GOSPODARKA SUROWCAMI MINERALNYMI – MINERAL RESOURCES MANAGEMENT

2023 Volume 39 Issue 2 Pages 109–123

DOI: 10.24425/gsm.2023.145881

JUSTYNA GÓRKA[1], DOMINIKA POPROCH[2], MAŁGORZATA CIMOCHOWICZ-RYBICKA[3], BARTOSZ ŁUSZCZEK[4]

Characteristics of sand recovered from the municipal wastewater treatment plant

Introduction

Wastewater treatment plants have become valuable elements of the concept of the circular economy through the implementation of the three Rs rule (reduce, reuse and recycle) (Schanmugam et al. 2022). Other valuable by products that may be processed and reused can be found during cleaning of streets to remove trash and dirt (Heshmati 2015). The products recovered from the WWTP include sludge (produced in mechanical and biological processes) as well as screenings and sand (recovered in mechanical processes). Sewage sludge can be further utilized for biogas production; biogas is a valuable source of heat and electricity

✉ Corresponding Author: Justyna Górka; e-mail: justyna.gorka@pk.edu.pl

[1] Faculty of Environmental Engineering and Energy, Cracow University of Technology, Kraków, Poland; ORCID iD: 0000-0002-9322-6206; e-mail: justyna.gorka@pk.edu.pl

[2] Doctoral School, Cracow University of Technology, Kraków, Poland; Krakow Water, Kraków, Poland; ORCID iD: 0000-0002-0524-6072; e-mail: dominika.poproch@wodociagi.krakow.pl

[3] Faculty of Environmental Engineering and Energy, Cracow University of Technology, Kraków, Poland; ORCID iD: 0000-0002-0216-9403; e-mail: mcrybicka@pk.edu.pl

[4] Kraków Water, Kraków, Poland; ORCID iD: 0000-0002-6466-0978; e-mail: bartosz.luszczek@wodociagi.krakow.pl

at the treatment plant (Górka et al. 2022). Subsequently, the stabilized sewage sludge can be directly utilized either as a soil conditioning agent or, after thermochemical/biochemical treatment, recovered as material (e.g. hydrogen), energy (e.g. heat and synthesis gas) or other resources (phosphorus) (Cieślik et al. 2015; Renfrew et al. 2022). Screenings, due to their diverse composition (18% of plastics, up to 26% of textile and a high content of organic compounds) are mostly neutralized in the combustion process (Wiśniowska 2016). On the other hand, sand, removed in grit chambers, may also be a raw material with great potential, and its recovery and re-utilization offer major financial benefits. If properly processed, it can have good properties as a raw mineral material with a "clean" composition.

Sand at the WWTP can be found in at least at two locations: in grit chambers (as a part of grit) and as a result of sewer cleaning. Grit chambers are an important element of all WWTP operations. The traditional design concept of the grit chambers is relatively simple and is based on the settling rate of the particles, which depends on their specific weight. An ideal sand particle considered in a design of grit chambers is a spherical, homogeneous one, with a size of 200 microns and a specific gravity of 2.65 $N \cdot m^{-3}$ (Tchobanoglous et al. 2014). Typical sand specific gravity ranges from 2.64 to 2.72 $N \cdot m^{-3}$, although the overall specific gravity of the particles in wastewater is lower due to the layers of organic material that normally cover the particle surface and range from 1.1 to 2.65 $N \cdot m^{-3}$ (Plana et al. 2020). In real life, the ideal conditions for sand separation are rarely met, as the material can be of a different origin, depending on the characteristic of the drainage area and the composition of raw wastewater – both these factors have an impact on sand characteristics (Kolosovska and Bauer 2022; Judd et al. 2017).

Grit chambers and sand removal are provided to reduce the risk of clogging of pipelines and aeration diffusers as well as to protect mechanical elements of the pumps against abrasion. They also protect the digestion tanks from the excess accumulation of mineral compounds, which reduce the active volume of the tanks (Malej 2004; Kolosovska and Bauer 2022). According to the Regulation of the Minister of Climate of January 2, 2020 on the waste catalog (Ordinance MC 2020), sand from grit chambers is classified as waste with the code 19 08 02. It is assumed that the average amount of sand collected at the treatment plant varies from 2 to 5 dm^3 per capita or from 3.7 to 55 dm^3 per 1,000 m^3 of wastewater (Imhoff 1996). Table 1 shows the amount of sand removed in real conditions at wastewater treatment plants.

Sand handling is still a serious operational problem. The sludge has a high content of organic compounds and high moisture and therefore, similar to screenings, is a potential source of odor. In order to reduce the odor nuisance, sand washers have been introduced; they reduce the content of organic compounds in the sand by washing (Yan et al. 2014). Sand with an organic content above 8% is transferred to specialized companies, while sand with an organic content below 8% can be reused, for example, it can supplement fine aggregate in the production of concrete mixture (Chen et al. 2016).

