Environment Protection Engineering

Vol. 47 2021 No. 1

DOI:10.37190/epe210105

MAREK KALENIK[1], MAREK CHALECKI[2]

INVESTIGATIONS ON THE EFFECTIVENESS OF WASTEWATER PURIFICATION IN MEDIUM SAND WITH ASSISTING OPOKA ROCK LAYER

The objective of the undertaken investigations was to examine in laboratory conditions whether an introduction of an assisting opoka rock layer with the granulation of 1–6 mm into the ground improves the removal efficiency of nitrogen and phosphorus compounds from domestic sewage. The performed investigations concerned the layer supporting the removal efficiency of domestic sewage in a home sewage treatment plant under infiltration drainage. The model investigations of wastewater purification were carried out in a medium sand bed with an assisting, 0.10 and 0.20 m thick opoka rock layer. The effectiveness of wastewater purification related to basic qualitative indicators (total suspended solids – TSS, BOD_5, COD, total nitrogen, total phosphorus) was in line with the Polish standards on sewage disposal into grounds and surface water. The medium sand soil bed with the 0.20 m thick assisting opoka rock layer showed higher effectiveness of wastewater purification than that 0.10 m thick. The application of the 0.20 m thick opoka rock layer increased the removal efficiency regarding TSS by 6.2%, total nitrogen by 20.4%, ammonium nitrogen by 8.3% and total phosphorus by 2.9%, and removal efficiency regarding BOD_5 by 1.2% and COD by 1.9% with relation to the 0.10 m thick assisting layer (all percentages – in average). The results confirm that the natural opoka rock with the granulation of 1–6 mm can be used to assist in the removal of nitrogen and phosphorus compounds from wastewater with the application of infiltration drainage.

1. INTRODUCTION

Construction of collection systems for gathering and disposal of sewage in rural areas is in many cases impossible due to scattered buildings, unfavorable topography of the area, and high investment costs. In these conditions, one can see an alternative in

[1]Warsaw University of Life Sciences – SGGW, Institute of Environmental Engineering, Department of Hydraulics and Sanitary Engineering, Nowoursynowska 159, 02-776 Warsaw, Poland, corresponding author, email address: marek_kalenik@sggw.pl

[2]Warsaw University of Life Sciences – SGGW, Institute of Civil Engineering, Department of Mechanics and Building Structures, Nowoursynowska 159, 02-776 Warsaw, Poland.

household sewage treatment plants with infiltration drainage where a two-stage system of sewage purification, i.e., mechanical, and biological, is applied. The mechanical sewage purification is realized in a septic tank where sedimentation, flotation, and fermentation occur during which mineral and organic impurities of density higher than the liquid density (sand, fecal matter, paper) and lower than it (fats) are removed from the sewage. The biological purification, however, is realized in a soil bed under the infiltration drainage where processes of nitrification (nitrogen removal), adsorption, and precipitation (phosphorus removal) occur. As a result of percolation through natural soil layers, the wastewater is subjected to biological purification under the influence of aerobic bacteria and other microorganisms that take up oxygen from the ground air. Fine solid particles and colloids are retained on the surface of ground grains. Part of the wastewater being filtrated in the ground is taken up by plant roots, other part raises towards the ground surface in ground capillaries, from where water evaporates, the remaining amount percolates into underground water.

In a home sewage treatment of such type, too high loading of a soil bed by sediments and colloid particles results in a filtration (clogging) cake which forms on a ground surface and pores [1, 2] and in a decrease of a ground permeability [3]. The TSS amount in raw wastewater flowing out from a septic tank into the soil bed can fluctuate between 20 $g\cdot m^{-3}$ and 475 $g\cdot m^{-3}$ [1, 4]. Differences between the TSS values in the sewage flowing out from the septic tank depend on the volume of the accumulated sediments. When the sewage is flowing through the septic tank, it rinses the sediments off it. The higher the volume of the accumulated sediment, the higher the TSS value for the sewage flowing out from the septic tank is. Microscopic analyses showed that the clogging cake forming in the soil contains mainly filamentous fibers of toilet paper which is washing out from the septic tank and undergoes biodegradation much more slowly than it is accumulated in the ground [1, 2]. The clogging cake forms mainly in poorly permeable soils. Examinations [5] show that the soil bed under the infiltration drainage can be a popular habitat of earthworms that loosen the bed (make vertical and horizontal channels) and thus increase the bed permeability. Investigations carried out in semi-technical conditions proved that if the earthworms are introduced into a clogged soil bed under the infiltration drainage, after two weeks they increase its permeability and reduce organic substances in the ground [6].

