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IZABELA SÓWKA[1], URSZULA MILLER[1], AGNIESZKA GRZELKA[1]

THE APPLICATION OF DYNAMIC OLFACTOMETRY IN EVALUATING THE EFFICIENCY OF PURIFYING ODOROUS GASES BY BIOFILTRATION

A widely used method for reducing odor emissions into the air at municipal waste plants is biofiltration. This method allows obtaining high gaseous pollutant removal efficiency at relatively low investment and operating costs. Evaluating the efficiency of a biofilter using dynamic olfactometry is a very useful tool because it allows determining the degree of total deodorization efficiency. Determining the concentrations of individual pollutants does not always give an overall assessment of the degree of olfactory pollution by the gases being emitted, and at the same may not be sufficient in the case of evaluating the efficiency of a deodorization installation. The paper presents the results of the evaluation of biofilter efficiency performed based on olfactometric determinations. The measurements were conducted for biofilter-treated gases emitted from various sources within four municipal waste processing plants. Obtained results indicated the biofiltration efficiency between 60.8 and 97.2% and showed that after the filter bed replacing (organic instead of mineral bed) deodorization efficiency significantly increased. An important aspect of the overall evaluation was the evaluation of odor hedonic quality, due to the frequently intense natural odor of the biofilter bed itself.

1. INTRODUCTION

Due to expansion of cities more and more frequently objects that may be olfactory burdensome such as objects connected with municipal waste plants including landfills and water treatment plants, as well as industrial plants, are located close to residential areas. The operation of such objects may cause complaints and protests concerning the emitted odors. Even though current legislation concerning emission of substances into the air does not define acceptable odor concentration, the problem of olfactory impact is more and more frequently discussed, and, in concern about air quality, even this aspect

[1]Unit of Engineering and Protection of Atmosphere, Faculty of Environmental Engineering, Wrocław University of Science and Technology, pl. Grunwaldzki 9, 50-377 Wroclaw, Poland, corresponding author I. Sówka, e-mail address: izabela.sowka@pwr.edu.pl

should be taken into account. Olfactory pollution is frequently caused by pollutants with a low olfactory detection threshold, whose concentrations in the emitted gases are small, and therefore a popular deodorization technique of outflow gases is biofiltration [1]. The removal of odors by this method is considered to be feasible. However, the resultant efficiency depends on many factors such as process parameters (e.g., pH, bed humidity, gas temperature), filtration bed type, the construction of the biofilter, the bed pollutant load, and gas to be treated [2]. In a biofilter, microorganisms form a biofilm on a porous substrate. Air contaminated with volatile compounds passes through the damp filtration bed, where the contaminants undergo three main processes: absorption in the water phase, adsorption on the solid bed surface and biodegradation by the microorganisms populating the biofilter. In a well-functioning biofilter, the contaminants are decomposed into simple compounds: carbon dioxide and water [3]. For this treatment process to be effective, an acclimatization of the microorganisms to the contaminant distribution is necessary. This is achieved by a change in the environmental conditions (an introduction of microorganisms directly into the treatment location, so that the contaminants are the sole source of carbon) or by a previous adaptation of microorganisms for degrading specific contaminants [4]. Biofiltration allows an effective removal of aromatic compounds such as benzene, toluene, styrene, as well as aliphatic compounds (dichloromethane, propane, isobutane), easily biodegradable organic compounds (alcohols, ketones, esters), and even hydrophobic terpenes (α-pinene), sulfur compounds (carbon disulfide, sulfur dioxide, hydrogen sulfide, thiols and thioethers) and nitrogen contaminants [5]. Furthermore, it is a relatively inexpensive gas treatment method (being economically attractive especially in the case of large gas streams containing low contaminant concentrations), does not produce toxic byproducts and allows reaching deodorization efficiency up to 99% [6].