The article discusses the quality of sand collected at the Kraków–Płaszów municipal wastewater treatment plant (flow capacity Q = 165,000 m^3/d). In 2019, the old sand separa-

Table 1. Sand removed at wastewater treatment plants

Tabela 1. Piasek usunięty w oczyszczalniach ścieków

No.	Location of wastewater treatment plant	Capacity	Amount of sand (19 08 02)			Online source
		$m^3 \cdot d^{-1}$	$Mg \cdot year^{-1}$	$Mg \cdot m^{-3}$	$dm^3 \cdot 1000\ m^{-3}$	
1	Nowiny	51,000	800	5.7	3.8	Kielce waterworks 2020
2	Kościana	3,987	40	3.7	2.4	Kościan waterworks 2020
3	Rzeszów	45,000	150	1.2	0.8	Marshal of the Podkarpackie Voivodeship 2021
4	Częstochowa	46,616	600	4.7	3.1	Warta SA Częstochowa 2018
5	Józefów	2,143	219	37.3	24.9	Józefów. Portal of the City Hall 2020
6	Słomniki	579	30	18.9	12.6	Słomniki 2020
7	Oleśno	2,500	120	17.5	11.7	OPWiK 2020
8	Maszew	18,055	260	5.3	3.5	Płock waterworks 2021
9	Kraków–Płaszów	165,000	3,156	7.7	5.1	Data collected by the authors
10	Kraków–Kujawy	53,000	1,608	5.7	3.8	

tors were replaced with more efficient versions by Kraków Water, as part of the modernization project. Thanks to these new high-performance devices, it was possible to optimize the process and subsequently minimize the amount of waste and odor nuisance. The application of such highly efficient devices offered the possibility of dropping the waste status. The final product (sand) has become a mineral resource with some possibilities of reuse and management.

1. Description of the Kraków–Płaszów WWTP

Sand samples have been collected from the technological line of the Kraków–Płaszów WWTP. The plant comprises mechanical and biological wastewater treatment as well as a sludge processing and biogas production line. The plant has been designed for 780,000 equivalent population (PE). According to the water permit, the average daily flow during the dry-weather period is 165,000 m^3/d^{-1}. At the wastewater treatment plant, there are two dense screen bars with a clearance of 30 mm and four rare screen bars with a clearance of 6 mm. The Kraków–Płaszów WWTP operates four aerated grit chambers with a horizontal flow; each unit consists of two chambers. Along each grit chamber there is a quite zone where grease flotation takes place. Each grit chamber is equipped with a pump conveyor coupled with two sand pumps. A wastewater and sand mixture is discharged to the sand separation building and then to the sand separator (Figure 1).

Fig. 1. Sand separator at the Kraków–Płaszów WWTP

Rys. 1. Separator piasku na oczyszczalni Kraków–Płaszów

Initially, the sand enters the tank equipped with a rotating mixer which provides the necessary agitation to separate the sand from the organic material. Water rich in organic matter is discharged over the weir while clean sand is collected at the bottom of the tank and then transferred on the inclined screw conveyer. Moving up the ramp, the sand is dewatered by gravity forces and finally dropped into the container. The sand-separation process takes place at two locations. The first one (WWTP – wastewater treatment plant) gets sand directly from the grit chambers connected to the Kraków sewage system. The other location (WN – wastewater network) treats sand from the sewer-cleaning vehicle (septic tankers) designed to clean the sewage manholes in Kraków. The guaranteed efficiency of sand separation and dewatering processes at the plant was as follows: sand will contain no more than 3% of organics and its moisture will be 10%.

2. Materials and methods

2.1. Laboratory experiments

During the laboratory experiments, the analysis of sand characteristic was performed. The analysis included the basic parameters such as: dry matter (DM), dry mineral matter (DMM) and graining. DM content was determined according to the standard PN-EN 15934,