The investigations, carried out only for a medium sand soil bed, showed that the average removal efficiency regarding total nitrogen (22%) and total phosphorus (23%) is small [7]. Moreover, other scientists confirmed in their works [8, 9] that the efficiency of removal of total nitrogen and total phosphorus from the sewage purified by well-permeable ground is small. A large number of household wastewater treatment plants with infiltration drainage on a certain area can lead to pollution of underground water with compounds of nitrogen [10] and phosphorus [11]. However, nitrogen and phosphorus compounds accumulated in the soil bed under the infiltration drainage can be successfully used by plants [12].

In the aim to improve the removal efficiency of phosphorus and nitrogen compounds in soil beds under the infiltration drainage one can use also the fungi: *Trichothecium roseum* for removal of phosphates (efficiency 97.5%), *Epicoccum nigrum*, *Geotrichum candidum* and *Trichoderma* for removal of ammonium nitrogen (efficiency 84%) and total nitrogen (efficiency 86.8%) [13]. The fungi strains can be introduced into the drainage layer and the soil bed to let them develop and clean wastewater introduced into the ground.

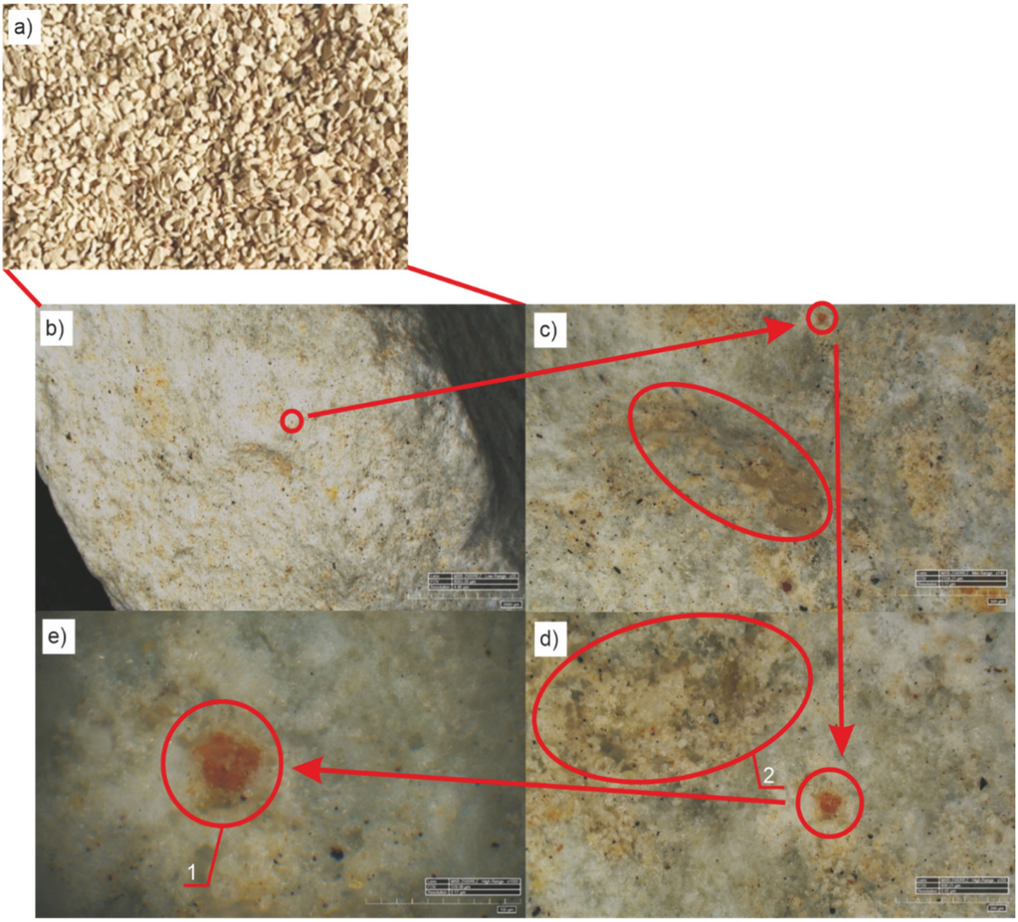

Fig. 1. Picture of an opoka rock surface made by the HIROX RH-2000 digital microscope: a) general view of grains, b) individual grain – magnification 35×, c) individual grain – magnification 140×, d) individual grain – magnification 350×, e) individual grain – magnification 1000×, 1 – ferruginous concretion, 2 – pores

To improve the efficiency of purification of wastewater in soil beds under the infiltration drainage, examinations were carried out with the use of an assisting layer made of dolomite [14], chalcedonite [7], and clinoptilolite [15]. These rocks contain calcium ions and are porous, thus, compared to the soil bed made only of quartz sand, significantly improve the removal efficiency of phosphorus and nitrogen compounds from sewage in a soil bed under the infiltration drainage. However, an application of opoka rock for sewage treatment in soil beds under the infiltration drainage has not been reported so far.

