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BIOFILTRATION AS AN EFFECTIVE METHOD FOR REDUCTION OF POLLUTANT EMISSIONS

Abstract
The development of industry and municipal infrastructure is a cause of increased emissions of malodorous substances into the atmosphere. These substances have a negative impact on human health and the environment. To protect the natural environment and human health, innovative methods of reducing emissions to the atmosphere are sought. These methods should be part of sustainable development principles. The work was carried out to assess the effectiveness of biofiltration in the reduction of odorous gas concentrations based on the measurements of biofilter efficiency in a sewage treatment plant. A mathematical simulation of the pollutant emission range in the environment was made to verify its change resulting from the use of a biofilter.

Key words
biofiltration, biofilter, malodorous gases

Introduction
Increased emissions of malodorous substances into the atmosphere are primarily related to industry, agriculture and municipal management. The main cause of their odor nuisance is the presence of odorous organic compounds (aliphatic, aromatic, aldehydes, ketones), as well as hydrogen sulfide, ammonia, sulfur oxides and nitrogen oxides in the emitted gases [1-3]. The malodorous substances coming from these sources have a negative impact on human health. Prolonged exposure to odors may cause depression, fatigue, respiratory problems, headaches, nausea, and eye and throat irritation [4]. Odors, especially volatile organic compounds (reactive organic gases), which are involved in photochemical reactions, are also characterized by relatively high toxicity and environmental harmfulness [5]. Hence, emission reduction and neutralization of malodorous gases is a strategic action from the environmental point of view. Choice of an appropriate technique depends on many factors such as the type of emission source or properties of the emitted gases and impurities they contain [4].

One of the most dynamically developing methods for deodorization of malodorous gases is biofiltration. The essence of biofiltration is the aerobic degradation of pollutants by microorganisms present in the filtering material, which results in the formation of non-toxic compounds that are not harmful to the environment [5-7]. Biological processes are carried out in bio-scrubbers, biofilters and with the use of sprinkling biological beds (three-phase bioreactors). Due to the relatively low investment and operating costs, wide application range and minimal waste generation, biofilters are used mainly in the treatment of malodorous gases [6-7].

The article defines the process of biofiltration as an effective method for deodorization of odorous gases. Attention has been paid to the parameters that must be satisfied by these gases to be treated. The structure of a model biofilter is shown. Taking as an example the Sewage Treatment Plant in Konin, an assessment of the effectiveness of biofiltration in the reduction of odor nuisance was conducted. The assessment was based on the concentration of malodorous substances before and after the installation for biological air purification (biofilter) and a mathematical simulation was performed to test the effects of minimizing the range of airborne emissions.

Biofiltration
Biofiltration is one of the methods to reduce the amount of malodorous gases. It involves passing of contaminated air through a layer of porous material containing microorganisms, where pollutants are removed due to biodegradation [2, 8-10]. During gas flow through the filtering material layer, the pollutants diffuse from the gas phase into the active biolayer surrounding the filtering material particles. In the liquid

phase containing microorganisms and dissolved pollutants, they are decomposed into carbon dioxide, water and biomass. Biological gas purification is based primarily on two processes – the absorption of pollutants in water and their biological decomposition [5, 11-12].

The smooth running of the biofiltration process and high efficiency of gas purification require strictly specified environmental conditions in which the process is carried out. Currently, with regard to construction and applied filling, various types of biofilters are used [13]. Their main component is a layer of filtering material to which gases are fed from the bottom of the perforated pipe system. In turn, the bed is humidified counter-currently and nutrients for microorganisms are introduced with water [12]. To achieve the maximum rate of biodegradation of pollutants, the filter material should provide the most favorable conditions for the development of microorganisms which are the purifying agent. It should be characterized by high porosity and large specific surface area. From an economic point of view, it should have low flow resistance (200-2000 Pa) [13]. In fact, materials of natural origin are good biofilters, particularly peat, compost, bark, wood chips, straw and moss. The efficiency of biofiltration is also affected by physicochemical conditions in the bed which directly determine the state and number of microorganisms. It is crucial to provide an environment that is optimal for their development, including the appropriate temperature, hydrogen ion concentration, redox potential, water content in the environment and nutrient availability [14].

It should also be noted that gases subjected to biofiltration must satisfy certain criteria, the main one being their susceptibility to biodegradation and water solubility. In addition, due to high toxicity to microorganisms contained in the bed, these gases should not contain heavy metals [15].