Table 2. Methodology of eluvation tests

Tabela 2. Metodyka badań elucyjnych

Indicator	2017	2018	2021
Antimony	PERKIN ELMER	PERKIN ELMER	PN-EN ISO 17294-2:2016-11
Bar	PN-EN ISO 14911-1:2002	PN-EN ISO 14911-1:2002	PN-EN ISO 14911-1:2002
Fluorides	PN-EN ISO 10304-1:2009	PN-EN ISO 10304-1:2009	PN-EN ISO 10304-1:2009
Sulfur	PN-ISO 9280:2002	PN-ISO 9280:2002	PN-ISO 9280:2002
Chlorides	PN-ISO 9297:1994	PN-ISO 9297:1994	PN-ISO 9297:1994
Arsenic	PN-EN ISO 11969:1999	PN-EN ISO 11969:1999	PN-EN ISO 17294-2:2016-11
Chrome	102: Flame determination of chrome	102: Flame determination of chrome	102: Flame determination of chrome
Cadmium	ASA: PN-ISO 8288:2002	ASA: PN-ISO 8288:2002	ASA: PN-ISO 8288:2002
Copper	ASA: PN-ISO 8288:2002	ASA: PN-ISO 8288:2002	ASA: PN-ISO 8288:2002
Nickel	ASA: PN-ISO 8288:2002	ASA: PN-ISO 8288:2002	ASA: PN-ISO 8288:2002
Lead	ASA: PN-ISO 8288:2002	ASA: PN-ISO 8288:2002	ASA: PN-ISO 8288:2002
Mercury	PN-EN 13346:2002	PN-EN 13346:2002	Mercury on the analyzer
Selenium	PN-EN 13346:2002	PN-EN 13346:2002	PN-EN ISO 17294-2:2016-11
Zinc	ASA: PN-ISO 8288:2002	ASA: PN-ISO 8288:2002	ASA: PN-ISO 8288:2002
Dissolved organic carbon (DOC)	PN-EN 1484:1999	PN-EN 1484:1999	PN-EN 1484:1999

while organic (volatile) solids were determined according to the standard PN-EN 15935. Sieve analysis was done following the standard PKN-CEN ISO/TS 17892-4, the dry method. Diameters d10, d30 and d60 were determined from the sieve curve; the graining differentiation index C_u and curvature index C_c were also calculated. The sand samples were collected according to the standard PN-EN ISO 5667-13:2011. Laboratory tests were performed over six months (one sample per month in triplicate).

Also, some eluviation tests were carried out, as follows: 100 g sample of sand was filled with water up to 1 dm^3. Then the sample was shaken for 24 h and filtered. The results are the average of individual years. Eluvation analysis were performed six times a year. The following were analyzed in the sample: chromium, cadmium, copper, nickel, lead, mercury, zinc, antimony, barium, fluorides, arsenic, selenium and dissolved organic carbon. Table 2 presents the methodology for determining eluvation indicators. Due to the extensiveness of the table, only methods from three measurement years (2017, 2018 and 2021) are presented. In those years, there were significant changes in the methods used to determine the individual indicators.

There are two locations where sand have been collected at the Kraków–Płaszów WWTP. They are:

- grit chamber (sample WWTP),
- sand from sewer manholes (sample WN).

To check whether mixing of these two types of sand has any impact on graining characteristics the sands were mixed at different ratios and the sieve curves were prepared. The tests were done for the following ratios (by mass): 25% WWTP + 75% WN, 50% WWTP + + 50% WN, 75% WWTP + 25% WN and also for the control samples with WWTP and WN only. The mixture was prepared after the sand samples were dried in temperature of 105°C.

3. Results

3.1. Volume and quality of the sand in the years 2016–2021

As part of the research, the annual mass balance of sand collected at the wastewater treatment plant was carried out. The balance sheet covers the years 2016–2021. In the early years, an upward trend in sand production can be noticed. Once new, high-performance devices (2019) have been in place, the amount of sand decreased by 20 to 28%. The decrease in amount of sand generated at the plant is related to the fact that less contaminated "clean" sand is produced at the sand separators.

Figure 3 shows the content of DM and DMM in sand in 2017–2022. From 2019 – the year when new sand separators were installed – the content of both DM and DMM increased significantly. The DMM exceeded 90% (10% of the organic content), while the DM in 2019–2022 was approx. 93% (reduction of the organic content to approx. 7%). Once high-

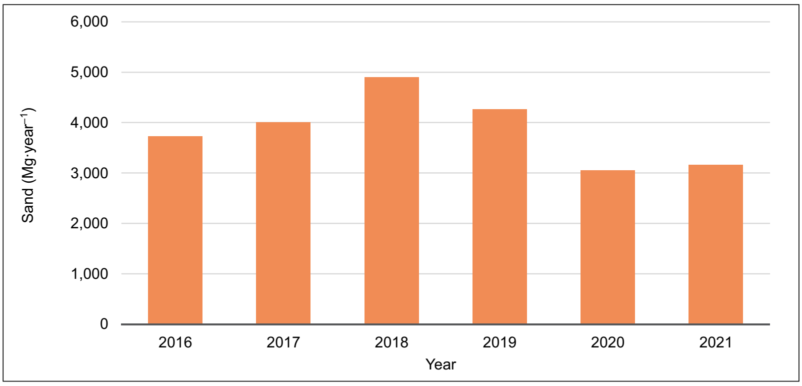

Fig. 2. Annual mass of sand generated at the Kraków–Płaszów WWTP in the years 2016–2021

Rys. 2. Roczna masa piasku wytwarzanego w oczyszczalni Kraków–Płaszów w latach 2016–2021