Bearing this fact in mind, the objective of these investigations was to check under laboratory conditions whether a natural opoka rock assisting layer with the granulation of 1–6 mm, introduced into the ground, improves the efficiency of nitrogen and phosphorus compounds removal from wastewater. In this aim, the model medium sand soil beds with opoka rock layers (Fig. 1) 0.10 and 0.20 m thick were applied, placed under the infiltration drainage of wastewater.

The opoka rock is a carbonic-silica rock (CaO content 32–39% wt. %, SiO_2 content 21–40 wt. %, contents of other components: Fe_2O_3, Al_2O_3, MgO does not exceed 5 wt. % [16]), characterized by very strong ability of surface fixing of adsorbed substances. It has a high specific area resulting from a high percentage of pores (over 40% of volume [17], Fig. 1d), it is coarse (roughness class 7 [17], Fig. 1b) and absorbable rock, it has high grindability and low compressive strength (ca. 10–30 MPa [17]), contains ferruginous concretions (Fig. 1e) and is neutral for the natural environment. Due to this fact, a hypothesis was assumed for the investigations that the opoka rock has very good adsorptive features what implies that bacteria taking part in aerobic purification of wastewater are well immobilized on the surface of its grains. The analysis of results of the investigations, presented in this paper, confirmed the assumed hypothesis because the nitrification process was very efficient in the tested soil bed what proves that nitirification bacteria well immobilize on the opoka layer.

2. EXPERIMENTAL

A measuring stand was built, having the form of a hermetic tank 1.20 m long, 0.20 m wide, and 1.70 m high (Fig. 2). The tank was made of plastic plates (9) mounted in metal frames (11). The wastewater from the tank (1) was transported with a pump (2) started by a controller (3), through a delivery pipe (4), to a drain line (5) of 100 mm in diameter, placed in a bed layer (6) made of stones with the diameter 20–40 mm. The dimensions of the drainage bed layer were: length 0.50 m, width 0.20 m, height 0.20 m. The wastewater flowed to the drainage bed layer through an outlet of 8 mm in diameter in the bottom of the drainage pipe. Then, after passing the drainage layer, the wastewater flowed through an assisting layer (7) into a soil bed (8). The ventilation of the drainage bed (6) took place through the drain line (5).

The measuring stand (Fig. 2) was built according to the Decree [21], with retain a 1.5-m layer between the pretreated wastewater infiltration level and the highest usable groundwater level of underground water (in the measuring stand, it is the off-take level of the pretreated wastewater).

The investigations were carried out with the use of the medium sand soil bed with the assisting natural opoka rock layer, having the thickness 0.10 or 0.20 m and granulation of 1–6 mm. The thickness of the sand soil bed was 1.40 and 1.30 m, respectively. Three openings (10) were made in the bottom of the measuring stand to enable outflow of the sewage drained through the assisting layer and soil bed to the collecting vessels (12). The soil was layered in the tank with the thickness 0.10 m each and then all layers were compacted.

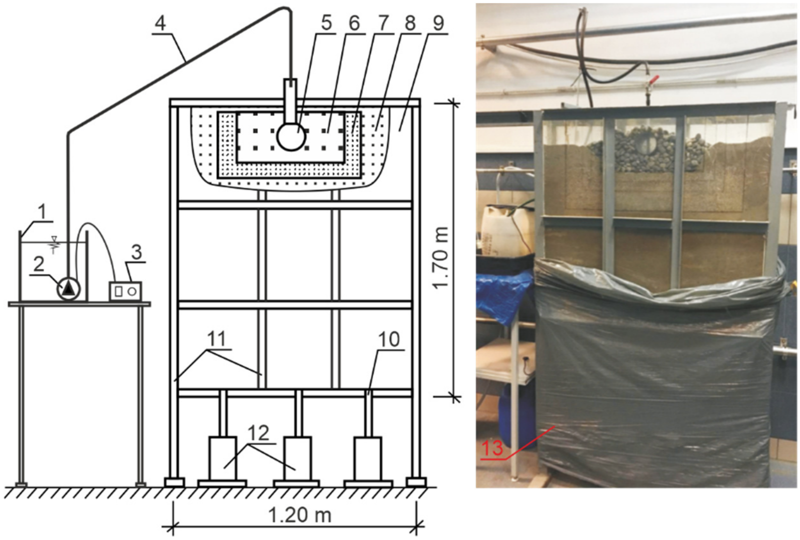

Fig. 2. Measuring stand: 1 – tank, 2 – pump, 3 – controller, 4 – delivery pipe, 5 – drain line, 6 – drainage bed, 7 – assisting layer (opoka rock), 8 – soil bed (medium sand), 9 – transparent plastic plate, 10 – wastewater outflow, 11 – metal frame, 12 – effluent collecting vessels, 13 – black foil covering the measuring stand during tests

The grain size distribution of the soil was determined with the sieve analysis. Three samples of the medium sand and opoka rock were subjected to the granulometric tests and the obtained results are presented in Fig. 3. Based on the tracer tests, it was determined the drainage time of the wastewater through the sand soil bed with assisting opoka rock layer, equal to 16 h.