Due to the varied chemical compositions and variability in the hedonic quality of odors emitted from various sources, finding a universal method of evaluating the efficiency in limiting odor emissions is very difficult. Analytical techniques only allow determining the qualitative composition of the gas and the concentration of individual components. However, they do not take into account the often complicated chemical transitions which chemical compounds undergo in a multicomponent mixture, the interactions between the individual components and the decomposition of thermally unstable volatile compounds [7]. Dynamic olfactometry, as a sensory technique, allows one to describe odor concentrations, and also description of more subjective parameters such as intensity and hedonic quality [8]. The measurement method described in the standard PN-EN 13725:2007 *Air quality. Determination of odor concentration by dynamic olfactometry* allows determination of odor concentrations as expressed in European odor units per cubic meter (ou_E/m^3) in emitted gas samples, e.g., at a few points in the process, as well as an estimation of the total odor emission from a chosen object. Therefore by the use of mathematical odor dispersion modeling, it is possible to determine the range and zones of object olfactory impact, as well as to control and evaluate the air quality.

The odor concentration is defined as the amount of odorant evaporated into 1 m^3 of neutral gas, which, at standard conditions, is olfactory detected by half of the people from a representative group exposed to an odorant [9].

In the paper, the results of olfactory measurements and the deodorization efficiency of gases treatment by the biofiltration method for four various municipal waste management plants have been presented. The influence of the filter bed type, as well as its own unique aroma and waste composting method, on biofiltration efficiency, has been indicated.

2. MATERIALS AND METHODS

The gas samples were taken according to the method described in VDI 3880:2011 and PN-EN 13725:2007 during non-rainy weather which ensured repeatability of the results. A standard sampler was used for taking samples, along with PTFE bags, which are non-absorbent and do not emit any odors. The remaining elements of the sampling apparatus were made from non-absorbent, odorless materials. The sampling was performed via a lung-type action (Fig. 1). Each time three samples were taken at both the biofilter input and output.

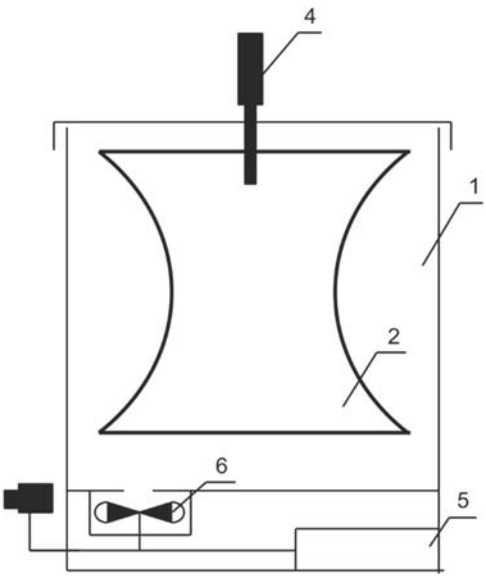

Fig. 1. Schematic of the apparatus used for taking samples for olfactory studies: 1 – vacuum chamber, 2 – plastic bag, 3 – plastic or Teflon tube, 4 – Teflon connector, 5 – battery, 6 – fan, 7 – on/off switch

Immediately after sampling, the samples were transported to the Olfactometric Research Laboratory to determine the odor concentrations. When it was necessary, samples were diluted. Measurements of odor concentration were conducted by using the dynamic olfactory methods according to the PN-EN 13725:2007 *Air quality. Determination of odor concentration by dynamic olfactometry*. The measurement equipment consisted of a four station TO8 olfactometer with all the necessary accessories. Per the appropriate standards, the measurements were conducted in a quiet and isolated room with stable temperature and lighting conditions. The measurement team consisted of four evaluators and one operator. The evaluators were selected according to the guidelines contained in the standard mentioned above with the use of a certified reference material (*n*-butanol in nitrogen). During the measurement, a sample of the analyzed gas was connected to the olfactometer, and the task for the evaluators was to signal whether they sense an odor in the presented gas stream or not. The gases were diluted with odorless air in a dynamic manner. The initial dilution that it would not be possible to detect an odor was chosen, and the dilution was decreased dynamically. Among the presented samples were also so-called blind samples or zero samples, where the odor-free air was presented. The olfactometer was connected to a computer equipped with special software. Each measurement consisted of four series. The results stored in the computer memory were calculated as the result of team measurement ($Z_{\text{ite,pan}}$) – an arithmetic mean of all the individual measurements which was the odor concentration in a given sample (Cod) expressed in ou_E/m^3 according to the PN-EN 13725:2007.

