STUDY OF EFFECTIVENESS OF SEWAGE TREATMENT IN MEDIUM SAND WITH A SUPPORTIVE SMALL COAL LAYER

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ABSTRACT

Aim of the study

The aim of the study was to laboratory determine whether introducing a supportive small coal layer with a granulation of 0.02–5 mm will improve the effectiveness of removal of nitrogen and phosphorus compounds from domestic sewage. The study concerned a layer that improves effectiveness of domestic sewage treatment in a household sewage treatment plant under an infiltration drainage system.

Material and methods

Sewage treatment model study was conducted in a medium sand bed with a supportive small coal layer with a thickness of 0.10 and 0.2 m. Total suspended solids (TSS) were determined with a gravimetric method, BOD_5 with an electrochemical method, COD with a titration method with potassium dichromate, ammonium nitrogen, nitrite nitrogen, nitrate nitrogen, total nitrogen and total phosphorus were determined using colorimetric methods, and the reaction with an electrometric method.

Results and conclusions

It was observed that in terms of basic quality parameters (TSS, BOD_5, COD, total nitrogen, total phosphorus) the effectiveness of sewage treatment was compliant with Polish guidelines for sewage disposal into ground and groundwaters. It was determined that a soil bed consisting of medium sand with a supportive layer of small coal with a thickness of 0.20 m is more effective in sewage treatment in comparison to a supportive layer with a thickness of 0.10 m. Application of the supportive layer of small coal with a thickness of 0.2 m in the medium sand soil bed improved the removal effectiveness of TSS by an average 19.8%, of BOD_5 by 1.1%, of COD by 4.7%, of total nitrogen by 24.7%, of ammonium nitrogen by 7.1% and of total phosphorus by 30.6% in comparison to the supportive layer with a thickness of 0.10 m. The study confirmed that small coal with granulation of 0.02–5 mm can be used to support removal of nitrogen and phosphorus compounds from sewage with an infiltration drainage system.

Keywords: household sewage treatment plant, infiltration drainage, small coal

INTRODUCTION

Currently in Poland, rural communes are struggling with the problem of sewage management. Decades of neglect regarding sewage disposal and treatment have led to large disproportions between the water supply system and the construction of sewage systems. In towns with a high building density with developed infrastructure, domestic sewage is discharged into collective sewage systems. However, in towns with a dispersed building development, the most common method of domestic sewage disposal from residential

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and farm buildings is their collection in a drainless tank, with subsequent disposal by a gully emptier to a sewage treatment plant, sometimes to a field or a ditch. This type of sewage system is expensive in operation, and drainless tanks are often leaking and sometimes lack ventilation chimneys, that are necessary to remove gases formed during fermentation. Untreated sewage and sediments that enter the ground are a major sanitary threat due to the presence of pathogenic bacteria and parasite eggs.

Construction of systems for collection and treatment of domestic sewage in rural areas is in many cases impossible due to the dispersed building development, unfavourable topography of the area and high investment costs. Under these conditions, home sewage treatment plants with an infiltration drainage, in which a two-stage domestic sewage treatment sys-

tem is used, i.e. mechanical and biological treatment, may be an alternative. Mechanical treatment of domestic sewage is carried out in a septic tank (2, see: Fig. 1) where sedimentation, flotation and fermentation processes occur. During these processes, mineral and organic impurities with a density greater than the liquid density (sand, faeces, paper) and the ones with a density lesser than the liquid density (fats) are removed from sewage. On the other hand, biological treatment of domestic sewage is carried out in a soil bed under an infiltration drainage (5, see: Fig. 1) where the processes of nitrification (nitrogen removal), adsorption and precipitation (phosphorus removal) take place. Then the treated sewage is discharged into the ground and groundwater. If a soil bed is moderately permeable, no filtration or straining supportive layers are used (see: Fig. 1c), whereas when a soil bed is
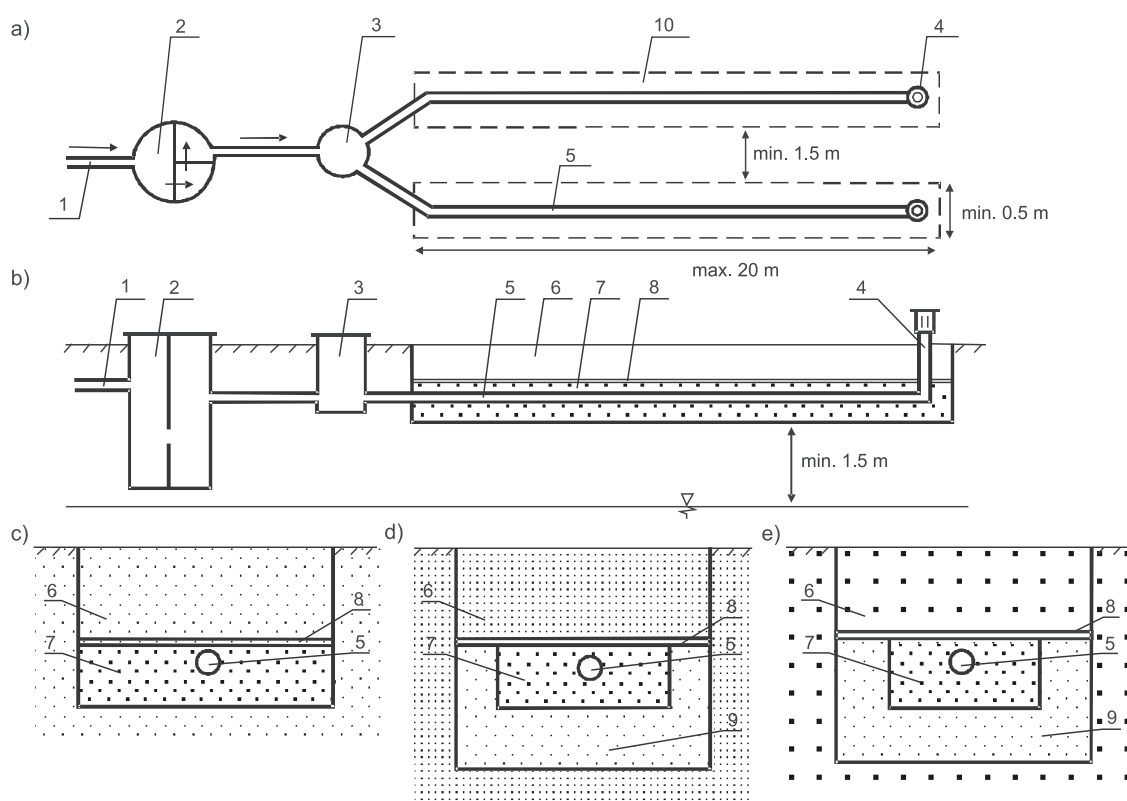