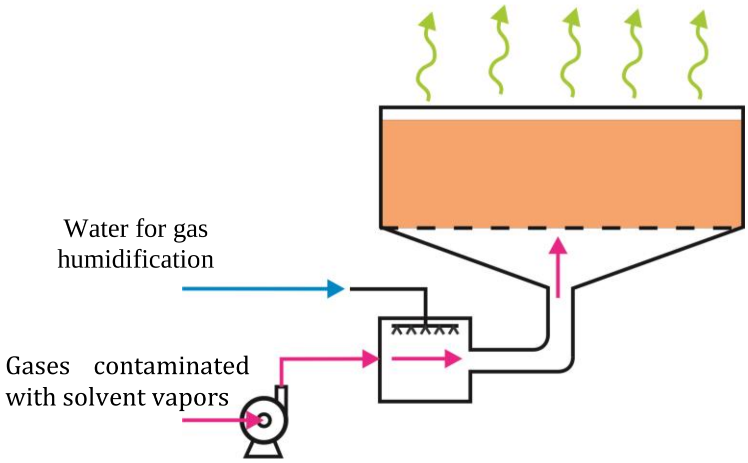

Fig. 1. Technological diagram of the analyzed biofilter
Source: Author's

The object of study
The object of the study was a biofilter used to purify air from the Sewage Treatment Plant in Konin. It is equipped with a biomass tank, i.e. a bioreactor with dispersed biomass, and a compatible machinery consisting of a fan and air humidifier. The whole is connected by ventilation ducts to transport air between the individual elements. This set is integrated with an electrical switchgear consisting of controllers, regulators and relays. The biofilter is connected to the instruments and indicators that control its work to coordinate the system operation. The biomass tank is made of glass-polystyrene laminated material resistant to atmospheric agents and polluted-air condensate. The structure is additionally strengthened with a steel frame made of closed profiles, which is permanently laminated into the tank walls. Radial fans made of stainless steel (A4, grade 316 in accordance with AISI) equipped with vibration compensators are used for air pumping. The whole apparatus is placed in a soundproof case which guarantees that noise levels do not exceed 80dB at 1 m distance.

Technical parameters of the analyzed biofilter:
- the amount of purified air – 6700 m3/h
- bed surface – ca.64 m2
- total amount of biomass – ca.96 m3

- type of biomass – pine bark
- fan motor power – up to 11 kW
- power of humidifier heater – up to 3 kW
- power of other devices – up to 4 kW
- water consumption – up to 140 dm3/h
- biofilter dimensions – 1.7 m × 2.0 m × 5.0 m (Height × Width × Length)

Research methodology

In order to assess the effectiveness of odorous gas emission reduction, the concentrations of individual pollutants were measured. Gas samples were collected three times at weekly intervals, respectively from the discharge end of the fan, from the humidifier where air is supplied from the treatment facilities and from the outlet pipe through which the purified air is emitted into the atmosphere. The samples were collected in accordance with the method described in standard PN-Z-04008-4: 1999P "Air purity protection – Collection of exhaust gas samples (emission) with air-like characteristics and their preparation for analysis by gas chromatography" during dry weather. The tests were conducted in June 2015.

The tested compounds (H_2S, mercaptans, diethylamine, trimethylamine) were determined by sampling the air with the use of a Sensidyne low-flow suction pump equipped with a flow meter and control valve. The assay was performed by gas chromatography with a mass detector after desorption from activated carbon. In turn, the concentration of ammonia, formaldehyde and SO_2 was determined using the LANCOM SERIES II meter from LAND INSTRUMENTS (UK).

A mathematical simulation was performed using the Opa03 program to verify the range of pollutant emissions. This system provides modeling of the range of air pollution from point, line and surface sources using a calculation algorithm compliant with the Regulation of the Minister of Environment no. 796 Dz.U. 87/2002 [16], no. 12 Dz.U. 1/2003 [17] and no. 2181 Dz.U. 260/2005 [18]. The basis for calculations is the Gaussian model of "streaks of pollution" formed by wind and diffusion processes.

Result and discussion

Concentrations of the analyzed pollutants at the inlet and outlet of the biofilter and effectiveness of biofiltration of these compounds are summarized in Table 1. It should be noted that the effectiveness of biofiltration is a function of biodegradability, concentration of pollutants and gas flow, as well as design parameters, including biofilter size and temperature.