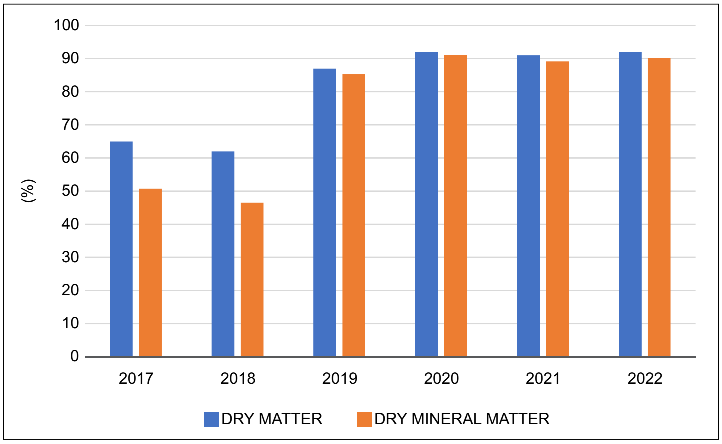

Fig. 3. DM and DMM content in sand collected at the Kraków–Płaszów WWTP in the years 2017–2022

Rys. 3. Zawartość SM i DMM w piasku pobranym z oczyszczalni Kraków–Płaszów w latach 2017–2022

-performance sand separators have been installed, the sand parameters improved, and a positive change in waste appearance was also noticeable. This is a very much needed phenomenon due to the technological and economic aspect of the treatment plant. Table 3 shows the results of the sand leachability tests. It was observed that concentrations of heavy metals analyzed in sand remained below the detection range (the values are either zero or close to zero).

The results indicate that just a simple method, namely the introduction of a new more advanced washing unit, produces material with a relatively low organic content and with the potential for various applications, for example, the production of construction materials.

Table 3. Summary of the results of sand leaching in 2017–2021 – the Kraków–Płaszów wastewater treatment plant

Tabela 3. Zestawienie wyników wymywania piasku w latach 2017–2021 – oczyszczalnia ścieków Kraków–Płaszów

Parameter	Unit	2017	2018	2019	2020	2020	2021	2021
					WWTP	WN	WWTP	WN
Chrome	$mg \cdot dm^{-3}$	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20
Cadmium		< 0.004	< 0.004	< 0.004	< 0.004	< 0.004	< 0.040	< 0.040
Copper		< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06	< 0.06
Nickel		< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.20	< 0.20
Lead		< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.20	< 0.20
Mercury		< 0.0010	< 0.0010	< 0.0003	<0.0004	<0.0004	< 0.0004	< 0.0004
Zinc		< 0.08	< 0.08	< 0.08	< 0.08	0.100	< 0.08	< 0.08
Antimony		0.001	< 0.001	< 0.020	< 0.020	< 0.020	< 0.020	< 0.020
Bar		< 0.010	0.010	< 0.010	< 0.010	< 0.010	0.014	< 0.010
Fluorides		0.330	0.310	0.220	0.830	0.055	0.280	0.063
Arsenic		0.0006	< 0.0005	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200
Selenium		< 0.0005	< 0.0005	< 0.0200	< 0.0200	< 0.0200	< 0.0200	< 0.0200
Dissolved organic carbon		37.80	229.00	16.00	8.95	1.46	76.30	49.70

3.2. Characteristics of the sand grain composition

The grain composition of the sand mixture which will later be used to make a concrete mix can be selected only after sieve analysis of all aggregate fractions. A content of organic compounds which are not wanted in concrete mixtures is an important feature if sand is to be used in construction. Figure 4 shows the content of DM and DMM in the control samples (WWTP and NW) as well as in the mixed samples. For each of the samples, the DM content was 97–98%. The lowest content of organic materials (only 0.8%) was found in the control sample from site 80 (WN) and for the mixture of 25% WWTP + 75% WN. In the control sample of sand coming from the separator fed from the grit chamber, the organic content reached 1.8%. Both parameters, i.e. DM and the organic content for all analyzed samples, reached the guaranteed values.

After the sieve analysis, a complete set of information on material graining was available. A good distribution of particle size provides various fractions of the material, (with the optimal crumb pile) including mostly fine particles and several types of coarse material.

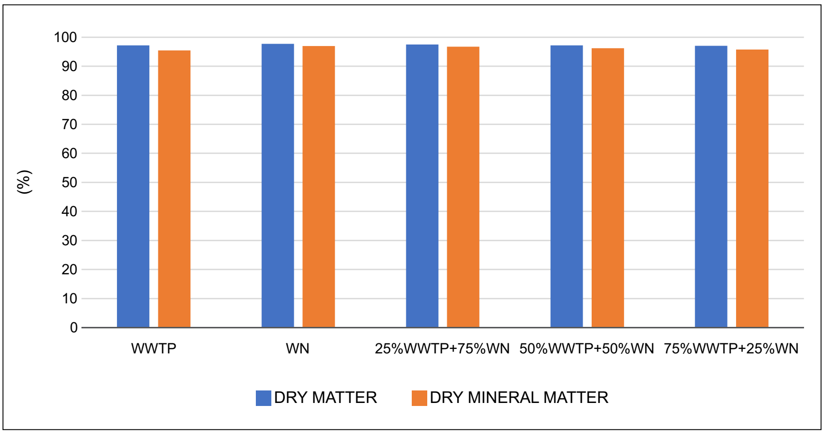

Fig. 4. Content of DM and DMM in the control samples of sand and the sand mixture