Fig. 1. Scheme of a sewage infiltration drainage: a) horizontal section, b) longitudinal section, c) cross-section of a drainage in moderately permeable ground, d) cross-section of a drainage in low-permeable soil, e) cross-section of a drainage in highly-permeable soil, 1 – sewage supply pipeline, 2 – septic tank, 3 – dispenser, 4 – ventilation pipes, 5 – sewage infiltrating pipeline, 6 – subsoil, 7 – sewage infiltration bed, 8 – geotextile, 9 – supportive layer, 10 – sewage infiltration layer

low-permeable, a filtration supportive layer (see: Fig. 1d) is used, and when a soil bed is highly-permeable, a straining supportive layer (see: Fig. 1e) is used. A layer that supports filtration or straining is usually made of medium sand with a thickness of 0.3 m (Małe oczyszczalnie ścieków, 1990).

A mound septic system is a specific solution for household sewage treatment plants with an infiltration drainage, and it is constructed in embankments (see: Fig. 2). This solution is used in permeable grounds with a high groundwater table. In a household sewage treatment plant with a mound septic system, sewage after a septic tank may be pumped into a dispenser with a standard pump (10, see: Fig. 2) or with an airlift pump (Kalenik, 2015; Kalenik, 2017; Kalenik and Chalecki, 2018; Kalenik and Malarski, 2018; Kujawiak et al., 2018). In this solution, the use of an airlift pump significantly improves the effectiveness of sewage treatment in the soil bed under the infiltration drainage as sewage is intensively oxygenated during its transport through the pressure pipeline (11, see: Fig. 2) to the dispenser (Kalenik, 2014b).

Household sewage treatment plants with an infiltration drainage to treat household sewage to be introduced into the ground after pre-treatment can be built outside an agglomeration within a land owned by the introducer, if the following conditions are met (Rozporządzenie Ministra Gospodarki Morskiej i Żeglugi Śródlądowej, 2019):

- the amount of sewage does not exceed 5 m³ per day,
- the BOD_5 of sewage inflowing into the infiltration drainage or mound septic system is reduced by 20% and the content TSS by 50%,

- the distance of underground waters from the level where sewage infiltration of pre-treated sewage occurs may not be lesser than 1.5 m from the highest useful groundwater aquifer.

Also, the plot area must be large enough to enable maintaining adequate distances from a septic tank to a house – 5 m, to a plot border – 2 m, to a well – 15 m and from a sewage infiltration drainage to a well – 30 m, to a tree – 3 m (Rozporządzenie Ministra Infrastruktury, 2002). According to The Construction Law (1994), construction of a household sewage treatment plant does not require a construction permit but only notifying the architectural and construction administration body.

In this type of household sewage treatment plants, overloading of the soil bed with suspensions and colloids leads to the formation of a so-called filter cake (Spychała and Nieć, 2013, Mazur et al., 2016) on the ground surface and in its pores, and a decrease in ground permeability (Nieć and Spychała, 2014). TSS content in raw sewage outflowing from a septic tank into the soil bed may vary from 20 g × m⁻³ to as much as 475 g × m⁻³ (Spychała and Nieć, 2013). Microscopic analyses have shown that the filter cake formed in the ground contains mainly threadlike toilet paper fibres that are washed out of the septic tank, and their biodegradation rate is much slower than their rate of accumulation in the ground (Spychała and Nieć, 2013).

The conducted studies (Hawkins et al., 2008) have shown that earthworms that aerate the soil (they create vertical and horizontal burrows) are eager to live in the bed ground located under the infiltration drainage, which improves the bed's permeability. Introducing earthworms into a clogged soil bed under an infiltra-
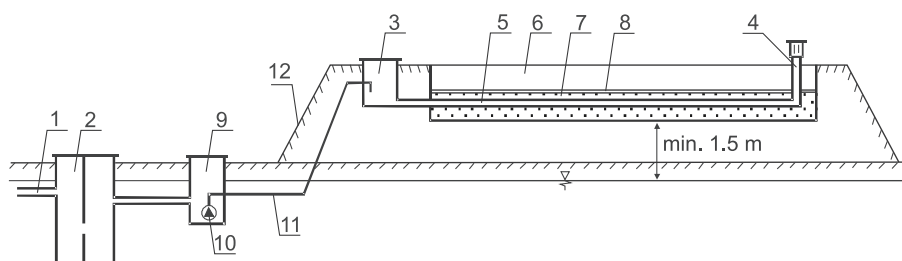

Fig. 2. Scheme of a mound septic system: 1 – sewage supply pipeline, 2 – septic tank, 3 – dispenser, 4 – ventilation pipes, 5 – sewage infiltration pipeline, 6 – subsoil, 7 – sewage infiltration bed, 8 – geotextile, 9 – sump , 10 – pump, 11 – pressure pipeline, 12 – ground embankment (mound)

tion drainage improves its permeability and reduces the content of organic substance in the bed in two weeks (Spychała and Pilc, 2011).