Table 1. Concentrations of gases from the biofilter and effectiveness of their reduction

Compound	**Concentration** μg/m3		**Biofiltration efficiency**	**Measurement error**
	Biofilter inlet	**Biofilter outlet**	%	%
SO2	158	15	91	15
H2S	154	9	94	13
Mercaptans	192	8	96	16
Diethylamine	1 526	133	91	13
Trimethylamine	788	68	91	13
NH3	1 799	163	91	15
Formaldehyde	1 987	188	91	11

Source: Author's

Based on the results presented above, the highest reduction of concentration was observed for mercaptans (96%) and hydrogen sulfide (94%). For other tested pollutants, the effectiveness of biofiltration is 90-91%. However, according to numerous studies, even such high efficiency of the process does not completely eliminate unpleasant odors. Odor nuisance was particularly noticeable directly in the vicinity of communal utilities.

Hong and Park [19] examined the effectiveness of biofiltration to remove ammonia generated during the composting of food waste from the food industry. They used biofilters with two different fillings, working in the same conditions. The research showed nearly 100% neutralization of ammonia generated during the composting process.

Similar results were achieved by Pagans et al. [20] who similarly studied the effectiveness of biofiltration with respect to ammonia produced during the composting of animal by-products. Research showed that in the early days of the experiment, the ammonia removal rate was very high (over 90%), and by the end of the experiment it had dropped significantly (down to 30%).

Biofilters are limited in their ability to remove volatile organic compounds (VOCs), due to the time required for their decomposition, effectiveness of the decomposition and process control. Most VOCs are not readily degraded by microorganisms in the filters and require a longer residence time, which in turn involves the need for larger systems with greater surface area. The effectiveness ranges between 40 and 70% [21]. Table 2 presents effectiveness of the removal of selected odors with the use of biofilters.

Table 2. Effectiveness of the removal of selected odorous substances by biofiltration

Pollutant	**Removal effectiveness, %**	**Concentration, μg/m3**
Hydrogen sulfide	99.99	30-3690000
Ammonia	96.4-98.3	1400-580000
VOCs, i.e. volatile organic compounds (converted to butanol)	40-70	140-40000
Aldehydes	75	-
Alcohols	90	-
Aromatic hydrocarbons	40-80	-
Odors	95-99	-

Source: [22]

Lebrero et al. [21] attempted to apply biofiltration using an activated sludge diffusion system (AS). The emitted malodorous substances got directly into the aeration tank where, together with oxygen, they diffused through the sludge to be degraded by appropriate microorganisms. Sludge from the sewage treatment plant containing aerobic bacteria was used as an inoculum. As a result, the reduction of hydrogen sulfide and butanone concentrations was 98-99.5%. Below is a graphical interpretation of the spread of pollutants without and with the use of a biofilter, respectively.

