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Research on Odours Emitted from Non-Hazardous Waste Landfill Using Dynamic Olfactometry

Marija Meišutovič-Akhtarieva[1], Eglė Marčiulaitienė[2]

Department of Environmental Protection, Faculty of Environmental Engineering, Vilnius Gediminas Technical University, Vilnius, Lithuania
E-mails: [1]marija.meisutovic@stud.vgtu.lt; [2]egle.marciulaitiene@vgtu.lt

Abstract. The article analyses the existing research on odour emissions from the passive odour source – municipal landfill for non-hazardous waste. The current research has been carried out in the Vilnius county, at the Kazokiškės landfill for regional municipal waste. Odour emissions were analysed using samples from waste of different age and at different outdoor air temperatures. The investigation determined the concentration of odourous volatile organic compounds (VOCs) formed in the landfill (mg/m^3) and odour emissions (OU$_e$/m^{2}s). The odour concentration varied between 0.02 OU$_e$/m^{2}s (from 9 year old waste at 11°C) to 1.29 OU$_e$/m^{2}s (from 0–3 year old waste at minus 1 °C and minus 10 °C). It was determined that as temperature decreases (within the range of 11 to minus 10 °C), the concentration of odour emissions increases. The coefficient of correlation between the temperature of environment and the concentration of odours emitted from the landfill stood at minus 0.91.

Keywords: odours, VOCs, landfills, dynamic olfactometry method.

Conference topic: Environmental protection.

Introduction

Odours form during the course of physical, chemical, biological and microbiological processes. Their sources are usually oil refineries, food production and processing companies, companies producing laundry and cleaning products, paper and paperboard, fertilisers, rubber, and plastics (Paliulis, Zuokaitė 2012). However, among the main odour sources are companies processing and disposing waste. Disposal of waste in the landfill accounts for the greatest part of environmental pollution with odourous gaseous pollutants. Waste landfills are categorised as diffuse air pollution sources as they vary in size during exploitation and the air flow emitted is not defined. Emissions from municipal waste landfills consist of 65% of methane and 35% of carbon dioxide, while traces of volatile organic compounds (VOCs) account for less than 1% of landfill gas (Allen *et al.* 1997). During decomposition of waste, odourous gaseous pollutants form as a result of chemical and biochemical reactions taking place in the landfill. The biological decomposition of solid municipal waste in landfills under anaerobic conditions causes not only unpleasant odours but also a considerable number of other environmental problems.

Odours arise from various pollutant chemical compounds whose maximum quantities are regulated by the laws and hygiene standards. However, despite the regulative framework, due to insufficient control and inappropriate prevention measures, the air is nevertheless being polluted with different chemical compounds. Unpleasant odours are frequently mentioned in the complaints of residents (Lukauskas, Zuokaite 2012). Odour emissions are usually regarded as undesirable or unpleasant from the moment they start negatively affecting the environment. Odours do not always pose direct harm to human health as people tend to smell odours even at low concentrations of chemical compounds in the air. Usually, only significantly high concentrations of chemical compounds – which are considerably higher than the individual sensitivity to odours – are harmful to human health.

Currently, two hygiene standards regulate odours in the air of living environment in Lithuania: the hygiene standard HS 121:2010 *The Threshold Value of Odour Concentration in the Air of Living Environment* and the hygiene standard HS 35:2007 *The Maximum Permitted Concentration of Chemical Substances (Pollutants) in the Air of Living Environment*. The threshold value of odour concentration – 8 OU$_e$/m^3 – indicated in the Lithuanian Hygiene Standard HN 121:2010 is applied only for odours emitted in the process of economic business activities involving the use of stationary sources of odour pollution.

Dynamic olfactometry is one of the most effective and frequently used research methods; it is carried out using a dynamic olfactometer. The dynamic olfactometer produces the flow of mixed neutral and odourous gases with specified dilution factors and delivers it to the outlet.

Research on odour emissions from landfills has been carried out by scientists from Belgium, Italy, Malaysia, Japan, Ireland, Turkey, etc. Many researchers measured odours in landfills using more than one method for odour identification.