The research conducted on a bed ground consisting of medium sand shows that the average effectiveness of total nitrogen (22%) and total phosphorus (23%) removal was low (Kalenik and Wancerz, 2013). Other researchers confirmed in their studies (Gill et al., 2009; Sieczka and Koda, 2016a) that the effectiveness of nitrogen and phosphorus removal from sewage by highly-permeable ground is low. A large number of household sewage treatment plants with infiltration drainage in a given area may lead to contamination of groundwaters with nitrogen and phosphorus compounds (Heatwole and Mccray, 2007; Sieczka and Koda, 2016b; Radziemska et al., 2017; Koda et al., 2017; Eveborn et al., 2012). On the other hand, phosphorus compounds cumulated in ground bed under an infiltration drainage may be successfully used by plants (Kvarnström et al., 2004). The following fungi may be used to improve the effectiveness of nitrogen and phosphorus removal in bed grounds located under infiltration drainages: *Trichothecium roseum* for removing phosphates (effectiveness – 97.5%), and *Epicoccum nigrum*, *Geotrichum candidum* and *Trichoderma* for removing ammonium nitrogen (effectiveness – 84%), total nitrogen (effectiveness – 86.8%) and for eliminating faecal type coliform bacteria (effectiveness – 20 ÷ 38%) (Kołwzan et al., 2018). Fungal strains may be introduced into the sewage infiltration layer and the soil bed where they will develop and purify the sewage introduced into the ground.

In order to improve the effectiveness of sewage purification in a highly-permeable soil bed, a research was conducted on application of following supportive layers: dolomite (Kalenik and Cieśluk, 2009), chalcedonite (Kalenik and Wancerz, 2013), clinoptilolite (Kalenik, 2014a; Kalenik and Chalecki, 2019), kermesite and gaize (Dacewicz, 2018), hydro-anthracite (Kalenik, 2019). On the other hand, there is no research regarding the use of small coal for treating sewage in soil beds in scientific and technical literature. Relatedly, the aim of the study was to laboratory determine whether introducing a supportive small coal layer with a granulation of 0.02–5 mm will improve the effectiveness of removal of nitrogen and phosphorus compounds from sewage. For this purpose, model medium sand soil beds with small coal layers (see: Fig. 3) with thicknesses of 0.10 m and 0.20 m located under the sewage infiltration drainage were used.

Small coal was used for the research as it is characterised by very strong binding properties of adsorbed substances on its surface, it has a significant specific surface area resulting from the large proportion of very small pores, it is abrasion-resistant and neutral to the environment (see: Fig. 3). Relatedly, a hypothesis that small coal is highly-adsorbent and it will immobilise bacteria that will take part in the aerobic sewage treatment process on coals grains was taken.

Fig. 3. Image of the surface of small coal taken with the HIROX RH-2000 digital microscope – 15 times magnified

DESCRIPTION OF TEST STATION AND RESEARCH METHOD

A test station in the form of an airtight, 1.20 m long, 0.20 m wide and 1.70 m tall tank was constructed in order to test the sewage treatment effectiveness (see: Fig. 4). The tank was made of plastic boards (9) mounted in a metal frame (11). Sewage from the tank (1) was passed through a pipeline (4) by a pump (2), activated with a driver (3), into infiltration pipeline with a diameter of 100 mm (5) that was located in a bed layer (6) made of stones with a diameter of 20÷40 mm. Dimensions of the infiltration bed layer are: length 0.50 m, width 0.20 m, height 0.20 m. Sewage was flowing into the bed layer through an inlet with a diameter of 8 mm located on the bottom of the infiltration pipeline. After flowing through the infiltration layer, the sewage was flowing through the supportive layer (7) into the soil bed (8). Ventilation of the infiltration bed (6) occurred through the infiltration pipeline (5).
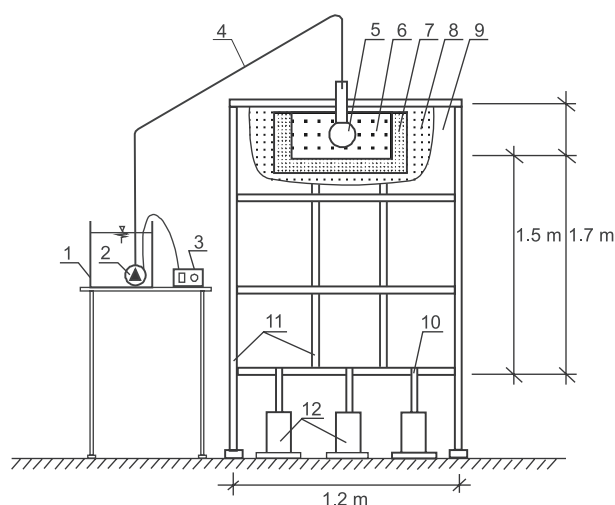
Fig. 4. Test station scheme: 1 – tank, 2 – pump, 3 – driver, 4 – pipeline, 5 – infiltration pipeline, 6 – infiltration bed, 7 – supportive layer (small coal), 8 – soil bed (medium sand), 9 – transparent plastic board, 10 – sewage outflow, 11 – metal frame, 12 – vessels collecting filtered sewage

The research was conducted with the use of a medium sand soil bed with a supportive layer consisting of small coal with a thickness of 0.10 m or 0.20 m and with a granulation of 0.02–5.0 mm. Thickness of the sand soil bed was 1.4 m and 1.3 m, respectively. Three outflow holes (10) were made in the bottom of the test station. They enabled the outflow of the sewage that flowed through the supportive layer and the soil bed into the vessels (12). The tank was filled with ground in the form of layers with a thickness of 0.10 m which were then thickened by compacting (ground density was not defined). The best effects of compacting sandy soils are obtained by compacting them in layers (Tymosiak and Sulewska, 2016).

