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Biofiltration – an ecological method of removing odors generated during drying sewage sludge-case study

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ABSTRACT

The emission of odor compounds is a serious problem for the environment. The complaints from the residents of nearby houses about discomfort indicate that this is not a sufficiently resolved problem and involves the need to take appropriate action. The article discusses the ecological method of using a biofilter, which is an installation for removing the odors generated in the process of solar drying of sewage sludge in a municipal wastewater treatment plant (WWTP). This technology is used in many Polish dryers, it involves sludge drying in the summer. Direct air outlet from the solar dryer causes the emission of these compounds, which can be a serious problem, especially in high-capacity WWTPs. One of the most ecological methods, which consists of directing the exhaust air through water scrubbers to the biofilter, was used in the described object. The analyses were carried out on a real object, examining the ratio of biofilter filling under various atmospheric conditions to the reduction of odor compounds formed. This solution, according to research, is an effective solution, but in such a system (solar dryer – biofilter), it is still not very popular.

Keywords: Odors; Biofiltration; Sewage sludge dryer; Gas ammonia

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1. Introduction

Sewage sludge (SS) is formed at wastewater treatment plant (WWTP) as a result of processes occurring in the biologically active wastewater treatment process. Sewage sludge usually constitutes 1%–2% of treated sewage [1–3]. Depending on the applied wastewater treatment methods, excess sludge contains about 97% of the water and from 30% to 50% mineral substances (obtained during the removal process) [4,5]. Sewage sludge contains substances such as heavy metals (Cd, Cu, Ni, Pb, Zn, Hg, Cr, Se, As, and Ag) [6,7], nutrients, such as phosphorus and nitrogen [8,9], organic pollutants (polycyclic aromatic hydrocarbons, adsorbed organic halides, polychlorinated biphenyls, dioxins, pharmaceuticals, and nanoparticles) [7,10].

As a result of physical, physicochemical, and biological processes, SS is generated as a product that should be managed or neutralized at a later stage. The quantities of sewage sludge generated in Poland are steadily increasing. It is estimated that 1 person can produce 10–15 kg of SS dry matter (d.m.) per year [3]. Directive 99/31/EC on the landfill of waste has been prohibited from depositing them on landfills since January 2013. Many WWTPs are faced with the problem of changing the existing methods of their development [11]. In most Polish WWTPs, the basic series of sludge treatment involves concentration, stabilization, drainage, and sanitation [1]. The priority way of dealing with sewage sludge is to use them in a way that does not cause a negative impact on the environment. The sewage sludge management is focused on increasing the degree of their processing with the thermal transformation methods [12–14].

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Sewage sludge processing depends on many factors, such as the physical, chemical, and sanitary properties [15]. Purified sewage sludge can be used for energy (biomass) to manufacture agricultural fertilizer and for the production of biofuels. In addition, sewage sludge can be dried before using it in various processes [16]. The high water content with metal ions and volatile and non-volatile organic matters in sewage sludge makes it a complex matter for its disposal [17].

Drying is a process that transforms waste into a product with the parameters that facilitate its transport, storage, and management. Sludge drying allows the largest reduction in weight and volume of sludge [18–20]. Equally important are the economic considerations, above all the accepted level of conversion costs and legal considerations. Currently, both thermal drying and solar sludge drying techniques are widely used [21]. Compared to solar drying, thermal drying consumes a lot of electricity or fossil fuels. It is also associated with higher greenhouse gas emissions [17,22].

Solar sludge dryers, arriving in Poland, are emitters of large amounts of sludge and odor. This is mainly due to the sludge drying technology itself and a much higher temperature than ambient. Solar dryers, due to their effectiveness, are becoming quite a popular method, but the odoriness of objects is treated quite marginally [23]. The odor that builds up during the drying of the sludge is associated with such factors as: increased sludge temperature, increases in the content of nitrogen and sulfur, an increase in nitrogen components along with pH, protein content (development of ammonia), and fat content (development of sulfur components) in sludge also the history of the sediments themselves, for example, transport or drainage method [24]. Since during the winter the driers usually work with lesser load or are stopped completely, it is necessary to store the sludge. This increases the nitrogen and sulfur content through extended storage time. In the exhaust air from the dryer, the following ingredients that produce an unpleasant odor, can be found, depending on the type of sludge and sewage sources (ammonia, dimethylamine, trimetyloamina, hydrogen sulfide, methylortcaptan, and dimethyltrisulfide) [25]. With the increase in the number of complaints of the people exposed to unpleasant odors, the interest of scientists in the matter of setting norms of concentration, frequency of occurrence, and intensity of odors emitted increases.