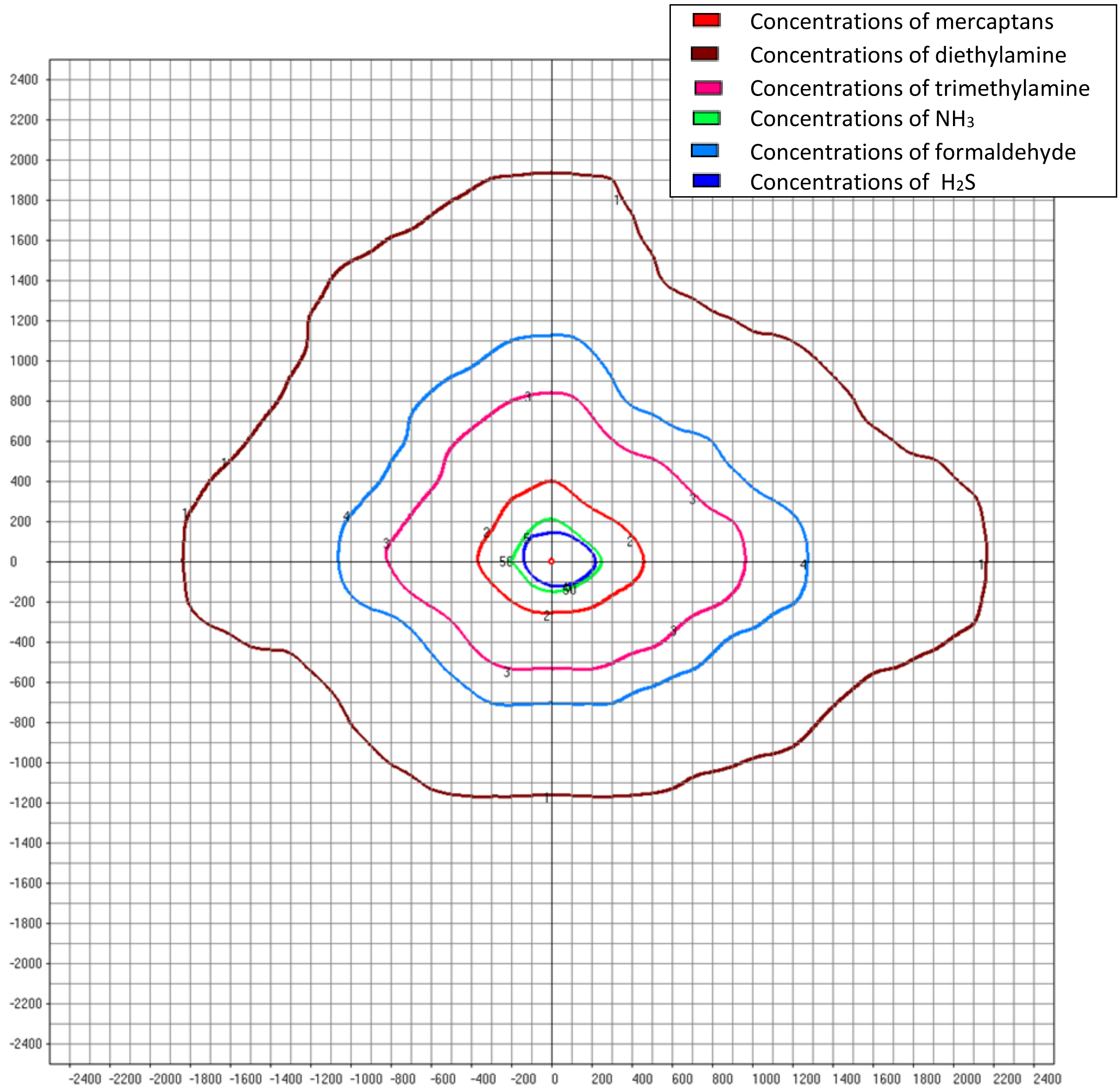

Fig. 2 Graphical interpretation of the spread of pollutants without a biofilter in relation to mean annual values (distance from the emitter given in meters)