The Belgium study in 2012 investigated odour emissions in the Belgium HLC landfill using the dynamic olfactometry method according to the European Standard EN13725 and involving a field monitoring team (Nicolas *et al.*

2006). The method used is based on field monitoring – the persons monitoring the field determine the maximum distance at which the source of pollution can be detected (smelled). The odour emissions identified by dynamic olfactometry stood at 0.5, 0.4 and 0.2 OU_e/m^2s; the parameter of the odour emissions from the entire landfill territory varied between 2000 to 13,000 OU_e/m^2s. Odour concentrations detected using the field monitoring method were 10 times higher (Nicolas *et al.* 2008).

Z. Sakawi *et al.* studied the impact of unpleasant odours from Malaysian landfills on the balanced human life. Special attention was paid to dynamic changes in odour sources, such as meteorological conditions. A questionnaire was devised for the residents of the areas surrounding the landfills. The purpose of the questionnaire was to find out if meteorological factors such as wind direction and speed, humidity and temperature strongly affect the concentration of odours diffusing from landfills. The authors concluded that the intensity of unpleasant odours is mostly dependent on the wind direction (Sakawi *et al.* 2011).

The Italian study in 2005 researched odours emitted from seven landfills. Sironi *et al.* (2005) suggested a methodology for estimating odour emissions. The following data had to be taken into account: annual data on quantities of waste admitted to landfill; density of waste; number of working days per annum; the height of waste stratum formed per day; the area of used landfill surface; the area of recultivated surface (Sironi *et al.* 2005).

The 2009 Japanese study compares the "triangle odour bag method" with the dynamic olfactometry method applied in the context of tightened odour control laws (Ueno *et al.* 2009). Odour measurements were carried out using a specific olfactometry method based on the use of a triangle odour bag – odour samples diluted at different concentrations were injected into small single-use bags. The odours were assessed by pre-selected assessors using a facial mask and sniffing directly out of the bag via a relatively large diameter glass tube. It was determined that the concentration of odour estimated by the triangle odour bag method was usually higher than that detected using the dynamic olfactometry in the forced choice mode.

The 2009 Irish study aimed at evaluating the potential of construction and demolition waste to reduce odour emissions from the surface of a landfill, the effectiveness of landfill cover made from commercial industrial waste, and the suitability of wood chip as an alternative landfill cover. An odour concentration analysis was carried out in order to determine if there were any residual unpleasant odours emitted from different types of landfill cover. The study results showed that the 200 mm deep combination layer of construction and demolition materials mixed with wood chip is effective at reducing odours (Solan *et al.* 2010).

A study in the Northern London used dispersion modelling for assessment of possible intensity of odours emanating from municipal waste landfills. It was determined that the highest odour concentration – around 25.0 OU_e/m^3 – was emitted towards the south-west of the landfill. The highest odour concentration around the landfill for 1 hour was on average 3 OU_e/m^3 about 1 kilometre north and 500 m west of the landfill site. For the 3 minutes timing, the stretch of 5 OU_e/m^3 flow would cover up to 2.5 km towards the north of the landfill site (Sarkar *et al*. 2003).

The Ukrainian study has detected high concentrations of ammonium (up to 1.19 mg/m^3) above the landfill, i.e. in the air above the waste storage territory (Korbut, Mal'ovaniy 2013). In the landfill site investigated, the waste was smouldering and sites of deliberate burning were observed. The analysis showed that above the smouldering site toxic compounds, such as methane, carbon monoxide, ammonium, phenantrene, and anthracene were detectable.

Lucernoni *et al.* (2016) analysed the concentration of landfill gas odours emanating from the surface of the landfill based on the correlation between the methane concentration and odour concentration. The concentration of odour at the landfill was 105,000 OU_e/m^3, the specific odour emission rate (SOER) stood at 0.011 OU_e/m^2s (Lucernoni *et al.* 2016).