At present, there are no legal regulations in Poland regarding the standardization of the odor air quality [26]. The best way to fight malodorous compounds is to remove or modernize the causes/source of their emission, but sometimes it is difficult or does not bring the required results. Then, the methods for deodorizing the waste gas are used instead, involving biological methods (biofiltration using microorganisms that break down impurities), masking and deactivating agents (change in the nature of the smell, neutralization), or low-temperature plasma techniques (identification of waste gases required) [27–30]. The reason for the more and more common use of biofiltration for gas purification, in addition to its low investment and operating costs and no waste, is the possibility of removing from gases also compounds that are poorly soluble or practically insoluble in water (including benzene, toluene, or xylene). Such chemical compounds can enter the bacterial cell on the basis of their selective solubility in the membrane cytoplasmic [30–34].

The use of biofilters is a virtually waste-free technology, but there is little information about the use of odorous gases from the dryer. Despite all efforts to minimize the odor emissions in the drying hall, of the analyzed sewage sludge dryer, that is, cyclical sewage sludge shifting, good aeration, containment, the problem still existed. The Water Company, taking into account complaints from residents, decided to build a biofilter. The installation was supposed to be ecological and effective. Despite several attempts to work on a biofilter bed, their removal efficiency was lower than 60%. Therefore, it was decided to introduce several modifications aimed at improving the work of the biofilter.

The article aims to present the biofiltration process which is the last stage of wastewater treatment and waste management as an ecological and environmentally safe technology. A novelty in the presented work is the use of counter-current spraying of purified gas in the degassing installation. In existing installations, biogas humidification with steam is most often used. The counter-current nebulization used in the research effectively reduces the number of gaseous pollutants and dust suspended in the treated gas.

2. Materials and methods

2.1. WWTP and sewage sludge dryer

The research was conducted from January to November 2018 in the area of the mechanical and biological WWTP located in the province of Greater Poland (Poland). The period studied was one of the low-rain and warm periods. Household and industrial sewage from the surrounding town is discharged into the facility (population about 2,000). Initial, mechanical wastewater treatment is carried out here without the use of a primary settling tank (as one of such a few technological systems in Poland). This is associated with lower investment and operating costs. The pre-treated mechanical sewage goes to a chamber with a low-load activated sludge, where it undergoes nitrification, denitrification, and biological phosphorus removal. After the sedimentation process in the secondary settler, the treated sewage is directed to the stabilization pond (natural cleaning) and then to the nearby river (third purity class water). Excess sludge is dehydrated (up to approx. 19% d.m.) and after stabilization, it is directed to the halls of the solar sewage sludge dryer, where it is dried to approximately 75% d.m. The solar dryer consists of two halls with a total area of 4.320 m^2, made of a steel frame covered with glass panels, equipped with exhaust and supply fans, and sludge turnover. For the needs of the dryer, sludge dehydration installations were made with the use of a decanter centrifuge, power, and sanitary installations with maneuvering areas. The drying room allows 4,500 tons of sewage sludge to dry during the summer and storage during the winter. Fig. 1 shows the object in question.

2.2. Biofilter

The biofilter was a reinforced concrete tank with a volume of 2,500 m^3. The air from the solar sludge drying