Contents of specific soil granulation fractions were determined with the sieve analysis method. Granulometric tests of three samples of medium sand and small coal were conducted and their results are presented in Figures 5 and 6. With the carried out tracing tests, it was determined that the time of filtration of

sewage through the sand soil bed with the supportive layer of small coal was 17 hours.

Knowing the type of soil (medium sand), the daily dose of sewage was determined, referring it to the length of the infiltration pipeline (in accordance with Polish recommendations). Hydraulic load of an infiltration pipeline according to guidelines (Centralny Urząd Gospodarki Wodnej, 1971) refers to a 1 m long pipeline, and in the case of medium sand it is 15 $dm^3 \cdot m^{-1} \cdot d^{-1}$. Relatedly, the daily sewage dose is 3 $dm^3 \cdot d^{-1}$. In the test station (see: Fig. 4), sewage was introduced into the infiltration pipeline (5) at 8 am, 4 pm and 12 pm in the amount of 1 dm^3.

Model sewage was used for the research purposes, and it was prepared accordingly to the norm (PN-C-04616/10, 1987) on distilled water from the following components: dehydrated enriched broth – 150 $g \cdot m^{-3}$, peptone – 50 $g \cdot m^{-3}$, urea – 30 $g \cdot m^{-3}$, anhydrous sodium acetate –10 $g \cdot m^{-3}$, soluble starch – 50 $g \cdot m^{-3}$, grey soap – 50 $g \cdot m^{-3}$, crystalline calcium chloride – 7 $g \cdot m^{-3}$, magnesium sulphate – 50 $g \cdot m^{-3}$, sodium chloride – 30 $g \cdot m^{-3}$, potassium chloride – 7 $g \cdot m^{-3}$. The sewage was analysed physically and chemically before and after infiltration through the soil bed with the supportive layer in order to determine values of the following indicators: TSS, BOD_5, COD, total nitrogen, total phosphorus, ammonium nitrogen, nitrate nitrogen, nitrite nitrogen and reaction. Determination of specific values was performed weekly, taking into account the time of sewage filtration through the soil bed with the supportive layer with thickness of 0.10 m or 0.20 m.

Model sewage was prepared every six days, and sewage quality indicators were determined on the first, third and sixth day from its dosing. The temperature in the laboratory during the research was stable and it was 14°C. Total suspended solids (TSS) were determined with a gravimetric method, BOD_5 with an electrochemical method, COD with a titration method with potassium dichromate, ammonium nitrogen, nitrite nitrogen, nitrate nitrogen as well as total nitrogen and total phosphorus were determined using colorimetric methods and the reaction by a electrometric method.

DISCUSSION OF RESULTS

The test station (see: Fig. 4) was constructed in accordance with the Regulation (Rozporządzenie..., 2019) and a 1.5 m deep layer was preserved between the sewage infiltration level and the highest useful groundwater aquifer (in the test station it is the purified sewage retrieval level) In the analysed experiment, the effectiveness of the total nitrogen and total phosphorus removal in the soil bed made of sand was not studied, as it is known to be poor from literature (Van Cuyk et al., 2001; Gill et al., 2009; Kalenik and Wancerz, 2013). However, this type of study was performed in 2013 for medium sand alone (see: Fig. 5), and its results (see: Table 1) were published in the work by Kalenik and Wancerz (2013).

It took seven weeks for the medium sand soil bed with the small coal layer to achieve readiness. The time was defined based on control determination tests for total nitrogen and total phosphorus only. In the sixth and seventh week, control determination tests for total nitrogen and total phosphorus were performed in order to check whether nitrogen and phosphorus compounds were already being removed, and whether their values were comparable (stable). During the filtration of sewage through the tested soil beds located under the sewage infiltration layer, soil with a depth of 2.0 ÷ 2.5 cm changed its colour from light to dark, what indicates the formation of a biological membrane that was the growth medium for bacteria and other microorganisms. The process is known and described in literature (Laak, 1986; Canter and Knox, 1991; Van Cuyk et al., 2001; Beal et al., 2005). During the research, the soil bed (medium sand) was saturated with sewage (it was wet) but sewage did not stagnate in the soil bed during the filtration.

Table 2 summarises the average values of indicators for the pollution of untreated and treated sewage on medium sand soil beds with a supportive layer of small coal of two thicknesses – 0.10 m and 0.20 m, depending on the working time of the test station. Analysing the test results, it can be concluded that after the infiltration of model sewage through the sandy soil bed with the small coal supportive layer, the content of TSS decreased, and so did the values of BOD_5, COD, total nitrogen, ammonium nitrogen and total phosphorus. Nitrite nitrogen occurred in trace amounts but on the other hand the content of nitrates and the pH value increased.

In the soil bed with a small coal layer with a thickness of 0.10 m, the effectiveness of TSS removal was 51.3%, and in the bed with the 0.20 m thick layer – 71.1%. In the bed with the medium sand layer alone the effectiveness of TSS removal was also high and amounted for 80.2% (Kalenik and Wancerz, 2013). What attracts attention is the fact that the studied soil bed is highly effective in terms of TSS retention. Large

Table 1. Results of the studies of raw and purified sewage for medium sand (average values) (Kalenik and Wancerz, 2013)

Indicator, unit	Raw sewage	Purified sewage			Regulation, 2019
		13 week	14 week	15 week	
TSS, $g \cdot m^{-3}$	64	16	10	12	50
BOD_5, $gO_2 \cdot m^{-3}$	153	2.2	5	3	40
COD, $gO_2 \cdot m^{-3}$	209.39	23.13	28.13	25.92	150
Total nitrogen, $gN \cdot m^{-3}$	16.33	15	14	9	30
Ammonium nitrogen, $gN–NH_4 \cdot m^{-3}$	6.4	0.03	0.035	0.03	–
Nitrate nitrogen, $gN-NO_3 \cdot m^{-3}$	0.62	94.15	92.12	89.67	–
Nitrite nitrogen, $gN-NO_2 \cdot m^{-3}$	0.014	0.007	0.004	0.006	–
Total phosphorus, $gP \cdot m^{-3}$	2.95	2.58	2.17	2.07	5
Reaction, pH	6.6	7.25	7.2	7.17	–

number of TSS introduced into the soil bed causes its quick colmatation which leads to the formation of a filter cake under the infiltration drainage (Spychała and Nieć, 2013; Mazur et al., 2016) which reduces the soil bed permeability and thus reduces the life–span of a sewage treatment plant with an infiltration drainage.