Having analysed the existing studies on odour emissions in landfills carried out by foreign researchers and taking into account the methodologies described in scientific articles, it was decided to investigate landfill odour emissions in relation to the age of waste and meteorological parameters. The dynamic olfactometry method was chosen for the analysis of odour concentration; gas chromatography was used to analyse the concentration of VOCs in selected air samples. The Kazokiškės landfill – the largest landfill of municipal non-hazardous waste in Lithuania – was chosen as the object of the research. Research purpose of this paper is to analyse the qualitative and quantitative composition of odours emitted from the Kazokiškės landfill of municipal non-hazardous waste and to identify the relationship between odour emissions, the age of waste and meteorological conditions.

According to the data of the Vilnius Department of the National Public Health Centre under the Ministry of Health of the Republic of Lithuania, in 2014–2015 no residents' complaints regarding annoying odours from the Kazokiškės landfill were received; in 2016, one complaint was received regarding the odours emanating from this landfill.

Characteristics of sampling area

The Kazokiškės landfill is situated in the southern part of Lithuania, at the Elektrėnai municipality, 3.5 km north from the Vievis town, 1.7 km east from Zelsva lake, and 1.6 km south from Cielgio stream. The landfill is located in the area of the previous gravel and sand quarry. 4 km north east from the landfill runs the river Neris, 9 km north from the landfill lies the Kernavė town. The closest residential homes are situated 500 m south west from the landfill. According to the data of Vilnius County Waste Management Centre, the landfill currently holds around 8.98 million tonnes of waste (in the first section – 1.34 million tonnes, in the second section – 7.64 million tonnes).

The total provisional landfill site area is 30.16 ha; out of it, 27 ha is for the waste heap consisting from 6 sections. Currently, sections 1a and 1b are fully filled, the second section is currently being filled. The overall filled area amounts to 14.8 ha. Figure 1 (taken from the Permit for Control of Integrated Pollution Prevention 2014, modified by the authors) shows the scheme of the landfill under investigation with the layout of the sections and air sampling sites (TIPK 2014).

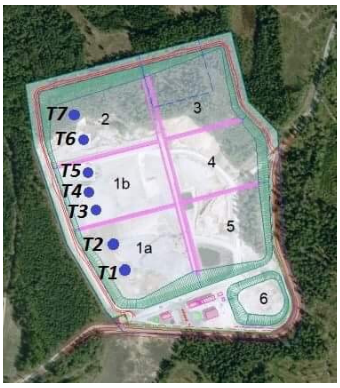

Fig. 1. Section of the Kazokiškės landfill: 1a, 1b – filled sections; 2 – almost filled section; 3–6 – future sections (yet to be set up); T1–T2 – air sampling sites

In 2012–2013, the company exploiting the landfill carried out exhaustive research on the composition of waste entering the landfill on a quarterly basis (VAATC 2015).

Table 1 provides the coordinates of odour sampling sites at LKS94 format and indicates preliminary age of waste.

Table 1. Coordinates of odour sampling points and preliminary age of waste

No.	X	Y	Section No.	Preliminary waste age, years
T1	552700	6074692	1a	7–9
T2	552661	6074790	1a	7–9
T3	552621	6074877	1b	4–6
T4	552591	6074946	1b	4–6
T5	552559	6074949	1b	4–6
T6	552531	6075024	2	0–3
T7	552508	6075064	2	0–3

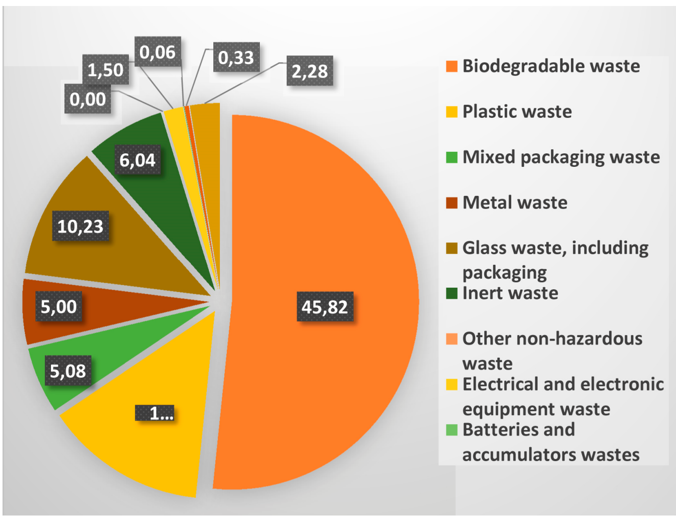

Fig. 2. Composition of municipal waste at the Kazokiškės landfill in 2012 and 2013, per cent