Rys. 4. Zawartość s.m. i s.m. m.m. w kontrolnych próbkach piasku iw mieszance piaskowej

Fig. 5. Sieve curves for the analyzed samples

Rys. 5. Krzywe sitowe dla analizowanych próbek

Graining should be continuous enough to ensure a good tightness of the concrete mix crumb pile. Fine material (sand) stabilizes the concrete mix, maintains its mouldability, viscosity and resistance to stratification. Coarse aggregate (gravel, grit), on the other hand, provides the necessary volume. An important element of the grain size selection is the so-called "sand point", denoting fractions of up to 2 mm. The designing of concrete mixes often begins and ends with the development of concrete mix recipes for a specific sand point, for which adequate workability is ensured. Figure 5 shows the particle size distribution curves of the individual sand samples that had been mixed at different ratios.

The curve for the WWTP control sample (sand from grit chamber separators) has only 2% of the material with a diameter above 2 mm, while the curve for the WN control sample (sand from cleaning sewer manholes) has 10% of material with a diameter of over 2 mm. All the curves stay within the area where granulation is suitable for stabilization with cement.

Mixing both types of sand (WWTP and WN) had an effect on the granulation of aggregates. The Cu heterogeneity index (Table 4) reached a value of 1.8–2.2, proving that the material is uniformly grained. However, the particle size curvature coefficient Cc stays within the range of 0.9–1.0, as in a well-grained material; the higher the Cu index, the better the soil compaction. Sand obtained from cleaning the sewers (WN) shows the highest grain differentiation index, so it can be well compacted. The sand point, i.e. the content of the fraction below 2 mm, stays within the range of 90–98%, depending on the type of sand and its mixing ratio. It means that the sand separated at the plant is a fine aggregate (see Table 5, according to the PN-EN 12620 standard *Aggregates for concrete)*. A higher amount of fine aggregates may result in a higher demand for cement slurry due to a higher water demand. It is also worth noting that the maximum size of sand grains remained below 4 mm. Consequently, the sand removed at the plant can be used as aggregate for concrete making. However, coarse fractions should be added to this sand if there are the specific requirements for particular cement.

The use of sand recovered at the wastewater treatment plant, initially as waste, and after the cleaning processes, obtaining a valuable raw material from it, is a process that has been used for many years and is quite widely described. An example may be the development of sand for specific needs of municipal and communication construction (Warta SA Częstochowa 2011; Borges et al. 2015). It should be remembered that in order to use such

Table 4. Granulations in the different sand samples

Tabela 4. Ziarnistość w różnych próbkach piasku

Parameter	WWTP	WN	25% WWTP + + 75% WN	50% WWTP + + 50% WN	75% WWTP + + 25% WN
Soil differential index (Cu)	1.84	2.17	2.14	1.86	1.86
Grain size curvature index (Cc)	1.02	0.89	1.02	0.96	1.03

Table 5. Granulation requirements according to the standard PN-EN: 12620 Aggregates for concrete

Tabela 5. Wymagania granulacyjne wg normy PN-EN: 12620 Kruszywa do betonu

Material	Diameter	Screening (mass percentage)				
		2D	1,4D[a] and [b]	D[c]	d[b]	d/2[a] and [b]
Coarse	D/d ≤ 2 or D ≤ 11.2 mm	100	from 98 to 100	from 85 to 99	from 0 to 20	from 0 to 5
	D/d > 2 and D > 11.2 mm	100	from 98 to 100	from 80 to 99	from 0 to 20	from 0 to 5
Fine	D ≤ 4 mm and d = 0	100	from 98 to 100	from 90 to 99	from 0 to 15	from 0 to 5
Natural granulation	D = 8 mm and d = 0	100	from 98 to 100	from 85 to 99	–	–
Continuous granulation	D ≤ 45 mm and d = 0	100	from 98 to 100	from 90 to 99	–	–
		100	from 98 to 100	od 85 do 99		

[a] When the specified screens do not match the exact screen numbers of the ISO 565: 1990 R series, the next closest screen size should be used.

[b] Additional requirements may be specified for concrete with discontinuous grading or for other special applications.

[c] The percentage of grains passing through D may be greater than 99% by weight, but in such cases the manufacturer should document and declare the typical particle size, including D, d d/2 sieves and Basic Set plus Set 1 or Base Set plus Set 2 for intermediate values between d and D. For sieves with a ratio of less than 1.4, the next lower sieve can be excluded.

a recovered raw material as a building material, it must be analyzed in terms of strength, porosity, densification ability, and in our climatic conditions, even frost resistance (Bieniowski et al. 2020).