The deodorization efficiency was calculated as

$$\eta = \frac{E_{\text{inlet}} - E_{\text{outlet}}}{E_{\text{inlet}}} \times 100\% \qquad (1)$$

where η was the biofiltration efficiency, %, E_{inlet} – the odor emission flux before the biofilter (upstream of the biofiltration system), ou_E/s, E_{outlet} – the odor emission from the biofilter, ou_E/s.

The emission was calculated from the following formula:

$$E = CV$$

where, E was the odor emission, ou_E/s, C – the odor concentration in the gas, ou_E/m^3, V – the gas flow rate, m^3/s (under standard conditions).

The odor modeling calculations were performed applying the Polish reference model[2] based on the Pasquill formula:

$$S_{xyz} = \frac{E_g}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left\{\exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right]\right\} \times 1000 \qquad (3)$$

[2]The methodology from the *Ordinance of the Minister of the Environment from 26.01.2010 Concerning Reference Values for Some Substances in Air* (Dz.U. Nr 16, poz. 87) with the use of the Operat FB software.

where: S_{xyz} – concentration of the substance in the air averaged over 1 h, μg/m^3, E_g – maximum emission of gaseous substance, mg/s, σ_y – horizontal atmospheric diffusion coefficient, m, σ_z – vertical atmospheric diffusion coefficient, *m*, $\overline{u}$ – average wind velocity in the layer from the geometric height of the emitter *h* to the effective height of the emitter *H*, m/s, *y* – component of the emitter distance from the point at which the calculation is made perpendicular to the direction of the wind, m, *z* – the height for which the concentration of the substance in the air is calculated, m.

3. RESULTS AND DISCUSSION

The results of measurements performed for the municipal waste management plant MWMP 1 are presented in Fig. 2 and Table 1. The measurements of odor concentration at the input and output of the biofilter were performed in five measurement series, where the biofilter operating conditions differed in values of the bed odor load. The treated gases came from the waste sorting hall. The first two series of measurements were conducted for mineral deposits, and then it was exchanged for organic material.

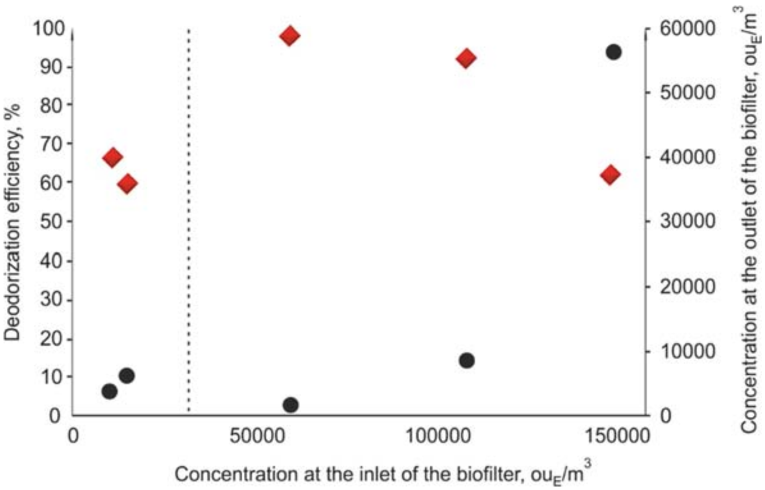

Fig. 2. Deodorization efficiency (squares) and odor concentration at the biofilter outlet (circles); the dashed line separates results obtained after the filter bed replacing

The odor concentrations in the analyzed gases ranged from 11 387 to 150 336 ou$_E$/m^3 and the obtained effectiveness from 60.8 to 97.2%. At the highest odor concentration at the biofilter inlet of 150 336 ou$_E$/m^3, the purification efficiency was 62.5%. The obtained results (Fig. 2) showed that after changing the filter bed (organic instead of a mineral one) deodorization efficiency was much higher (97.2%) than that noticed for the previous filter material (60.8%). The mineral filter material may not create the optimum conditions for the settlement of the biofilter microflora.