A characteristic symptom of soil bed colmatation is the leakage of odours through ventilation chimneys of drains. It proves that the bed permeability decreased drastically, and sewage stagnates in the infiltration bed and oxygen does not reach its interior. Therefore, the conditions in the infiltration bed become anaerobic,
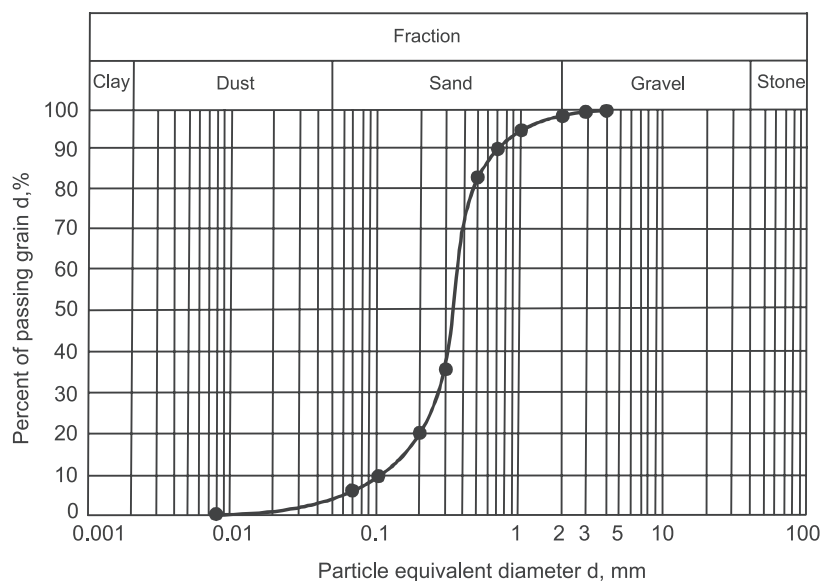

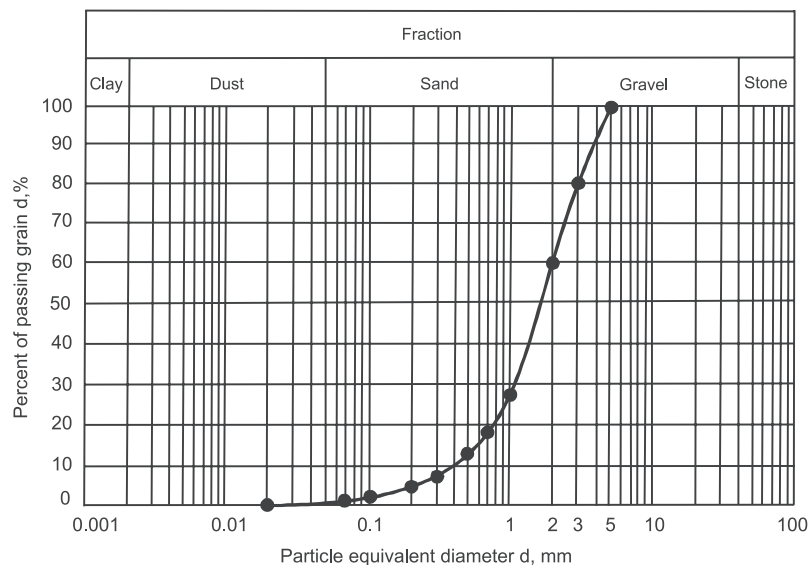**Fig. 5.** Soil granulation curve – medium sand

Fig. 6. Small coal granulation curve – coarse

and the rotting sewage emits odour. In this study, sewage did not stagnate in the infiltration bed and there was no odour coming from the infiltration bed.

Also in highly-permeable soil beds with a supportive layer made of dolomite (Kalenik and Cieśluk, 2009), chalcedonite (Kalenik and Wancerz, 2013), clinoptilolite (Kalenik, 2014a; Kalenik and Chalecki, 2019), and hydro-anthracite (Kalenik, 2019) the effectiveness of TSS retention was high and equalled 98.2% and 99.1% for dolomite, 94% for chalcedonite, 81.9% and 85.4% (2014a) and 72.5% and 75.8% (2019) for clinoptilolite, 77.1% and 80.2% for hydro-anthracite.

Average effectiveness of BOD_5 and COD value reduction in sewage was high and it equalled 98.7% and 90.4%, respectively, in the soil bed with the small

coal layer with a thickness of 0.10 m, and in the bed with the 0.2 m thick layer – 99.8% and 95, respectively. In the bed with the medium sand layer alone, the effectiveness of BOD_5 and COD value reduction was also high and equalled 97.8% and 87.7% (Kalenik and Wancerz, 2013), respectively. Laboratory research by Chmielowski and Ślizowski (2008) also confirmed the effectiveness of BOD_5 and COD value reduction in sewage treated by highly-permeable soil, and it equalled 97.9% for BOD_5, and 85.2% for COD.