Very good results were obtained in quite unusual studies from the processing of technological waste from wastewater treatment plants and water treatment plants. As a result of autothermal combustion in a fluidized bed furnace of mixtures of primary (high mineral) and secondary sludge, with the addition of sludge from water treatment, ashes were obtained, which were successfully used to create components of building materials used in road construction (concrete blocks, curbs, road surface) (Intowgc 2020).

Conclusions

Following the idea of sustainable development, wastewater treatment plants become the water and raw material recovery plants that enable the minimization of the environmental footprint (Szulc 2018). The reasonable use of resources is one of the solutions to environmental problems as well as to the economic challenges of the Europe. However, this requires giving up the linear economy based on the "production – consumption – disposal" model and replacing it with a circular economy in which waste can be a source for the recovery of various raw materials, including minerals. The economical use of raw materials can bring significant savings and contribute to the reduction of greenhouse gases and other emissions, including emission to water and soil (Pietrzyk-Sokulska 2016).

Sand is a raw material that can be recovered with mechanical treatment. However, such recovery is not efficient at many sites, which limits its possibilities. The scale of the problem can be illustrated by the fact that the Kraków–Płaszów WWTP removes over 3,000 tons of sand each year. The current cost of its disposal (the price as in the tender documents) is PLN 2,000 per ton. Legal regulations (sand has its waste code) also make matters difficult. However, a higher efficiency of its accumulation, and a lower organic content have opened possibilities of research on the use of this raw material e.g. in construction works.

In the Kraków–Płaszów WWTP, due to the replacement of sand separation/washing units, the amount of sand has significantly decreased resulting in real economic and environmental benefits. In addition, the quality of sand has improved significantly. In 2019, approx. 4,265 Mg of sand was produced. The annual operation of new separators reduced the amount of sand down to 3,054 Mg (2020), i.e. by approx. 28%. Once optimization of the separation/washing process took place, a significant improvement in the sand quality was observed (laboratory tests confirmed the reduction of organic compounds to below 3% of dry weight). The leachability tests showed no environmental impact of this raw material. In addition, sand removed in the treatment plant can become a useful product. Based on the sand-grain analysis, it was proven that sand from the wastewater treatment plant can be used as fine-grained aggregate in the production of concrete. Wastewater treatment plants can be a good source of a sand fraction of 0–4 mm, with a variety of applications.

The research was carried out as part of a Research project funded by the Ministry of Education and Science, Implementation Doctorate Program, DWD/5/0187/2021.

REFERENCES

Bieniowski et al. 2020 – Bieniowski, M., Bauman-Kaszubska, H. and Kozakiewicz, P. 2020. Considerations on the management of sand produced in sewage treatment plants (*Rozważania na temat zagospodarowania piasku powstających w oczyszczalniach ścieków*). *Forum Eksploatatora* 108(3), pp. 52–55 (*in Polish*).

Borges et al. 2015 – Borges, N.B., Campos, J.R. and Pablos, J.M. 2015. Characterization of residual sand removed from the grit chambers of a wastewater treatment plant and its use as fine aggregate in the preparation of non-structural concrete. *Water Practice and Technology* 10(1), pp. 164–171, DOI: 10.2166/wpt.2015.018.

Chen et al. 2016 – Chen, Y.P., Guo, J.S., Wang, J., Yan, P., Ji, F.Y., Fang, F. and Dong, Y. 2016. A grit separation module for inorganic matter removal from activated sludge: investigation on characteristics of split sludge from the module. *Environmental Technology* 37(24), pp. 3168–3176, DOI: 10.1080/09593330.2016.1181108.

Cieślik et al. 2015 – Cieślik, B.M., Namieśnik, J. and Konieczka, P. 2015. Review of sewage sludge management: standards, regulations and analytical methods. *Journal of Cleaner Production* 90, pp. 1–15, DOI: 10.1016/j.jclepro.2014.11.031.

Górka et al. 2022 – Górka, J., Cimochowicz-Rybicka, M. and Poproch, D. 2022. Sludge management at the Kraków–Płaszów WWTP – case study. *Sustainability* 14(13), pp. 1–11, DOI: 10.3390/su14137982.

Heshmati, A. 2015. *A Review of Circular Economy and its Implementation*, pp. 1–63. No. 9611. IZA, Bonn, Germany.

Imhoff, K. 1996. *City sewerage and sewage treatment. Guide* (*Kanalizacja miast i oczyszczanie ścieków. Poradnik*). Bydgoszcz, pp. 264–265 (*in Polish*).

Intowgc [Online:] http://www.intowgc.pl/index.php [Accessed: 2020].

Józefów. Portal of the City Hall. [Online] https://www.jozefow.pl/oczyszczalnia-sciekow-147 [Accessed: 2021-07-06].