The sand soil bed itself was not investigated in the experiment because it is known from the literature [7–9] that the removal efficiency of total nitrogen and total phosphorus for the sand soil bed is low.

According to the Polish recommendations [18], the infiltration drainage for sewage is designed considering the daily sewage dose for a given type of soil, the dose related to the drain line length, whereas according to the recommendations of CEN/TR 12566

-2:2005 [19] – to the sewage draining area. The Technical Report of CEN/TR 12566 -2:2005 concerns mainly rules of construction of the systems designed for draining sewage in the ground. Therefore, the daily sewage dose for the sand was referred to the drain line length (according to the Polish recommendations). The hydraulic load of the drainage line according to the recommendations is related to the 1 m long line and for the medium sand, it is equal to 15 $dm^3·m^{–1}·day^{–1}$ [18]. The drain line in the measuring stand was 0.20 m long. Thus, the daily wastewater dose was equal to 3 $dm^3·day^{–1}$. The wastewater was dosed into the drainage line in the measuring stand at 8 a.m., 4 p.m., and 12 p.m, each time in 1 dm^3 dose.

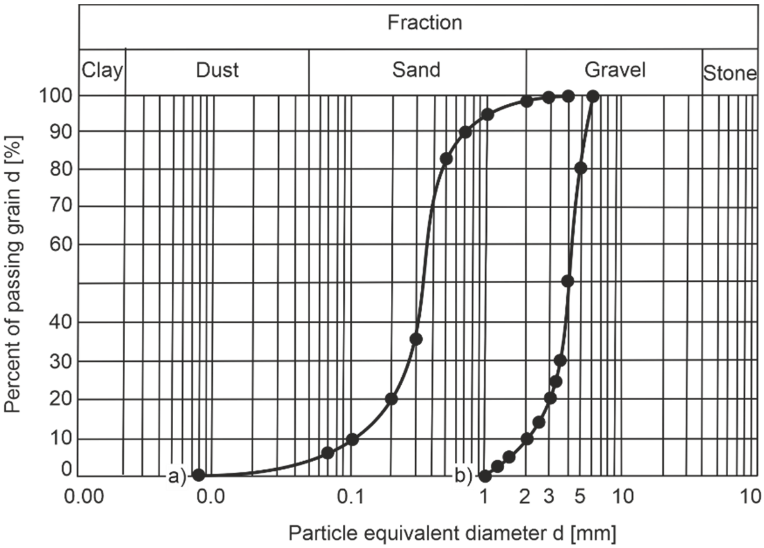

Fig. 3. Grain size distribution: a) medium sand, b) opoka rock

The model wastewater was used in the investigation, made according to the standard PN-C-04616/10 of distilled water and the following compounds: enriched dry broth – 150 $g·m^{–3}$, peptone – 50 $g·m^{–3}$, urea – 30 $g·m^{–3}$, anhydrous sodium acetate – 10 $g·m^{–3}$, soluble starch – 50 $g·m^{–3}$, grey soap – 50 $g·m^{–3}$, crystalline calcium chloride – 7 $g·m^{–3}$, magnesium sulfate – 50 $g·m^{–3}$, sodium chloride – 30 $g·m^{–3}$, potassium chloride – 7 $g·m^{–3}$ [20]. The wastewater, both before its introduction in the bed and after its drainage through the soil bed with the assisting layer, was physically and chemically analyzed to determine the following indicators: TSS, BOD_5, COD, total nitrogen, total phosphorus, ammonium nitrogen, nitrate nitrogen, nitrite nitrogen, pH value. The individual indicators were determined once a week with consideration of the wastewater filtration time of the soil bed with the 0.10 or 0.20 m thick assisting layer.

The model wastewater was prepared every six days and the wastewater quality indicators were determined always on the first, third, and sixth day of its dosing time. The temperature in the room was stable throughout the entire test period and equal to 14 °C. The TSS content was determined in weighing, with the use of filters with pores having a diameter of 0,7 μm, BOD_5 – by the electrochemical method, COD – by titration with potassium dichromate; total nitrogen, total phosphorus, ammonium nitrogen, nitrate nitrogen, nitrite nitrogen – by colorimetric methods, pH – by the electrometric method. During the tests, the measuring stand (Fig. 2) was covered with a black foil to prevent the white light from reaching the investigated soil beds.

Statistical analysis was also carried out to check whether the differences of average values in the results of removal of impurities from wastewater for 0.10 and 0.20 m thick opoka rock assisting layers were statistically significant. The normality of distribution was checked with the use of the Shapiro–Wilk test and then the homogeneity of variance with the use of the Levene test. Calculations of normality of distribution and homogeneity of variance were made with the use of the Statistica software.