Source: Author's

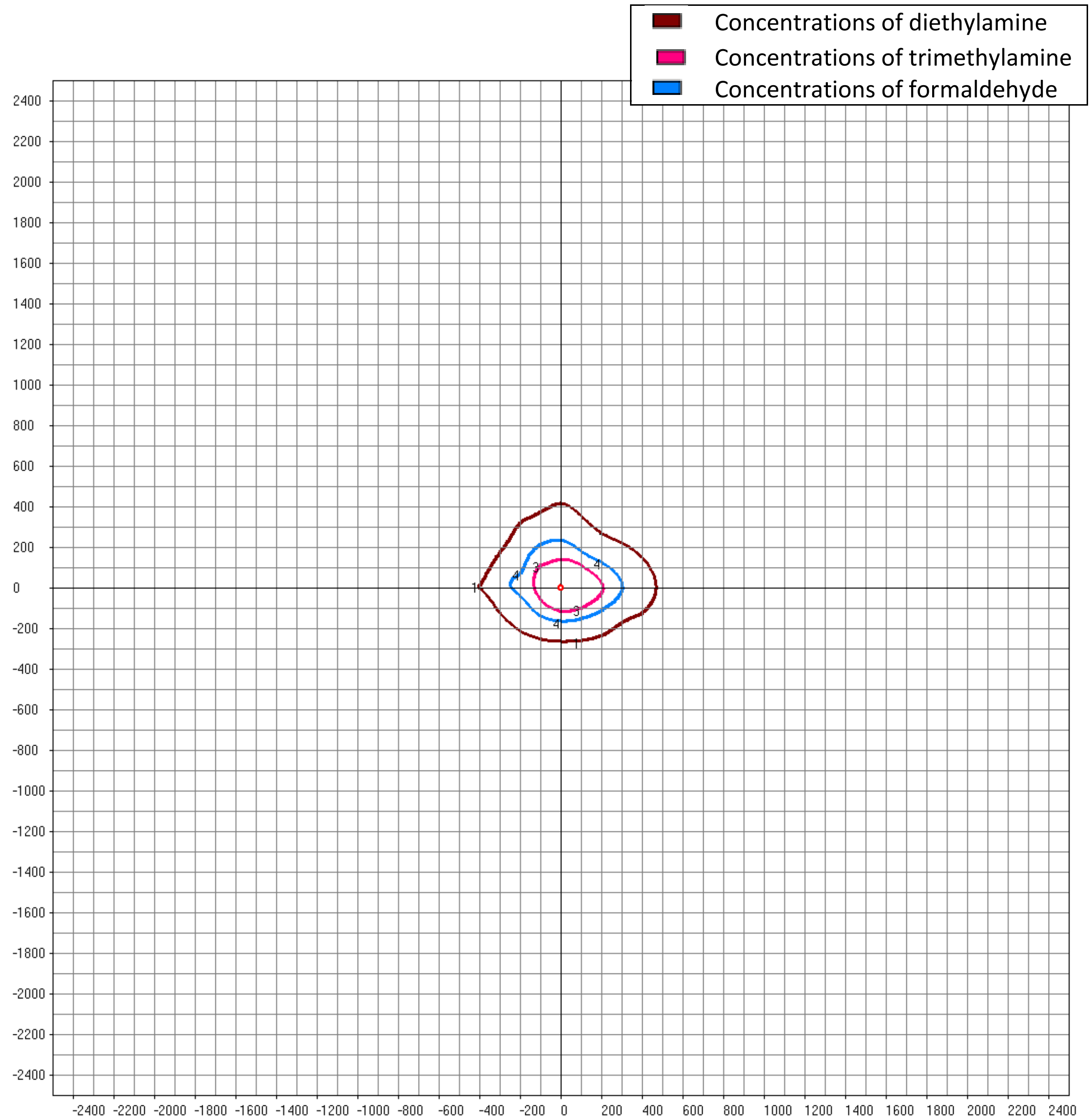

Fig. 3. Graphical interpretation of the spread of pollutants with a biofilter in relation to mean annual values (distance from the emitter given in meters)
Source: Author's

The spread of pollutants is determined primarily by meteorological conditions, topographic features and buildings situated near the source of emission. It should be borne in mind, however, that due to the strong wind currents, the pollutants reach their maximum concentrations sometimes up to several kilometers from the emission source. The performed simulation calculations can be very helpful in air monitoring, as for different atmospheric conditions and terrain roughness they allow us to predict the range of emissions and pollutant concentration on a given surface depending on the source parameters and the amount of pollutants produced.

Summary

The operation of municipal facilities is associated with emissions of harmful chemicals and nuisance odors. The sources of these increased emissions are particularly wastewater treatment plants, where there is direct movement (mixing) or flow of sewage and sludge, as well as large plants where composting or co-composting of waste from food industry is carried out.

Odorous substances include hydrogen sulphide (H2S), ammonia (NH3) and vapors of organic substances i.e. aldehydes, organic acids and ketones, which are a result of microbiological processes. An effective method to eliminate nuisance odors is to limit their emissions by closing (encapsulating) the objects in which these substances are formed and then deodorizing the contaminated air or waste gas streams before they are discharged into the atmosphere.

Deodorization is one of the more difficult issues of the waste gas treatment technology. A low odor detection threshold (the concentration of odorant in the air at which there is a 50% chance of sensing the difference between the smell of contaminated and pure air) of many gases with nuisance odor causes that in most cases it is necessary to remove almost completely the odorous compound [11].

Deodorization of contaminated air can be carried out using a variety of technologies, including absorption, adsorption, condensation and biological methods. However, biological methods, especially biofiltration, are becoming increasingly popular. This method compared to conventional physicochemical methods is characterized by significantly lower investment and operating costs, the possibility of using different filter materials, depending on the type of pollution and the possibility of re-using the applied filter material.
Depending on substances contained in the gas, the efficiency of its purification ranges from 90 to 94% which confirms high effectiveness of this method. Waste gas purification by biofiltration is successfully used in many sectors of the economy and produces satisfactory results [13].

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