Judd et al. 2017 – Judd, S.J., Khraisheh, M., Al-Jaml, K.L., Jarman, D.M. and Jahfer, T. 2017. Influence of composite particle formation on the performance and economics of grit removal. *Water Resource* 108, pp. 444–450, DOI: 10.1016/j.watres.2016.11.025.

Kielce waterworks. [Online:] https://wod-kiel.com.pl [Accessed: 2020-02-06] (*in Polish*).

Kolosovska, T. and Bauer, S.K. 2022. Evaluation of grit properties at a medium-capacity wastewater treatment plant: A case study. *Resources, Conservation & recycling Advances* 14, pp. 1–9, DOI: 10.1016/j.rcradv.2022.200080.

Kościan waterworks. [Online:] https://platformazakupowa.pl/transakcja/341856 [Accessed: 2020-05-05] (*in Polish*).

Malej, J. 2004. *Waste and sewage sludge, characteristics, disposal and management* (*Odpady i osady ściekowe, charakterystyka, unieszkodliwianie zagospodarowanie*). Koszalin (*in Polish*).

Marshal of the Podkarpackie Voivodeship. [Online:] https://bip.podkarpackie.pl [Accessed: 2021-07-06] (*in Polish*).

Oleskie Przedsiębiorstwo Wodociągów i Kanalizacji sp. z o.o. w Oleśnie (OPWiK). [Online:] http://oleskiewodociagi.pl/217/postep-robot-dla-zadania-rozbudowa-i-modernizacja-oczyszczalni-sciekow-w-olesnie.html [Accessed: 2021-07-06] (*in Polish*).

Ordinance MC 2020. Ordinance of the Minister of the Climate of 2 January 2020 on the waste catalog (*Rozporządzenie Ministra Klimatu z dnia 2 stycznia 2020 w sprawie katalogu odpadów*) (Dz.U. 2020 poz.10) (*in Polish*).

Pietrzyk-Sokulska, E. 2016. Recycling as a potential source for mineral raw materials with selected groups of waste (*Recykling jako potencjalne źródło pozyskiwania surowców mineralnych z wybranych grup odpadów*). *Zeszyty Naukowe IGSMiE PAN* 92, pp. 141–162 (*in Polish*).

Plana et al. 2020 – Plana, Q., Pauleat, A., Gadbois, A., Lessard, P. and Vanrolleghem, V.A. 2020. Characterizing the settleability of grit particles. *Water Environment Research* 92(5), pp. 731–739, DOI: 10.1002/wer.1268.

Płock waterowrks. [Online:] https://wodociagi.pl/dzialalnosc/ekologia/scieki/ [Accessed: 2021] (*in Polish*).

PKN-CEN ISO/TS 17892-4:2009 Geotechnical tests – Soil laboratory tests – Part 4: Determination of the particle size distribution.

PN-EN 12620:2004 Aggregates for concrete.

PN-EN 15934:2013-02 Sewage sludge, treated bio-waste, soil and waste – Determination of dry matter by determination of the dry residue content or the water content.

PN-EN 15935:2022-01 Soil, waste, treated bio-waste and sewage sludge – Determination of losses on ignition.

Renfrew et al. 2022 – Renfrew, D., Vasilaki, V., McLeod, A., Lake, A., Danishvar, S. and Katsou, E. 2022. Where is the greatest potential for resource recovery in wastewater treatment plants? *Water Research* 222, pp. 1–13, DOI: 10.1016/j.watres.2022.118673.

Schanmugam et al. 2022 – Schanmugam, K., Gadhamshetty,V.,Tysklind, M., Bhattachatyya, D. and Upadhyayula, V.K.K. 2022. A sustainable performance framework for circular management of municipal wastewater treatment plants. *Journal of Cleaner Production* 339, pp. 1–17, DOI: 10.1016/j.jclepro.2022.130657.

Słomniki. [Online:] file:///C:/Users/pldph/Downloads/P-13-168-LKR-06-01.pdf [Accessed: 2020].

Szulc, P. 2018. Wastewater grit problem – case study, potencial possibilities of disposal and reusage based on Poznań WWTP example (*Piasek z oczyszczalni ścieków – analiza problemu, możliwości odzysku i wykorzystania na przykładzie oczyszczalni ścieków w Poznaniu*). *Gaz, woda, technika sanitarna* 5, pp. 190–193, DOI: 10.15199/17.2018.5.9 (*in Polish*).

Tchobanoglous et al. 2014 – Tchobanoglous, G., Stensel, H.D., Tsuchihashi, R., Burton, F.L., Abu-Orf, M., Bowden, G. and Pfrang, W. 2014. *Wastewater engineering: treatment and resource recovery*. Metcalf and Eddy, 5th ed. McGraw-Hill Education, New York, USA.