Table 1

Measured odor concentrations and biofiltration efficiencies for MWMP 1

Series No. & (measuring period)	Emitter	Odor concentration [ou_E/m^3]	Average odor concentration [ou_E/m^3]	Biolfiltration efficiency [%]
1 (December 2015)	biofilter inlet	12 177	11 387	68.4
		9806		
		12 177		
	biofilter outlet	4871	3597	
		2896		
		3025		
2 (January 2016)	biofilter inlet	17 984	15 318	60.8
		12 177		
		15 792		
	biofilter outlet	6597	6000	
		5087		
		6317		
3 (March 2016)	biofilter inlet	53 119	60 994	97.2
		57 926		
		71936		
	biofilter outlet	1722	1726	
		1878		
		1579		
4 (June 2016)	biofilter inlet	150 242	150 336	62.5
		156 894		
		143 872		
	biofilter outlet	60 491	56 360	
		53 119		
		55 470		
5 (October 2016)	biofilter inlet	118 500	110 121	92.1
		103 353		
		108 511		
	biofilter outlet	7782	8647	
		8483		
		9675		

Table 2 presents the results of measurements of odor concentrations performed for the biofiltration installations at two municipal waste management plants (MWMP 2 and MWMP 3). In both cases, biofilters are used for air coming from the waste composting process. However this process was performed using different methods. At MWMP 2, the process was performed by the container method, while at MWMP 3, the tunnel composting in special sleeves was used. Additionally, the input gases purified using the biofilter at MWMP 2 were initially conditioned with the use of a scrubber.

Table 2

Measured odor concentrations and biofiltration efficiencies for MWMP 2 and MWMP 3

Object (measuring period)	Emitter	Odor concentration [ou_E/m^3]	Average odor concentration [ou_E/m^3]	Biofiltration efficiency [%]
MWMP 2 (September 2014)	biofilter inlet	10 624	9698	94.2
		10 624		
		7845		
	biofilter outlet	395	559	
		645		
		636		
MWMP 3 (April 2014)	biofilter inlet	724	1038	61.1
		1117		
		1272		
	biofilter outlet	470	404	
		347		
		395		

A higher gas treatment efficiency was obtained for the MWMP 2 than for MWMP 3 despite a bigger bed odor load. The compounds produced by the composting process include both substances created from anaerobic conditions and decay processes (hydrogen sulfide, skatols, thiols) as well as substances which are the products of biochemical transformation (e.g., organic acids) and those unique to the composting process (aldehydes, geosmin, limonene) [10]. Pretreatment of gases flowing into the filtration bed in a scrubber allows for a removal of sulfur compounds, which prevents the acidifying of the bed and it may cause a reduction or change in microbiological activity and a worsening in deodorization effects.

For the next object (MWMP 4), an expanded research protocol was performed including a background measurement that was defined as the natural odor of the biofilter (the output gases were sampled and measured when the biofilter was flushed with pure air). The results of the measurements presented in Table 3 showed the deodorization efficiency amounted 93.7% and taking into account the background (emissions at the output decreased by the emission caused by flushing the bed with clean air) – 94.4%.

The own unique aroma of biofiltration bed comes from the materials used in the biofilter (e.g., compost, wood chips, bark) [11]. However, it does not result in olfactory pollution and is often characterized as a pleasant "forest" smell. Therefore, to evaluate the deodorization efficiency for biofiltration, it is necessary to evaluate the hedonic quality of the air at the biofilter output.

Table 3

Measured odor concentrations and biofiltration efficiencies for MWMP 4 in November 2015

Emitter	Odor concentration [ou_E/m^3]	Average odor concentration [ou_E/m^3]	Biofiltration efficiency [%]
Background (flow of clean air through the biofilter)	512	446	–
	431		
	395		
Biofilter input	11 585	10750	93.7
	13 777		
	6889		
Biofilter output	899	698	
	636		
	558		