3. RESULTS

Based on the results of control tests of the total nitrogen and total phosphorus, the biologically active layer in the medium sand soil bed with the natural opoka rock layer was formed for 10 weeks. During to last weeks, the control tests of the total nitrogen and phosphorus were made to check whether their concentrations stabilize. During the wastewater filtration through the soil bed under the drainage layer, the 3.0–3.5 cm thick soil changed its color from pale to dark what indicates that a biological film arose in the soil which was a bed for bacteria and other microorganisms [9, 22]. During the tests, the soil bed (medium sand) was saturated with the wastewater but the wastewater did not stagnate in the soil bed during the filtration.

Table 1 contains average values of the contamination indicators of raw wastewater and the wastewater purified on the medium sand soil bed in the dependence on the measuring stand operation time. Concentrations of the indicators for raw wastewater are related to the average capacity of the septic tank – 0.15 $m^3 \cdot d^{-1}$. After the drainage of the model wastewater through the experimental bed the following indicators decreased their values: BOD_5, COD, TSS, total nitrogen, ammonium nitrogen, and total phosphorus. The nitrite nitrogen occurred in the purified wastewater at a trace level, whereas nitrate content and pH increased.

The average TSS removal efficiencies for the soil bed with the 0.10 m and 0.2 m opoka rock layers amounted 69.7%, and 75.9%, respectively. High TSS retention efficiencies cause its fast clogging and formation of a clogging cake under the infiltration drainage [1]. In the investigations being presented, the wastewater did not stagnate in the infiltration drainage and the bed did not emit odors.

Table 1

Characteristics of wastewater quality before and after purification
in medium sand with assisting opoka rock layer (average values)

Indicator, unit	Raw wastewater				Purified wastewater				Limit value [21]
	Week								
	11	12	13	14	11	12	13	14	
Assisting opoka rock layer, thickness 0.10 m									
TSS, $g \cdot m^{-3}$	133.5	136.1	134.7	135.1	39.5	41.3	40.8	41.6	50
BOD_5, g $O_2 \cdot m^{-3}$	191.7	194.6	193.4	190.2	3.5	3.7	3.4	3.3	40
COD, g $O_2 \cdot m^{-3}$	301.9	302.6	305.6	304.6	19.4	19.1	17.4	18.6	150
Total nitrogen, g $N \cdot m^{-3}$	37.3	36.5	35.8	37.1	25.2	25.0	24.4	23.8	30
Ammonium nitrogen, g NH_4^+-$N \cdot m^{-3}$	0.85	0.89	0.82	0.79	0.10	0.12	0.12	0.11	–
Nitrate nitrogen, g NO_3^--$N \cdot m^{-3}$	0.76	0.79	0.79	0.72	2.78	2.74	2.78	2.72	–
Nitrite nitrogen, g NO_2^--$N \cdot m^{-3}$	0.022	0.025	0.024	0.026	0.006	0.009	0.006	0.008	–
Total phosphorus, g $P \cdot m^{-3}$	1.36	1.38	1.32	1.36	0.08	0.07	0.05	0.07	5
pH	7.26	7.29	7.25	7.23	7.39	7.42	7.41	7.40	–
Assisting opoka rock layer, thickness 0.20 m									
TSS, $g \cdot m^{-3}$	135.5	132.2	134.4	132.5	31.5	31.9	32.8	32.4	50
BOD_5, g $O_2 \cdot m^{-3}$	196.3	195.8	193.5	194.7	1.1	1.2	1.1	1.0	40
COD, g $O_2 \cdot m^{-3}$	298.4	304.1	306.5	299.8	12.5	12.4	13.1	12.8	150
Total nitrogen, g $N \cdot m^{-3}$	35.7	38.1	36.8	38.0	17.7	18.3	16.9	16.5	30
Ammonium nitrogen, g NH_4^+-$N \cdot m^{-3}$	0.81	0.87	0.85	0.83	0.04	0.06	0.03	0.04	–
Nitrate nitrogen, g NO_3^--$N \cdot m^{-3}$	0.86	0.87	0.81	0.84	2.48	2.41	2.35	2.32	–
Nitrite nitrogen, g NO_2^--$N \cdot m^{-3}$	0.030	0.031	0.026	0.028	0.004	0.005	0.004	0.003	–
Tolal phosphorus, g $P \cdot m^{-3}$	1.32	1.36	1.37	1.38	0.04	0.03	0.02	0.02	5
pH	6.93	6.92	6.91	6.95	7.23	7.21	7.24	7.21	–

The average efficiency of the BOD_5 and COD removal was high and in the soil bed with the 0.10 m thick opoka rock layer amounted 98.2% and 93.9% respectively, whereas in the soil bed with the 0.20 m thick layer – 99.4% and 95.8%. The high efficiency of the BOD_5 and COD removal in the wastewater purified in a well permeable soil was also confirmed in the laboratory tests performed by Chmielowski and Ślizowski [23] – the respective values amounted there 97.9% for BOD_5 and 85.2% for COD.