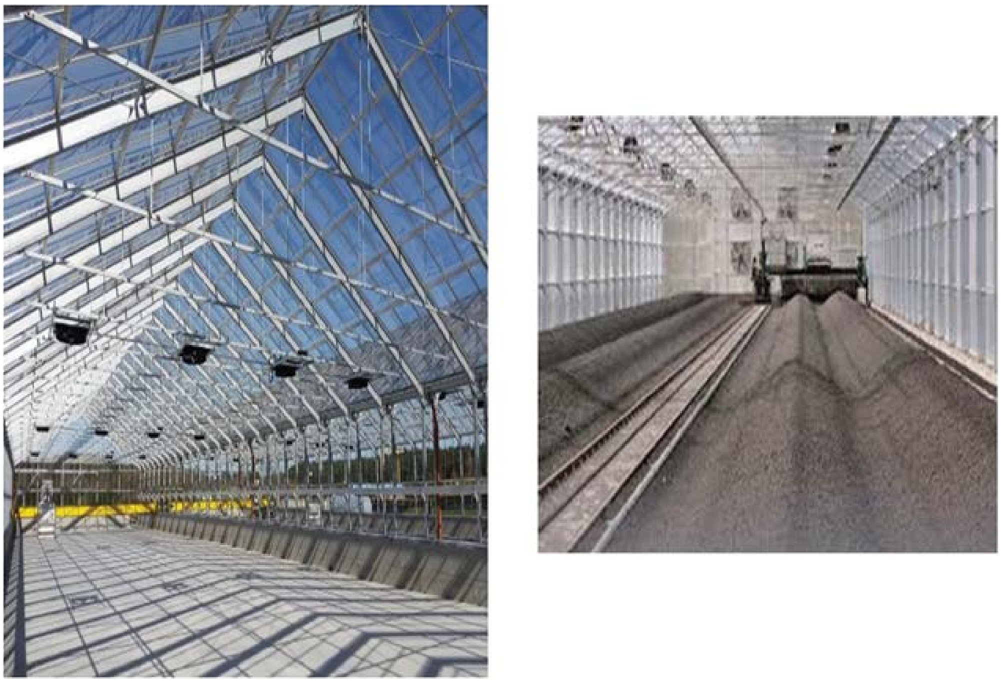

Fig. 1. Solar sludge dryer.

hall is directed to the biofilter by fans through a channel with a spraying nozzle system installed (Fig. 2). The biofilter was filled with wood chips of various sizes (from 1 to 35 cm). The biofilter chamber was filled in about 90% (Fig. 3). The physicochemical parameters of the biofilter are presented in Table 1.

2.3. Analytical methods

Summarizes the analytical methods used during the experiment (Table 2).

3. Results and discussion

3.1. Biofilter evaluation and modification suggestions

Drying of sewage sludge in the area of the object allowed for obtaining waste in the form of granules (R10). This product is easy to transport, store, and can be successfully used as a soil improver. Due to the low efficiency of the installed biofilter (at the level of 60%), numerous activities were undertaken to improve its operation. In the first step, several modifications were proposed:

- the biofilter bed was inoculated with activated sludge from a local WWTP (concentration 25 g dm^{-3}),
- modification of the inlet channel from the dryer by filling it with Białecki’s rings,
- reducing the efficiency of the fans to 85% of their efficiency (for all 20 fans),
- change spray direction from vertical down to vertical up,
- crushing the chips, which was to increase their surface (initially wood chips from 10 to 40 cm),
- adding “new” chips of smaller sizes – maximum 20 cm.

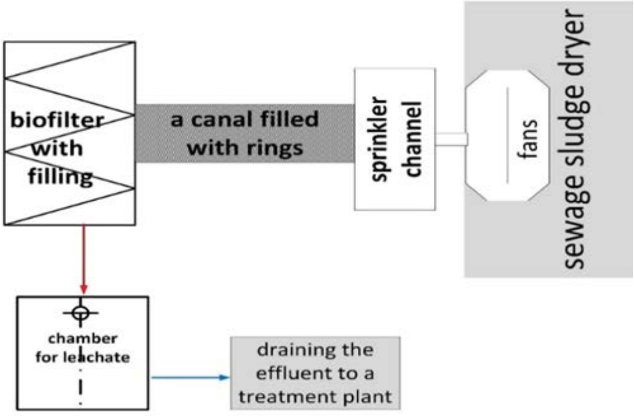

Fig. 2. Diagram of the research facility – sewage sludge dryer with a biofilter.

The first “*in situ*” analysis after the commissioning of the biofilter took place in its 4th week of operation. The samples of the biofilter filling and water from the screw were taken as well as the gases (H_2S and NH_3) were measured on the surface of the biofilter and in the solar hall of the sludge dryer. The air temperature on this day was around 15°C. Subsequent analyses in a similar range were performed every 4–5 weeks.

The monitoring of biofilter commissioning was carried out for a period of 3 months. The results of microbiological and physicochemical analyses obtained at that time confirm the initial operation of the biofilter. The biofilter is not a filter in the strictly technical sense, but rather a bioreactor in which the settled microorganisms

Fig. 3. View of the filling of the biofilter and the air supply channel from the dryer.