On average, the effectiveness of total nitrogen removal in soil bed with the small coal layer with a thickness of 0.10 m equalled 31.9%, and 56.6% for the 0.20 m thick layer. In the bed with the medium sand layer alone the effectiveness of total nitro-

Table 2. Characteristic of the sewage quality before and after the treatment in medium sand with the small coal supportive layer (average values)

Indicator, unit	Raw sewage				Purified sewage				Regulation, 2019
	8 week	9 week	10 week	11 week	8 week	9 week	10 week	11 week	
Supportive layer consisting of small coal; thickness of 0.10 m									
TSS, g · m⁻³	77.9	77.6	78.1	77.4	38.1	37.8	37.6	38.0	50
BOD_5, gO_2 · m⁻³	291.3	295.5	299.1	298.2	3.8	3.9	3.6	3.7	40
COD, gO_2 · m⁻³	386.6	393.1	382.9	395.0	37.7	38.1	36.9	37.4	150
Total nitrogen, gN · m⁻³	34.4	34.8	34.6	34.7	23.6	23.4	23.8	23.5	30
Ammonium nitrogen, $gN\text{-}NH_4$ · m⁻³	1.87	1.89	1.90	1.92	0.23	0.22	0.24	0.22	–
Nitrate nitrogen, $gN\text{-}NO_3$ · m⁻³	1.75	1.73	1.69	1.73	16.95	17.02	16.85	16.93	–
Nitrite nitrogen, $gN\text{-}NO_2$ · m⁻³	0.045	0.047	0.048	0.044	0.008	0.006	0.007	0.006	–
Total phosphorus, gP · m⁻³	5.06	4.96	5.07	5.04	2.61	2.58	2.64	2.54	5
Reaction, pH	7.44	7.45	7.49	7.43	7.71	7.63	7.70	7.67	–
Supportive layer consisting of small coal; thickness of 0.20 m									
TSS, g · m⁻³	77.6	78.2	77.5	77.8	17.5	18.1	17.7	17.9	50
BOD_5, gO_2 · m⁻³	294.6	297.2	298.4	290.1	1.3	1.2	1.1	1.3	40
COD, gO_2 · m⁻³	392.1	389.7	385.9	390.3	17.3	16.9	17.5	16.8	150
Total nitrogen, gN · m⁻³	34.7	34.5	34.7	34.5	15.3	14.8	15.1	14.9	30
Ammonium nitrogen, $gN\text{-}NH_4$ · m⁻³	1.93	1.87	1.91	1.88	0.09	0.11	0.10	0.09	–
Nitrate nitrogen, $gN\text{-}NO_3$ · m⁻³	1.68	1.70	1.71	1.72	12.03	11.89	11.87	11.94	–
Nitrite nitrogen, $gN\text{-}NO_2$ · m⁻³	0.047	0.043	0.047	0.049	0.003	0.004	0.002	0.003	–
Total phosphorus, gP · m⁻³	4.99	5.02	5.01	5.04	1.03	1.04	1.08	1.05	5
Reaction, pH	7.94	7.93	7.90	8.02	8.21	8.14	8.19	8.23	–

gen removal was low and equalled for 22% (Kalenik and Wancerz, 2013) on average. Thus, the use of the supportive small coal layer significantly increased the total nitrogen removal effectiveness from sewage. Also in highly-permeable soil beds with a supportive layer made of dolomite (Kalenik and Cieśluk, 2009), chalcedonite (Kalenik and Wancerz, 2013), clinoptilolite (Kalenik, 2014a; Kalenik and Chalecki, 2019), hydro-anthracite (Kalenik, 2019) the effectiveness of total nitrogen removal from sewage increased significantly and equalled 35% and 44% for dolomite, 66.8% for chalcedonite, 29.5% and 37.3% (2014a) and 26% and 55.3% (2019) for clinoptilolite, 28.4% and 57.8% for hydro–anthracite.

The effectiveness of ammonium nitrogen removal in the bed with the small coal layer with a thickness of 0.10 m equalled 87.8%, and the nitrate nitrogen content in treated sewage increased 10-fold on average. In the bed with the layer with a thickness of 0.20 m the effectiveness of ammonium nitrogen removal was even higher and equalled 94.9%, and the nitrate nitrogen content in treated sewage increased only 7-fold on average. In the bed with the medium sand layer alone the effectiveness of ammonium nitrogen removal was also high and equalled for 99% (Kalenik and Wancerz, 2013) on average. Also in highly-permeable soil beds with a supportive layer made of dolomite (Kalenik and Cieśluk, 2009), chalcedonite (Kalenik and Wancerz, 2013), clinoptilolite (Kalenik, 2014a; Kalenik and Chalecki, 2019) and hydro-anthracite (Kalenik, 2019) the effectiveness of ammonium nitrogen removal was high and equalled 98.2% and 99.1% for dolomite, 94% for chalcedonite, 81.9% and 85.4% (2014a) and 72.5% and 75.8% (2019) for clinoptilolite, 77.1% and 80.2% for hydro-anthracite. Also, Wąsik and Chmielowski's (2017) research confirm high effectiveness of ammonium nitrogen removal in highly-permeable beds, and it equalled 66.74%.

High content of nitrate nitrogen in treated sewage in the tested soil beds proves that there are very good nitrification conditions indicating that nitrifying bacteria immobilise well on small coal. On the other hand, according to Van Cuyk et al. (2001) and Gill et al. (2009), nitrification occurs very poorly on sand-only beds. Sand grains are made of quartz. Microscopic studies show that the surface of sand grains is not porous and is highly-polished. Also in the treated sewage

(for both tested soil beds) the pH value increased by ca. 3.0% on average.