Figure 2 represents the average composition of waste disposed of in the landfill in 2012–2013 showing that biodegradable waste accounted for the largest share of the waste disposed of.

Research methodology

The article presents the investigation of odour emissions at the Kazokiškės landfill using the dynamic olfactometry method. Figure 3 shows the fundamental scheme of odour sampling, transportation and research.

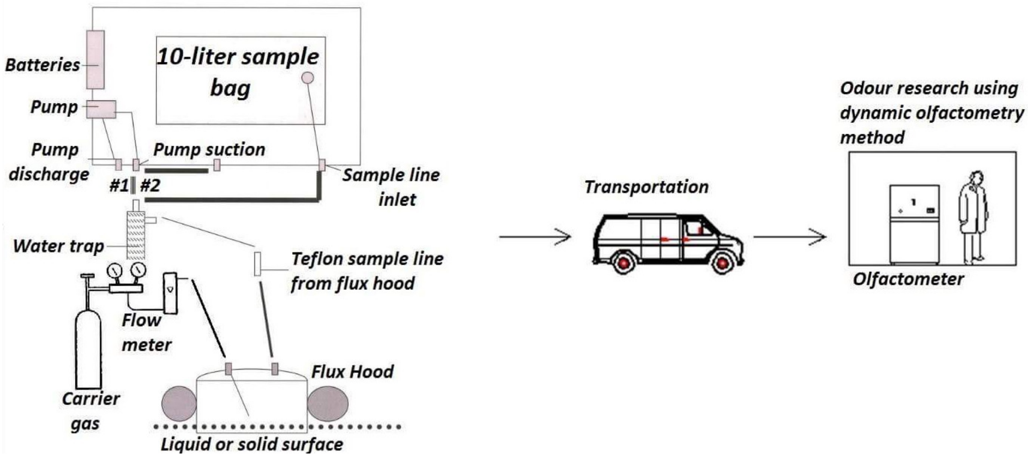

Fig. 3. Odour sampling, transportation and research: the fundamental scheme

The odour assessment investigation using dynamic olfactometry was carried out in the odour research laboratory of Vilnius Gediminas Technical University. Samples for delayed dynamic olfactometry were taken from the odour source and transported to the laboratory for analysis. Air (odour) samples were taken from the surface of the landfill using the 0.113 m^2 odour sampling hood. This hood is designed to collect air (odour) samples from passive, flat hard or liquid odour sources. During odour sampling, odourless synthetic air is released under the hood. The sample from the air (odour) under the hood is then placed to Nalophan NA (PET) sampling bags stored in the AC'SCENT vacuum chamber. The samples were analysed at the same day, i.e. as soon as possible after collection. The time between the odour sampling and analysis was less than 30 hours (according to LST EN13725+AC).

Odour sampling analysis was carried out using a forced choice method according to the European Standard *Air Quality. Determination of Odour Concentration by Dynamic Olfactometry* (LST EN13725+AC). According to this method, the members of assessors' panel indicate the site of odourous stimulus and state if this site was indicated by guessing, suspecting, or with certainty.