Table 1
Physicochemical parameters of biofilter filling

Parameter	Coconut fiber	Root wood	Wood shavings	Bark
pH	6.3	5.3	5.3	4.4
Dry mass (%)	33.1	70.8	67.3	83.0
C organic (%)	43.3	42.8	44.7	49.5
C total (%)	43.7	42.9	44.9	49.9
N total (%)	0.49	0.25	0.17	0.32
C/N	89	172	264	156

select pollutants from the flowing air and transform through their immune system into environmentally friendly products.

Materials of natural origin, such as compost (produced as a result of the technological process of oxygen decomposition of organic matter), peat, bark, wood chips, straw, moss, heather are used as biofiltration fillers that form the basis for the development of microorganisms. A good filtration material should have an appropriate structure and porosity [33,34].

The moisture content of the bed was normal and ranged from 57% to 72%. Biofilters work most efficiently at bed moisture in the range of 20% to 80%. The presence of moisture in the biofilter layer promotes the process of microbial oxidation, is the basic condition ensuring optimal activity of microorganisms, and largely determines the efficiency of gas purification [30,34].

The conducted microbiological analyzes indicate the proper development of biofilm in the reactor filling (Table 3) and the obtained results confirm, among others, the development of mold fungi and actinomycetes, constituting an important element during the course of various processes.

The effect of their development is also a characteristic smell of peat or humus formed on the surface of the biofilter. The observed bed heating and the generation of exhaust gases is also a beneficial effect of the metabolic activity of the microorganisms inhabiting the bed.

In winter, the biofilter chamber was not used for the process gas purification process, which resulted in a lack of sufficient oxygen and poor humidity. It could also affect the presence in the biofilter of rotting zones. After starting the filtration process, supplying process air to biomass, and resuming humidification to the desired values, the pH indicator and humidity changed. Originally, slightly acidic (pH = 6.1) the filling material became inert (pH = 6.8) as the biofilter was extended (Table 4). The most optimal pH range is around 6–7.5 [29].

Over the period considered, the reduction of ammonia gas pollutants ranged from 81% to 89%. The increase in the degree of removal of gaseous pollutants, in addition to the operation of the biofilter, increased along with the inlet air and bed temperature. Although the assumed efficiency of ammonia removal was not assumed in the project, its concentration level was below the threshold of smell perceptibility. It was found that H_2S was reduced to a level below the quantification threshold, which is in line with the design assumptions (reduction above 90%). Table 5 summarizes the results of measurements pertaining to the ammonia and hydrogen sulfide content obtained during the "*in situ*" tests and read from the sensors mounted on the assessed object.

According to the literature data, biofiltration as a method of deodorizing the gases emitted from such facilities as waste composting plants, dryers, or WWTPs allows achieving good treatment efficiency (above 99%). However,

Table 2
Applied analytical methods

Type of examination	Aim of the study	Methodology
Microbiological characteristics of the filling used	To determine the microbiological state of the filling used, wood chip samples were taken from the surface of the biofilter as well as from a depth of about 30–40 cm. Samples immediately after collection were secured in clean, tight containers. Larger fragments were crushed. Determining the total number of heterotrophic bacteria, the total number of mold fungi, the total number of actinomycetes and MPN (the most probable number of organisms) phase I and II nitrifying bacteria	• 10 g of material from the biofilter was taken and shaken in 90 mL of saline, followed by a series of dilutions and spread on suitable media for bacteria, actinomycetes, and fungi. Nitrifying bacteria using ammonia were grown on special liquid mineral substrates. The culture was carried out at 28°C. The number of bacteria, actinomycetes, and fungi was determined by the Koch plate method, while the number of nitrifying bacteria by the NPL method (the most probable number) using an appropriate culture system. Three test series were performed for each portion of the material.
Physico-chemical characteristics of the filling used	The aim of the study was to determine whether the filling used was characterized by appropriate conditions for the development of microorganisms.	• The pH measurement was carried out based on PN-Z-15011-3: 2001 with the use of pH Elektron CP-401. The samples were subjected to preliminary shaking in distilled water for 3 h. Moisture measurement was made using a drying and weighing method based on PN-EN 13183-1: 2004. Organic carbon according to PN-EN 15936: 2013-02. Total carbon according to PN-EN 15407: 2011. Total nitrogen according to PN-ISO 7150-1
Olfactometer	Physical and chemical compounds (ammonia and hydrogen sulfide) present in the air above the biofilter, in the biofilter, and in the sludge solar drying hall were tested at designated measuring stands	Gas composition was determined by: German type SR2-DO analyzer adapted to measure six gas concentrations (CH_4, CO_2, CO, O_2, H_2S, and NH_3) and Nanosens DP-27 BIO analyzer adapted for measuring gas concentrations (CH_4, CO_2, CO, O_2, H_2S, H_2, VOC, NH_3, C_2H_2, and HCHO)
Water from the scrubber from the intake air humidifier	The aim of the study was to determine how much water leaches ammonia from the gas being purified (before the biofilter)	Ammonium nitrogen according to PN-73/C-04576/02, for the determination of total nitrogen and total organic carbon content a Kiper TOC 10C Analyzer PX-120 carbon analyzer with autosampler 127 AS40-Dione was used