Phosphorus in a soil bed is removed mainly in adsorption and precipitation processes, and it is also retrieved by plants. The effectiveness of adsorption and precipitation processes depends both on the potential and the value of the redox reaction as well as the presence of iron, aluminium and calcium ions in the soil bed, as well as on the content of native phosphorus in the bed and its sorption capacity. In soil beds, the reaction of which is slightly acidic or neutral, the dominant role in adsorption processes is attributed to iron and aluminium compounds, which adsorb phosphorus in the form of insoluble complex compounds, causing its long-term retention. In soil beds which are alkaline, phosphorus adsorption processes occur due to calcium compounds, as they form permanent mineral connections with them. Studies show that in the soil bed with a small coal layer with a thickness of 0.10 m the effectiveness of total phosphorus removal was 48.5%, and 79.1% in the bed with the 0.20 m thick layer. On the other hand, in the bed with the medium sand layer alone the effectiveness of total phosphorus removal was low and equalled for 23% (Kalenik and Wancerz, 2013) on average. Thus, the use of the supportive small coal layer significantly increased the total phosphorus removal effectiveness from sewage. Also in highly-permeable soil beds with a supportive layer made of dolomite (Kalenik and Cieśluk, 2009), chalcedonite (Kalenik and Wancerz, 2013), clinoptilolite (Kalenik, 2014a; Kalenik and Chalecki, 2019), hydro-anthracite (Kalenik, 2019), the effectiveness of total phosphorus removal from sewage increased significantly and equalled 37% and 63% for dolomite, 43% for chalcedonite, 53.1% and 89.2% (2014a) and 56.5% and 82.4% (2019) for clinoptilolite, 52.3% and 75.3% for hydro-anthracite.

Table 3 compares the effectiveness of pollution removal in a bed with sand only and in sand beds with a supportive small coal layer with a thickness of 0.1 m and of 0.2 m.

The performed tests (see: Table 2) show that the effectiveness of sewage treatment in a soil bed with a supportive layer of small coal meets Polish requirements for the introduction of wastewater into soil and groundwater (Rozporządzenie..., 2019). The results of studying the effectiveness of sewage purification in a soil bed

with a supportive small coal layer are comparable with earlier tests with following supportive layers: dolomite (Kalenik and Cieśluk, 2009), chalcedonite (Kalenik and Wancerz, 2013), clinoptilolite (Kalenik, 2014a; Kalenik and Chalecki, 2019), kermesite and gaize (Dacewicz, 2018), hydro-anthracite (Kalenik, 2019).

Also, a statistical analysis was performed in order to check whether average values concerning the effectiveness of sewage pollution removal for supportive small coal layers with a thickness of 0.10 m and 0.2 m (Table 2) are statistically significant. First, the normality of distribution was checked with the Shapiro-Wilk test, and then the homogeneity of variance with the Levene test. Calculations of normality of distributions and homogeneity of variances were made with the Statistica computer programme, and the obtained results are summarised in Table 4. In both tests (see: Table 4) the value of calculated probability for specific

Table 3. Comparison of effectiveness of sewage treatment in medium sand with a supportive small coal layer

Indicator, unit	Medium sand (Kalenik and Wancerz, 2013)	Supportive layer consisting of small coal; thickness of 0.10 m	Supportive layer consisting of small coal; thickness of 0.20 m
TSS, %	80.2	51.3	71.1
BOD_5, %	97.8	98.7	99.8
COD, %	87.7	90.4	95.1
Total nitrogen, %	22	31.9	56.6
Ammonium nitrogen, %	99	87.8	94.9
Total phosphorus, %	23	48.5	79.1

Table 4. Results of statistic calculation from Shapiro-Wilk and Leven tests. The differences in the mean values are significant with a probability of $p > 0.05$

Parameter	Thickness [m]	Probability value calculated with Shapiro-Wilk test $p_{obl.}$	Probability value calculated with Levene test $p_{obl.}$
Total suspended solids	0.10	0.79823	0.7457
Total suspended solids	0.20	0.97188	
BOD_5	0.10	0.97188	0.5060
BOD_5	0.20	0.27245	
COD	0.10	0.98859	0.4973
COD	0.20	0.51304	
Total nitrogen	0.10	0.84997	0.4680
Total nitrogen	0.20	0.79823	
Ammonium nitrogen	0.10	0.27245	1.00
Ammonium nitrogen	0.20	0.27245	
Nitrate nitrogen	0.10	0.92452	0.8675
Nitrate nitrogen	0.20	0.51406	
Nitrite nitrogen	0.10	0.27245	0.1682
Nitrite nitrogen	0.20	0.68296	
Total phosphorus	0.10	0.97007	0.1975
Total phosphorus	0.20	0.57735	
Reaction	0.10	0.71428	1.00
Reaction	0.20	0.71428	

groups was calculated $p_{obl.} > 0.05$ from the adopted significance level $\alpha = 0.05$, which means that the normal distributions and homogeneity of variance in the examined groups were met. Then the Student's t-test for two populations was used, assuming the null hypothesis (H_0: $n_1 = n_2$) that the differences in mean values are statistically equal, and an alternative one (H_1: $n_1 \div n_2$) that the differences in mean values are statistically different. Calculation of the $t_{obl.}$ statistic value (t-Student), was also made using the computer programme Statistica, and the results obtained are summarised in Table 5.

For the alternative hypothesis a critical area $t_{obl.} \geq t_{\alpha = 0.05}$ was determined and from the tables of the t-Stu-

dent's distribution for $v = n_1 + n_2 - 2 = 6$ degrees of freedom and $\alpha = 0.05$, i.e. the chosen 5% error risk (significance level), the critical value $t_{\alpha = 0.05} = 2.447$ was read. In table 5 we can see that $|t_{obl.}| \div t_{\alpha = 0.05}$ so the null hypothesis can be rejected and it can be concluded that differences between mean values in the results of the effectiveness of sewage pollution removal for supportive small coal layers with a thickness of 0.10 m and 0.2 m are indeed different statistically. This is confirmed also by the counted probability value, and namely $p_{obl.}$ is lower than $p < 0.05$ (of the adopted significance level).