The average total nitrogen removal efficiency in the soil bed with the 0.10 m thick opoka rock layer amounted 32.9% and with the 0.20 m thick layer – 53.3%. The application of the opoka rock assisting layer significantly improved the average total nitrogen removal efficiency related to the bed consisting only of medium sand where the average total nitrogen removal efficiency amounted 22% [7].

The ammonium nitrogen removal efficiency in the soil bed with the 0.10 m thick opoka rock layer amounted 86.6% on average, wherein the nitrate nitrogen content in the purified wastewater increased 4 times on average. In the soil bed with the 0.20 m thick opoka rock layer, however, the ammonium nitrogen removal efficiency was even higher and equal to 94.9% on average, wherein the nitrate nitrogen content in the purified sewage increased 3 times on average. The high ammonium nitrogen removal efficiency in well permeable soil was also confirmed in the tests performed by Wąsik and Chmielowski [24] – it amounted 66.74%. Kalenik and Chalecki [15] also obtained high ammonium nitrogen removal efficiencies in well permeable soil beds with clinoptilolite assisting layer: 88.8% for a layer 0.10 m thick and 95.2% for that 0.25 m thick. The efficiencies of ammonium nitrogen removal in well permeable soil beds with clinoptilolite and opoka assisting layer are similar because both rocks contain a lot of calcium ions and have high specific surfaces resulting from a high percentage of pores.

High nitrate nitrogen content in the purified wastewater in the investigated soil bed proves very good conditions of the nitrification process. Nitrifying bacteria are well immobilized on the natural opoka rock. The nitrification process in a sand soil bed is very slow [8, 9] as it depends on pH, ventilation, and total nitrogen content in the ground. Sand is a loose mineral fraction consisting mainly of quartz grain. Microscopic observations prove that the quartz grain surface is not porous and is characterized by a high roundness level and smooth, slippery surface [25] what makes it very hard to settle for nitrification bacteria.

pH in the wastewater purified in the 0.10 m thick opoka rock layer increased by 2.0% on average, whereas in the 0.20 m thick opoka rock layer – by 4.1%.

Phosphorus is removed from the soil bed mainly in adsorption and precipitation processes as well as it is absorbed by plants. The efficiency of the adsorption and precipitation depends on pH, the redox potential, presence of ions of iron, aluminum, and calcium in the soil bed, the native phosphorus content in the bed as well as on its sorption capacity. In the soil beds having light acid or neutral reaction, the dominant role in the adsorption process is attributed to iron and aluminum compounds which adsorb phosphorus in form of insoluble complex compounds causing its long-lasting retention. In alkaline soil beds, however, the phosphorus adsorption processes occur thanks to the calcium compounds, with which the phosphorus creates permanent mineral compounds. Examinations showed that the average total phosphorus removal efficiency for the soil bed with the 0.10 m thick assisting opoka rock layer amounted 95.0% and for the soil bed with the 0.20 m thick layer – 97.9%. The application of the natural opoka rock assisting layer in the medium sand soil bed significantly improved the total phosphorus removal efficiency related to the bed consisting only of medium sand where the total phosphorus removal efficiency amounted 23% on average [7]. The opoka rock with granulation of 1–6 mm, characterized by high porosity, coarseness, and calcium content, is an efficient adsorbent of phosphorus compounds. The wastewater purification efficiency in the soil bed with the assisting opoka rock layer satisfies the Polish requirements concerning the introduction of wastewater into the ground and underground water [21] (Table 1).

Both in the Shapiro–Wilk and Levene tests for individual groups, the values of calculated probability p_{cal} are greater than the assumed significance level $\alpha = 0.05$, which means that the conditions of normal distribution and homogeneity of variance in the examined groups are satisfied (Table 2).

Table 2

Probability values (p_{cal}) obtained with the Shapiro–Wilk and Levene statistics. The differences of average values are significant with probability $p > 0.05$

Indicator	Thickness [m]	Shapiro–Wilk test	Levene test
TSS	0.10	0.44656	0.5242
	0.20	0.92091	
BOD_5	0.10	0.84997	0.2143
	0.20	0.68296	
COD	0.10	0.49814	0.2002
	0.20	0.65323	
Total nitrogen	0.10	0.65323	0.4727
	0.20	0.79599	
Ammonium nitrogen	0.10	0.27245	0.7796
	0.20	0.40639	
Nitrate nitrogen	0.10	0.22423	0.1112
	0.20	0.77312	
Nitrite nitrogen	0.10	0.22423	0.0781
	0.20	0.68296	
Total phosphorus	0.10	0.40639	0.7796
	0.20	0.27245	
Reaction	0.10	0.97188	0.5060
	0.20	0.22423	

Then the *t*-Student test was applied for two populations: according to the zero hypothesis (H_0: $n_1 = n_2$) the differences between the average values are statistically equal to each other and according to the alternative hypothesis (H_1: $n_1 \neq n_2$) these differences are statistically different. Calculations of the value of *t*-Student statistics $|t_{cal}|$ were performed with the use of the STATISTICA software and the obtained results are shown in Table 3.