Table 3
Results of microbiological tests on the material from the biofilter

Date of collection	Total number of heterotrophic bacteria (22°C/72 h) cfu g^{-1}	Total number of mold fungi (28°C–30°C/72 h) cfu g^{-1}	Total number of actinomycetes (28°C/6 d) cfu g^{-1}	NPL nitrifying bacteria Phase I and II
02.2018	$96 \cdot 10^7$	$14 \cdot 10^5$	$108 \cdot 10^3$	≥2,400
03.2018	$108 \cdot 10^7$	$14 \cdot 10^5$	$108 \cdot 10^3$	≥2,400
04.2018	$112 \cdot 10^7$	$15 \cdot 10^5$	$100 \cdot 10^3$	≥2,400
05.2018	$180 \cdot 10^7$	$40 \cdot 10^4$	$120 \cdot 10^3$	≥2,400
06.2018	$160 \cdot 10^7$	$40 \cdot 10^4$	$100 \cdot 10^3$	≥2,400
07.2018	$240 \cdot 10^7$	$15 \cdot 10^5$	$121 \cdot 10^3$	≥2,400
08.2018	$260 \cdot 10^7$	$17 \cdot 10^5$	$143 \cdot 10^3$	≥2,400
09.2018	$263 \cdot 10^7$	$17 \cdot 10^5$	$142 \cdot 10^3$	≥2,400
10.2018	$230 \cdot 10^7$	$16 \cdot 10^5$	$131 \cdot 10^3$	≥2,400
11.2018	$198 \cdot 10^7$	$16 \cdot 10^5$	$134 \cdot 10^3$	≥2,400

Table 4
Results of physicochemical tests of the material derived from the biofilter (averaged)

Date of collection	pH	Humidity
02.2018	6.1	57%
03.2018	6.4	58%
04.2018	6.1	60%
05.2018	6.0	72%
06.2018	6.0	66%
07.2018	6.9	58%
08.2018	7.1	62%
09.2018	7.1	60%
10.2018	6.9	61%
11.2018	7.0	61%

as numerous studies report, even such a high efficiency of the process does not completely eliminate unpleasant odors [30,35,36].

The biofilter bed was sprayed with process water from the WWTP. The analyses of water consumed with an interval of 1 month showed a significant, nearly 6-fold increase in the concentration of organic carbon and ammonium nitrogen (Table 6). No negative effect of process water on the quality and condition of the biofilm was observed.

Another innovative solution was to change the method of humidifying the air supplied to the biofilter. The methods used in this type of system consist of supplying steam to the collector introducing gas to the biofilter. In the discussed installation, only an air tunnel with a nebular spray in counter-current was used. The tunnel – filled with Białka's rings and a sprinkler system – stops solid pollutants such as dust

Table 5
Results of measuring the concentration of pollutants in the incoming and outgoing gases

Date of collection	Hall of solar sludge dryer		Biofilter		Above the biofilter	
	NH_3 ppm	H_2S ppm	NH_3 ppm	H_2S ppm	NH_3 ppm	H_2S ppm
Data from reports from 2017 r.	15.62	0.04	14.03	0.03	–	–
02.2018 (temperature –1°C)	19.56	0.04	15.87	0.03	7.32	0.01
03.2018 (temperature 2°C, rain 2 mm)	18.21	0.04	12.09	0.03	5.23	Below the determination limit
04.2018 (temperature 15°C)	18.42	0.05	11.36	0.02	3.60	Below the determination limit
05.2018 (temperature 20°C, rain 1 mm)	26.07	0.04	14.89	0.02	3.55	Below the determination limit
06.2018 (temperature 28°C)	29.50	0.04	13.03	0.02	3.25	Below the determination limit
07.2018 (tempeature 28°C, rain 5 mm)	31.21	0.05	14.31	0.03	3.65	Below the determination limit
08.2018 (temperature 32°C)	30.09	0.05	11.23	0.02	3.21	Below the determination limit
09.2018 (temperature 23°C, rain 2 mm)	29.45	0.04	10.26	0.01	2.90	Below the determination limit
10.2018 (temperature 16°C)	29.18	0.03	11.21	0.01	3.10	Below the determination limit
11.2018 (temperature 7°C)	28.62	0.03	10.45	0.01	3.16	Below the determination limit