Dilution levels of the olfactometer and the methodology for calculating odour concentration

The current study used the AC'SCENT olfactometer with 14 dilution levels (dilution from 54,054 to 7.8 times); the odour samples with odourless air were diluted at certain ratios and submitted for assessors who smell it. The assessors' panel consisting of five members carried out three cycle measurements. Data obtained during the first (preparatory) measurement cycle are always rejected, data from two subsequent cycles are taken into account when calculating odour concentration (in OU_e/m^3). Having determined the geometric means from olfactometer dilutions of all (14) channels, geometric means of assessors' individual threshold estimates are calculated. The first retrospective check is carried out on the basis of the ratio between the individual threshold estimate Z_{ITE} and the geometric mean $\overline{Z}_{ITE}$ of all individual threshold estimates:

If $Z_{ITE} \geq \overline{Z}_{ITE}$, then the calculation formula to be used is the following:

$$\Delta Z = \frac{Z_{ITE}}{\overline{Z}_{ITE}}. \quad (1)$$

If $Z_{ITE} < \overline{Z}_{ITE}$, then the calculation formula to be used is the following:

$$\Delta Z = -\frac{Z_{ITE}}{\overline{Z}_{ITE}}. \quad (2)$$

If it turns out that ΔZ of one of the assessors exceeds the limits of the $-5 \leq \Delta Z \leq 5$ criteria, the result of the assessor with the largest ΔZ value is rejected. The second retrospective check is carried out; the subsequent ΔZ check has to take into account the values within the minus 5 to plus 5 range. Thus, unreliable results are rejected.

The odour concentration C_{od} of the sample investigated is calculated using the following formula:

$$C_{od} = \overline{Z}_{ITE,pan} \cdot 1 OUE / m^3 \quad (3)$$

Passive odour sources are estimated based on the specific odour emission rate (SOER) measured in $OU_e/m^2/s$. It is calculated using the following formula:

$$SOER = Q_{air} \cdot \frac{C_{od.}}{A_{base}}, \quad (4)$$

where Q_{air} – flow rate of synthetic (odourless) air into the hood, 0.00005 m^3/s, C_{od} – odour concentration, OU_e/m^3, A_{base} – surface area of odour sampling, m^2.

In addition, passive odour sources are estimated based on the odour emission rate (OER), OU/s. It is calculated using the following formula:

$$OER = SOER \cdot A_{em}, \quad (5)$$

where *SOER*– specific odour emission rate, OU_e/m^2s, A_{em} – surface area of odour source (landfill), m^2.

The investigation of odour concentration using the dynamic olfactometry method was carried out three times: on 28 September 2016 (the first study), 16 December 2016 (the second study), and 22 December 2016 (the third study). Meteorological conditions at the sampling time are given in Table 2. The concentration values determined are provided in Table 3.

Table 2. Meteorological conditions at the time of odour sampling

Study No.	Ave. environmental temperature (°C)	Ave. wind speed (m/s)	Relative air humidity (%)	Atmospheric pressure at sea level (hPa)
1st study	11.1	2.6	77%	1022
2nd study	0.4	3.8	89%	1031
3rd study	–1	2.6	85%	1029
4rd study	–10	3,8	45%	1042

Table 3. Odour concentration flow at the Kazokiškės landfill, OU_e/m^2s

Study No.	Odour sampling points						
	T1	T2	T3	T4	T5	T6	T7
1st study	0.02	0.02	0.03	0.03	0.07	0.11	0.11
2nd study	0.05	0.07	0.27	0.11	0.45	0.45	1.08
3rd study	0.07	0.11	0.27	0.23	1.29	0.45	1.29
4rd study	0,11	0,11	0,32	0,27	1,08	0,64	1,29

Experimental research using the dynamic olfactometry method showed that as temperature decreases, the concentration of odour emissions increases. The coefficient of correlation between temperature and odour concentration stood at minus 0.91, showing inverse proportion between the two values.

The calculation of correlation coefficient showed a weak link minus 0.42 between humidity and odour emission concentration. Similar link (0.81) has been observed between the atmospheric pressure and odour emission concentration. Results are shown in Figure 4.

The relationship between the age of waste in the Kazokiškės landfill and odour concentration at different sections of the landfill was studied. Figure 5 shows that as the age of waste increases, the concentration of odours decreases. The waste in section 1a are up to 9 years old, in section 1b – up to 6 years old; the 2nd section is currently nearly full, its waste is 3 to 0 years old.