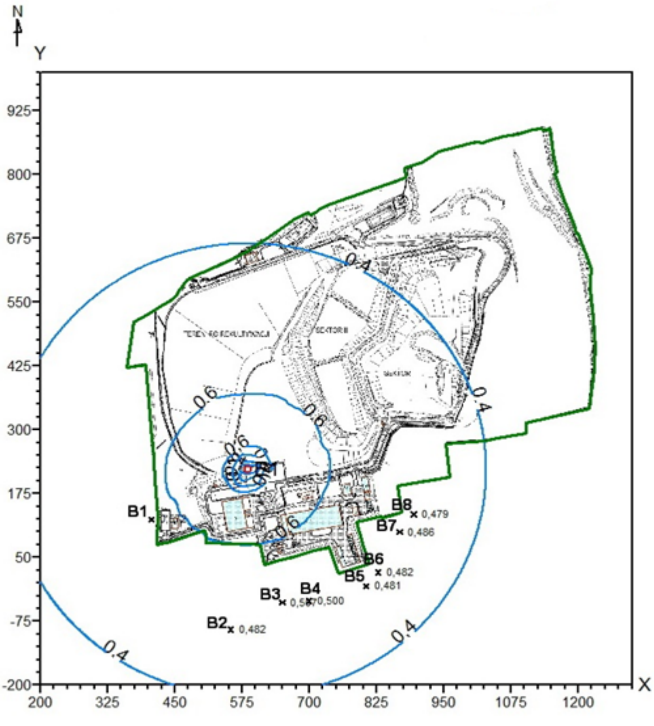

Fig. 3. Distribution of maximal odor concentration, ou_E/m^3 – variant 1

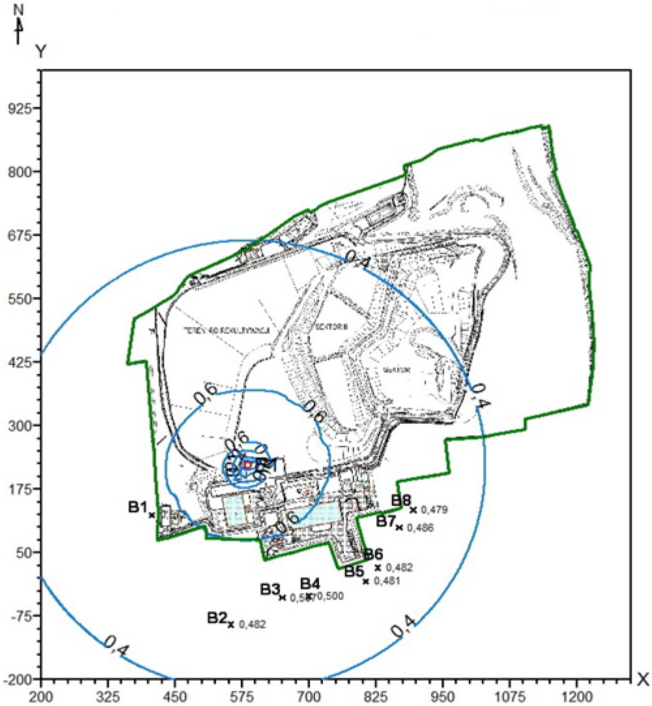

Fig. 4. Distribution of maximal odor concentration, ou_E/m^3 – variant 2

To examine the influence of the bed aroma of the biofilter on the olfactory impact range of a municipal management object resulting from mathematical modeling, air dispersion calculations for two emissions variants were performed: without (1) and with the effect of the measured background of the biofilter bed (2). The results of the calculations are shown in Figs. 3 and 4. In both cases, the calculations showed that the allowable frequency of 3% exceedances of the limit value defined as 1 ou_E/m^3 [12] at the ground, as well as at buildings level (in points B1–B8) was not exceeded. Assuming Dutch requirements [13] (allowable frequency of exceedances of 5 ou_E/m^3 is equal to 2% on the scale of the year), the olfactory impact does not result in exceedances of the requirements both, at the ground and buildings level. The highest one-hour odor concentrations were 0.680 ou_E/m^3 (variant 1) and 0.601 ou_E/m^3 (variant 2). No exceedances of one-hour concentrations were found. The obtained exceedance frequency in the area under study and at all residential buildings was 0%. Based on the performed calculations, it may be concluded that the efficiency of the analyzed biofilter was sufficient and for the analyzed scenarios (both with and without taking into account the biofiltration bed aroma), the installation will not negatively impact on the surrounding area, both at ground level, and in residential buildings.

4. CONCLUSION

Analyzing the efficiency of a gas treatment installation on limiting odor emissions, it is extremely important to evaluate odor reduction in an air mixture. The biofiltration efficiency depends on the installation operating parameters, as well as on the composition and concentrations of contaminants in exhaust gases. In the general evaluation of odor emissions, searching for an effective deodorization method, it may be necessary to take into account the hedonic quality of the emitted gases as a result of the specific odor of the filtration bed.

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