Table 6
Results of physicochemical tests of water coming from the scrubber

Date of collection	Ammonium nitrogen (mg dm^{-3})	Total nitrogen (mg dm^{-3})	Total carbon (mg dm^{-3})
02.2018	56	67	140
03.2018	69	75	160
04.2018	211	254	190
05.2018	329	365	720
06.2018	279	314	652
07.2018	64	69	150
08.2018	58	65	120
09.2018	58	66	130
10.2018	56	64	120
11.2018	54	62	120

generated during sludge drying and gaseous pollutants by dissolving them in water and discharging them to a drain.

The water samples were taken from the inspection tank /well on two dates – in April and May. In the first term, the carbon content was 140 mg dm^{-3}, while after a month the value of this indicator increased almost six times. An analogous situation was found for ammonium and total nitrogen. The sample from the month of May was characterized by more intense coloring and turbidity compared to the sample from April. The main task of water is to spray inlet air, biomass spray to maintain a constant level of humidity and dissolve the inlet air pollution. After passing through the biomass, water washes out small parts of the bed together with microorganisms and aerobic fungi. In the tank, organic compounds begin the fermentation process, which leads to the deterioration of water quality, precipitation at the bottom of the tank, and, as a result, putrefaction processes. The characteristic intense smell of the water sample from May confirms the occurrence of the putrefaction processes in the reservoir. This water is topped up and cyclically replaced. The technological assumption did not specify the time of water retention in a closed circuit. Therefore, it can be concluded that this period should be set experimentally in such a way as not to disturb the process. It was decided to direct most of the leachate to the treatment process and the discharged water was replaced with process water. This improved the microbiological parameters of the biofilter and raised the pH to the required level. The element requiring remodeling was the sealing of the air channel inspection hatches. The power of fans and the resistance caused by forced flow through the bed cause that the air "searches" for leaks. As a consequence, the air is not subjected to the biofiltration process and escapes into the environment together with odorous pollutants. The operator has undertaken to remove the leak.

4. Conclusion

The process was controlled and modified over 10 months. Due to the type of biofilter (open system), the parameters of the biofiltration process were influenced by both changes in ambient temperature and precipitation. This had a positive effect on the development of microorganisms on the surface of the biofilter filling, but also on an increased amount of odors. During the biofilter start-up, numerous technological changes were made that improved the quality of its work. The operators have supplemented, among others, wood chips and currently, the deposit height is 1.7 m (95% of the height). The results of microbiological cultures of the "new" filling confirmed the rapid and intensive development of microorganisms on the surface of the chips.

The research confirms the effectiveness of biological filtration. The effect assumed in the projections of installations for purifying the gases generated in the sludge dryer was to reduce the malodorous substances:

- H_2S > 90% reduction,
- ammonia > 70% reduction and this result were obtained. In the analyzed period, the operator made changes:
- completed the filling of the biofilter,
- changed the method of moistening the bed (the leachate was discharged for treatment)
- sealed the solar halls
- changed the method of humidifying the supply air.

The changes improved the efficiency of the process. The results were confirmed by the olfactometric method – no perceptible gaseous pollutants.

Initial results indicated a reduction of contamination by nearly 50%, while with the growth of microorganisms on the surface of the filling, the effectiveness increased significantly.

This contributes to the improvement of air quality both near the sewage treatment plant and in nearby housing estates.

The operation of the biofilter, its effectiveness depends on many variables, such as relative humidity (between 40% and 70%), high specific surface area (300–1,000 m^2 m^{-3}), air temperature, precipitation, wind strength, and direction [31,37,38]. In addition, the operation of the treatment plant (degree of treatment), as well as the quality of the wastewater, can also be affected periodically. However, in the case of the installation in question, biofiltration is an effective and ecological method.

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