The T6 site was analysed not only by the dynamic olfactometry method but also using the gas chromatography method. Table 4 presents results on VOCs in air samples detected using the gas chromatography method. The application of the gas chromatography method for investigation of odourous substances is limited as often the concentration of substances in the air is below the threshold required for this method (HS 35:2007).

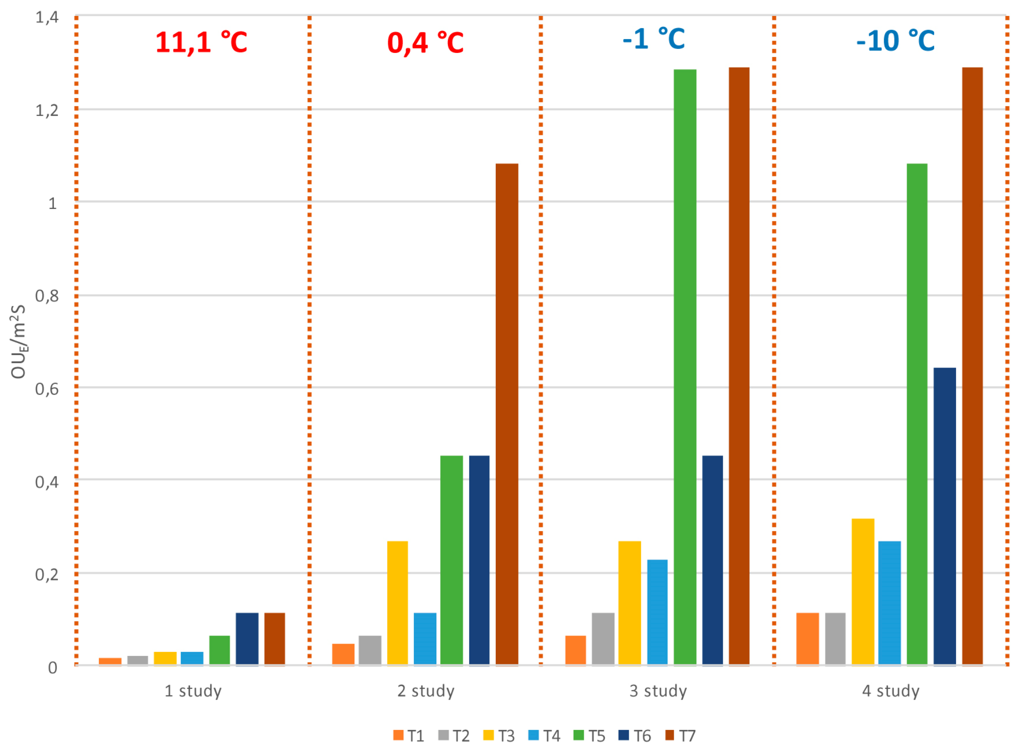

Fig. 4. The relationship between temperature and odour concentration

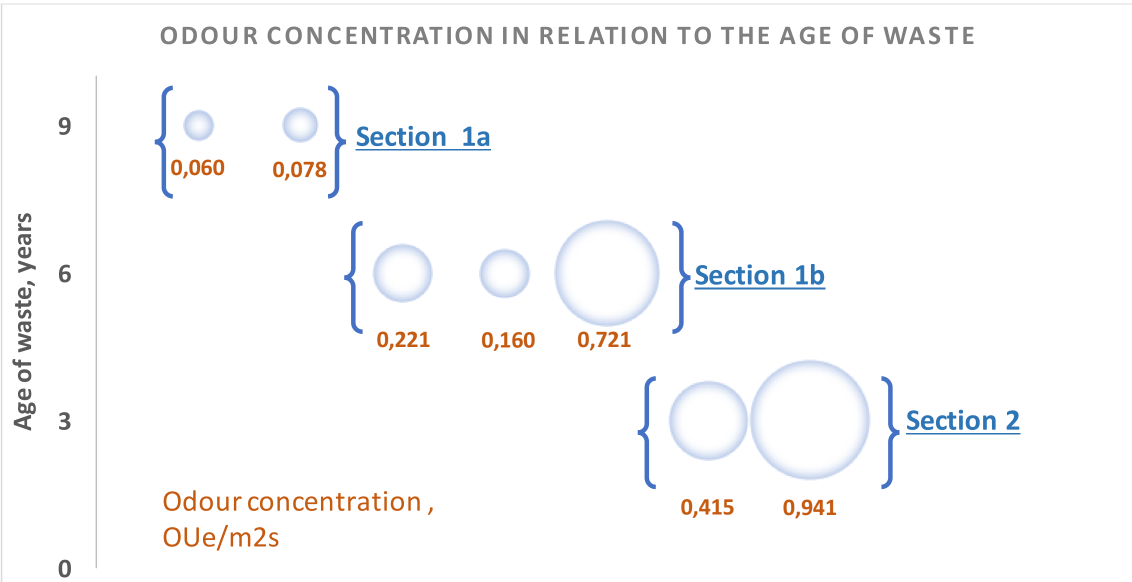

Fig. 5. Odour concentration in relation to the age of waste

Table 4. Odour characteristics, odour threshold, and concentration of VOCs investigated at samples from the T6 odour sampling site, mg/m3 (HS 35:2007)

VOCs	Odour characteristics	Odour threshold, mg/m^3	1st study, mg/m^3	2nd study, mg/m^3	3rd study, mg/m^3	Maximum concentration, mg/m^3
Acetone	slightly sweet, solvent-like	13.9	0.808	0.188	0.55	0.35
Benzene	solvent-like	32.5	<0.188	0.006	0.007	1.5
Butyl acetate	–	0.047	<0.184	<0.005	0.009	0.1
Ethanol	Sweet	0.28	<0.221	0.35	0.049	1.4

End of Table 4

VOCs	Odour characteristics	Odour threshold, mg/m^3	1st study, mg/m^3	2nd study, mg/m^3	3rd study, mg/m^3	Maximum concentration, mg/m^3
Xylene (sum)	aromatic, sweet	0.078	<0.616	0.033	0.05	0.2
Isopropanol	–	1.185	<0.243	<0.005	0.009	0.6
Toluene	flowery, pungent, naphthalic, camphor-like	0.644	<0.241	0.037	0.067	0.6
Trichlorethylene	solvent-like	8.0	<0.270	0.011	<0.005	4
Styrene	Sharp, rubber-like, plastic-like	0.16	0.08	<0.005	0.013	0.04