Table 5. Results of statistic calculation from the Student's t-test. The differences in the mean values are significant with a probability of $p < 0.05$

Parameter	Thickness [m]	Average	Standard deviation	Calculated value of the Student's t-test $|t_{obl.}|$	Calculated probability value $p_{obl.}$	Read value of the Student's t-test from tables $p = 0.05$ and $v = 6$ $t_{a = 0.05}$
Total suspended solids	0.10	37.875	0.222	103.956	0.00000196	
Total suspended solids	0.20	17.800	0.258			
BOD$_5$	0.10	3.750	0.129	40.133	0.0000340	
BOD$_5$	0.20	1.225	0.096			
COD	0.10	37.525	0.506	54.521	0.0000136	
COD	0.20	17.125	0.330			
Total nitrogen	0.10	23.575	0.171	98.727	0.00000229	
Total nitrogen	0.20	15.025	0.222			
Ammonium nitrogen	0.10	0.228	0.0096	18.385	0.000351	2.447
Ammonium nitrogen	0.20	0.098	0.0096			
Nitrate nitrogen	0.10	16.938	0.070	112.621	0.00000154	
Nitrate nitrogen	0.20	11.933	0.071			
Nitrite nitrogen	0.10	0.0068	0.00096	6.928	0.00617	
Nitrite nitrogen	0.20	0.0028	0.00050			
Total phosphorus	0.10	2.593	0.043	79.877	0.00000432	
Total phosphorus	0.20	1.050	0.022			
Reaction	0.10	7.673	0.033	–21.229	0.000229	
Reaction	0.20	8.192	0.039			

SUMMARY

Sewage treated in sandy soil beds with a supportive small coal layer with a granulation of 0.02÷5 mm met the Polish requirements concerning the rules of household sewage introduction into ground and groundwaters (Rozporządzenie…, 2019) in terms of basic quality indicators (TSS, BOD5, COD, total nitrogen and total phosphorus). It was determined that a soil bed consisting of medium sand with a supportive layer of small coal with a thickness of 0.20 m is more effective in sewage treatment in comparison to a supportive layer with a thickness of 0.10 m. Application of the supportive layer of small coal with a thickness of 0.2 m in the medium sand soil bed improved the removal effectiveness of TSS by an average 19.8%, BOD_5 by 1.1%, COD by 4.7%, total nitrogen by 24.7%, ammonium nitrogen by 7.1% and total phosphorus by 30.6% in comparison to a supportive layer with a thickness of 0.10 m.

Small coal with a granulation of 0.02÷5 mm can be used to remove nitrogen and phosphorus compounds from sewage in household sewage treatment plants with the infiltration drainage. Very high effectiveness of TSS removal from sewage in the tested model soil beds may lead to a quick bed colmatation under a sewage infiltration drainage. Consequently, septic tanks should be designed so that they can block as much total suspended solids as possible, e.g. multi-chamber tanks instead single-chamber ones.

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Rozporządzenie Ministra Infrastruktury z dnia 12 kwietnia 2002 roku w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie. (Dz. U. Nr 75, poz. 690).

Rozporządzenie Ministra Gospodarki Morskiej i Żeglugi Śródlądowej z dnia 12 lipca 2019 roku w sprawie substancji szczególnie szkodliwych dla środowiska wodnego oraz warunków, jakie należy spełnić przy wprowadzaniu do wód lub do ziemi ścieków, a także przy odprowadzaniu wód opadowych lub roztopowych do wód lub do urządzeń wodnych (Dz. U. 2019, poz. 1311).

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BADANIA SKUTECZNOŚCI OCZYSZCZANIA ŚCIEKÓW W PIASKU ŚREDNIM Z WARSTWĄ WSPOMAGAJĄCĄ Z MIAŁU WĘGLOWEGO

ABSTRAKT

Cel pracy

Celem badań było sprawdzenie w warunkach laboratoryjnych, czy wprowadzenie do gruntu warstwy wspomagającej z miału węglowego o granulacji 0,02÷5 mm poprawi skuteczność usuwania związków azotu i fosforu ze ścieków bytowych. Przeprowadzone badania dotyczyły warstwy wspomagającej skuteczność oczyszczania ścieków bytowych w przydomowej oczyszczalni pod drenażem rozsączającym.

Materiał i metody

Badania modelowe oczyszczania ścieków przeprowadzono w złożu z piasku średniego z warstwą wspomagającą z miału węglowego o miąższości 0,10 i 0,20 m. Zawiesiny ogólne oznaczano metodą wagową, BZT_5 metodą elektrochemiczną, ChZT metodą miareczkową z dwuchromianem potasu, azot amonowy, azot azotynowy, azot azotanowy oraz azot ogólny i fosfor ogólny oznaczano z zastosowaniem metod kolorymetrycznych, a odczyn metodą elektrometryczną.

Wyniki i wnioski

Zaobserwowano, że w odniesieniu do podstawowych parametrów jakościowych (zawiesin ogólnych, BZT_5, ChZT, azotu ogólnego, fosforu ogólnego), skuteczność oczyszczania ścieków była zgodna z polskimi wytycznymi odprowadzania ścieków do gruntu i wód podziemnych. Stwierdzono, że złoże gruntowe z piasku średniego z warstwą wspomagającą z miału węglowego o miąższości 0,20 m wykazuje większą skuteczność oczyszczania ścieków w porównaniu do warstwy wspomagającej o miąższości 0,10 m. Zastosowanie w złożu gruntowym z piasku średniego warstwy wspomagającej z miału węglowego o miąższości 0,20 m zwiększyło skuteczność usuwania zawiesiny ogólnej średnio o 19,8%, BZT_5 średnio o 1,1%, ChZT średnio o 4,7%, azotu ogólnego o 24,7%, azotu amonowego średnio o 7,1% i fosforu ogólnego o 30,6% w porównaniu do warstwy wspomagającej o miąższości 0,10 m. Badania potwierdziły, że miał węglowy o granulacji 0,02÷5 mm może być stosowany do wspomagania usuwania związków azotu i fosforu ze ścieków z zastosowaniem drenaży rozsączających.

Słowa kluczowe: przydomowa oczyszczalnia ścieków, drenaż rozsączający, miał węglowy