For the alternative hypothesis, it was determined a critical region $|t_{cal}| \geq t_{\alpha=0.05}$ and, for $v = n_1 + n_2 - 2 = 6$ degrees of freedom and $\alpha = 0.05$, i.e., selected 5% risk of error (significance level), the critical value $t_{\alpha=0.05} = 2.447$ was read from the *t*-Student distribution tables. Analysis of Table 3 allows us to state that $|t_{cal}| \geq t_{\alpha=0.05}$, i.e., the zero hypothesis must be rejected, thus the differences between the mean values of the results of the removal of impurities from wastewater for 0.10 and 0.20 m thick opoka rock assisting layers are indeed statistically different. This is also confirmed by the calculated probability value $|p_{cal}| < 0.05$ (assumed significance level).

Table 3

Results of calculations of the *t*-Student statistics.
The differences of average values are significant with probability $p < 0.05$

Indicator	Thickness [m]	Average	Standard deviation	*t*-Student statistics $\|t_{cal}\|$	Probability p_{cal}	*t*-Student statistics $t_{\alpha = 0.05}$ [a]
TSS	0.10	40.800	0.927	22.914	0.000182	2.447
	0.20	32.150	0.569			
BOD_5	0.10	3.475	0.171	49.612	0.000018	
	0.20	1.100	0.082			
COD	0.10	18.625	0.881	10.006	0.002125	
	0.20	12.700	0.316			
Total nitrogen	0.10	24.600	0.632	38.300	0.000039	
	0.20	17.350	0.806			
Ammonium nitrogen	0.10	0.1125	0.0096	9.899	0.002192	
	0.20	0.0425	0.0126			
Nitrate nitrogen	0.10	2.755	0.030	12.111	0.001212	
	0.20	2.390	0.071			
Nitrite nitrogen	0.10	0.0073	0.0015	4.333	0.022669	
	0.20	0.0040	0.0008			
Total phosphorus	0.10	0.0675	0.0126	9.798	0.002260	
	0.20	0.0275	0.0096			
Reaction	0.10	7.405	0.013	16.461	0.000488	
	0.20	7.223	0.015			

[a]Value read from the *t*-distribution tables for $p = 0.05$ and $v = 6$.

4. CONCLUSIONS

The wastewater purified in the sand soil beds with the opoka rock with granulation of 1–6 mm fulfilled the Polish recommendations [21] on the rules of wastewater disposal into ground regarding basic quality indicators (TSS, BOD_5, COD). The test proved that the medium sand soil bed with the 0.20 m thick assisting opoka rock layer is characterized by higher effectiveness of wastewater purification than the 0.10 m thick bed. The application of the 0.20 m thick opoka rock assisting significantly improved the removal efficiency regarding TSS by 6.2%, total nitrogen by 20.4%, ammonia nitrogen by 8.3%, and total phosphorus by 2.9%, as well as removal efficiency regarding BOD_5 by 1.2% and COD by 1.9% concerning those for the 0.10 m thick assisting opoka rock layer.

The opoka rock with granulation of 1–6 mm can be used to assist in the removal of nitrogen and phosphorus compounds from domestic wastewater with the application of infiltration drainage. However, the very good TSS removal from the wastewater in the investigated soil beds can lead to their fast clogging under the infiltration drainage. Due to this fact, one has to design septic tanks in such a way that they can retain the largest possible amount of TSS – e.g., multi-chamber tanks instead of one-chamber ones or, behind the septic tank, apply prefabricated treatment units used for septic tank effluent.

REFERENCES

[1] SPYCHAŁA M., NIEĆ J., *Impact of septic tank sludge on filter permeability*, Environ. Prot. Eng., 2013, 39 (2), 77–89.

[2] SPYCHAŁA M., NIEĆ J., PAWLAK M., *Preliminary study on filamentous particle distribution in septic tank effluent and their impact on filter cake development*, Environ. Technol., 2013, 34 (20), 2825–2833.

[3] NEĆ J., SPYCHAŁA M., *Hydraulic conductivity estimation test impact on long-term acceptance rate and soil absorption system design*, Water, 2014, 6, 2808–2820.

[4] GAJEWSKA M., *Fluctuation of nitrogen fraction during wastewater treatment in a multistage treatment wetland*, Environ. Prot. Eng., 2011, 37 (3), 119–128.

[5] HAWKINS C.L., SHIPITALO M.J., MOYE RUTLEDGE E., SAVIN M.C., BRYE K.R., *Earthworm populations in septic system filter fields and potential effects on wastewater renovation*, Appl. Soil Ecol., 2008, 40 (1), 195–200.

