ukrainian)

11. Shamanskyi S.I, Boichenko S.V. (2015) Enerhoefektyvna ta ekolohichno bezpechna tekhnolohiia stabilizatsii osadiv stichnykh vod aviapidpryiemstv [Energy-efficient and environmentally friendly technology for stabilizing airline wastewater sludge]. Enerhozberihaiuchi tekhnolohii ta obladnannia, vol. 5, no 8, pp. 39-45. Retrieved from: http://nbuv.gov.ua/UJRN/Vejpte_2015_5%288%29__8 (accessed 23 December 2024).

12. Bondar O.I., Lozovitskyi P.S., Mashkov O.A., Lozovytskyi A.P. (2015) Stan nakopychenykh osadiv stichnykh vod m. Kyieva [Ecological condition of accumulated sewage sludge in Kyiv]. Naukovo-praktychnyi zhurnal Ekolohichni nauky, no 7, pp. 38-53. Retrieved from: http://ecoj.dea.kiev.ua/archives/2015/7/5.pdf. (accessed 10 December 2024).