Warta SA Częstochowa. [Online:] https://www.wartasa.eu/12,Parametry-sciekow [Accessed: 2018] (*in Polish*).

Warta SA Częstochowa. [Online:] https://www.wartasa.eu/n31,Zagospodarowanie-odpadow-w-postaci-piasku-i-skratek-na-potrzeby-budownictwa-komunikacyjnego [Accessed: 2011] (*in Polish*).

Wiśniowska, E. *Waste management in a sewage treatment plant. Vol. II – screenings* (*Gospodarka odpadami w oczyszczalni ścieków. Cz. II – skratki*). [Online] https://sozosfera.pl/odpady/gospodarka-odpadami-w-oczyszczalni-sciekow-cz-ii-skratki/ [Accessed: 2016] (*in Polish*).

Yan et al. 2014 – Yan, P., Ji, F., Fan, J. and Zong, S. 2014. Grit Separation Module Performance and Influencing Factors for Grit Removal Efficiency from Activated Sludge. *Separation Science and Technology* 49(1), pp. 121–129, DOI: 10.1080/01496395.2013.828311.

CHARACTERISTICS OF SAND RECOVERED FROM THE MUNICIPAL WASTEWATER TREATMENT PLANT

Keywords

circular economy, sand, grit chamber, sand separator, mineral resources

Abstract

This article investigates the possibilities of the recovery of raw materials at the Kraków–Płaszów municipal wastewater treatment plant (WWTP). The materials include sand coming with raw sewage and delivered by septic tankers, after cleaning sewage systems. Following the Regulation of the Minister of Climate (January 2020), sand from grit chambers is classified in the waste catalog as waste, with the code of 19 08 02. (Journal of Laws of 2020, item 10). The purchase of very efficient units has optimized the grit chamber operation and minimized the amount of waste generated as well as being an odor nuisance. The paper presents a mass balance for sand collected at the WWTP. Due to the use of new sand separators, the amount of this waste has been reduced by 28%. The paper presents the sieve curves of sand collected at the wastewater treatment plant and during the cleaning of sewage wells, as well as for sand mixtures. The sand mixture was prepared to allow some variations in the grain size characteristics of the sand. The graining differentiation indexes and curvature indexes were calculated. In addition, in laboratory tests, the leachability of heavy metals and the content of dry matter (DM) and dry mineral matter (DMM) were determined. The laboratory tests confirmed the reduction of organic solids to a level below 3% of dry weight; the content of heavy metals remained below the level of detection. The experiments confirmed that sand from the WWTP can be used as fine-grained aggregate in the production of concrete.

CHARAKTERYSTYKA SUROWCÓW ODZYSKIWANYCH Z MIEJSKIEJ OCZYSZCZALNI ŚCIEKÓW – PIASEK Z PIASKOWNIKÓW

Słowa kluczowe

gospodarka o obiegu zamkniętym, oczyszczalnia ścieków, piasek z piaskowników

Streszczenie

W artykule przedstawiono możliwości odzysku surowców z miejskiej oczyszczalni ścieków Kraków–Płaszów. Do surowców tych zalicza się: piasek ze ścieków dopływających miejską siecią kanalizacyjną oraz piasek z czyszczenia sieci kanalizacyjnej dowożony samochodami asenizacyjnymi. Zgodnie z rozporządzeniem Ministra Klimatu ze stycznia 2020 r. w sprawie katalogu odpadów (Dz.U. z 2020 r., poz. 10) piasek z piaskowników klasyfikowany jest jako odpad o kodzie 19 08 02. Zastosowanie wysokosprawnych urządzeń pozwoliło zoptymalizować pracę piaskowników, zminimalizować ilość wytwarzanych odpadów, a także zmniejszyć ich uciążliwość zapachową. W pracy przedstawiono bilans ilościowy piasku pochodzącego z oczyszczalni ścieków. Dzięki zainstalowaniu nowych separatorów zmniejszeniu uległa ilość generowanego piasku o 36%. Przedstawiono krzywe sitowe piasku pochodzącego z oczyszczalni ścieków i z procesu czyszczenia studzienek kanalizacyjnych oraz ich mieszaniny w ustalonych proporcjach. Mieszanie miało na celu zmianę charakterystyki uziarnienia piasku. Obliczono wskaźniki różnoziarnistości oraz wskaźniki krzywizny uziarnienia. Ponadto wykonano analizy laboratoryjne piasku, tj. badania wymywalności metali ciężkich oraz zawartości suchej masy i suchej masy organicznej. Badania laboratoryjne potwierdziły skuteczność redukcji związków organicznych do poziomu poniżej 3% suchej masy oraz wartości metali ciężkich znajdowały się poza zakresem oznaczalności. Na podstawie oceny składu ziarnowego oraz analiz laboratoryjnych udowodniono, że piasek z oczyszczalni ścieków może być wykorzystany jako kruszywo drobnoziarniste w produkcji betonu.