[6] SPYCHAŁA M., PILC L., *Can Earthworms De-Clog Sand Filters?*, Polish J. Environ. Stud., 2011, 20 (4), 1037–1041.

[7] KALENIK M., WANCERZ M., *Research of sewage treatment in mean sand with assisting layer with chalcedonic – laboratory scale*, Infra. Eco. Rural Areas, 2013, 1 (3), 163–173 (in Polish).

[8] GILL L.W., O'LUANAIGH N., JOHNSTON P.M., MISSTEAR B.D.R., O'SUILLEABHAIN C., *Nutrient loading on subsoils from on-site wastewater effluent, comparing septic tank and secondary treatment systems*, Water Res., 2009, 43 (10), 2739–2749.

[9] VAN CUYK S., SIEGRIST R., LOGAN A., MASSON S., FISCHER E., FIGUEROA L., *Hydraulic and purification behaviors and their infiltrations during wastewater treatment in soil infiltration systems*, Water Res., 2001, 35 (4), 953–964.

[10] HEATWOLE K.K., MCCRAY J.E., *Modeling potential vadose – zone transport of nitrogen from onsite wastewater systems at the development scale*, J. Contam. Hydrol., 2007, 91 (1–2), 184–201.

[11] EVEBORN D., KONG D., GUSTAFSSON J.P., *Wastewater treatment by soil infiltration: Long-term phosphorus removal*, J. Contam. Hydrol., 2012, 140–141 (10), 24–33.

[12] KVARNSTRÖM M.E., MOREL C.A.L., KROGSTAD T., *Plant-availability of phosphorus in filter substrates derived from small-scale wastewater treatment systems*, Ecol. Eng., 2004, 22 (1), 1–15.

[13] THANH N.C., SIMAR R.E., *Biological treatment of domestic sewage by fungi*, Mycopath. Mycol. Appl., 1973, 51, 223–232.

[14] KALENIK M., CIEŚLUK M., *Sewage treatment in gravel with assisting dolomite layer*, [In:] W. Sądej (Ed.), *Sewages and waste materials in environment*, Warmia and Mazury Center of Agriculture Consulting Service in Olsztyn, Olsztyn 2009, 23–33.

[15] KALENIK M., CHALECKI M., *Investigations on the effectiveness of wastewater purification in medium sand with assisting clinoptilolite layer*, Environ. Prot. Eng., 2019, 45 (2), 117–126.

[16] BĄK B., SZELĄG A., *Opoka and gaize-forgotten rocks of Lublin region*, Open. Min., 2013, 54 (2), 107–116 (in Polish).

[17] TROCHONOWICZ M., *The efficacy analysis of the diaphragms made using the method of chemical injection in the walls of calcareous stones. Part I. The research of possibility of the diaphragm formation in the calcareous stone and mortar*, Const. Arch., 2012, 11, 99–112 (in Polish).

[18] TABERNACKI J., HEIDRICH Z., SIKORSKI M., KUCZEWSKI K., ŁOMOTOWSKI J., JASIŃSKI P., LIPOWSKI K., *Album of model solutions of disposal and neutralization of communal sewage from rural homesteads,* Publisher IMUZ, Falenty1990 (in Polish).

[19] CEN/TR 12566-2:2005, *Small wastewater treatment systems for up to 50 PT – Part 2: Soil infiltration system*, European Committee for Standardization, Brussels 2005.

[20] PN-C-04616/10, *Water and wastewater, Special test for sediments, The cultivation of standardized activated sludge in laboratory conditions*, Standardization publication, Warsaw 1987 (in Polish).

[21] *Decree of the Minister of Marine Economy and Inland Navigation of 12 July 2019 on substances that are particularly harmful to the aquatic environment and conditions to be fulfilled during wastewater introduction into water or ground as well as during rainwater and snowmelt discharge into water or water equipment*, Dz.U., 2019, 1311 (in Polish).

[22] BEAL C.D., GARDNER E.A., MENZIES N.W., *Process, performance, and pollution potential: A review of septic tank-soil absorption systems*, Aust. J. Soil Res., 2005, 43 (7), 781–802.

[23] CHMIELOWSKI K., ŚLIZOWSKI R., *Defining the optima range of a filter bed's d_{10} replacement diameter in vertical flow sand filters*, Environ. Prot. Eng., 2008, 34 (3), 35–42.

[24] WĄSIK E., CHMIELOWSKI K., *Ammonia and indicator bacteria removal from domestic sewage in a vertical flow filter filled with plastic material*, Ecol. Eng., 2017, 106, 378–384.

[25] MYCIELSKA-DOWGIAŁŁO E., WORONKO B., *Rounding and frosting analysis of quartz grains of sand fraction, and its interpretative value*, Geol. Rev., 1998, 46 (12), 1275–1281 (in Polish).