2-butanone	Sweet	0.87	5.832	0.237	0.509	0.1
n-butanol	–	0.09	<0.206	0.009	0.009	0.1
Ethylbenzene	petrol-like	–	<0.207	0.008	0.022	0.02
2-butoxyethanol	–	0.0051	<0.247	0.018	<0.005	0.03

< – less than the threshold value of the method.

The analysis of the results of gas chromatography involves the assessment of odour threshold of VOCs and odour characteristics. It turned out that in the first study only styrene and 2-butanol concentrations were higher than the odour threshold, in the second study – 2-butoxyethanol. The maximum permitted concentration of chemical substances (pollutants) in the air of living environment was exceeded by acetone, styrene, 2-butanone and ethylbenzene. According to the literature sources used, the main odorous chemical compounds emitted from landfills are aliphatic (fatty) acids, amines, ammonium, aromatic compounds, sulfur compounds (organic and inorganic). The analysis of gas chromatography results shows that there is a linear relationship between acetone and 2-butanone as their correlation coefficient is minus 0.84. Since this has been determined based solely on the three studies carried out in this research, one can only assume that there might be a linear relationship between acetone and 2-butanone.

Conclusions

1. The highest odour concentration flow identified in the landfill sites studied was 1.29 OU_e/m^2s, the lowest – 0.02 OU_e/m^2s. It was observed that as the age of waste increases, odour concentration decreases.
2. It was determined that as temperature decreases (within the range of 11.1 to minus 10 ^oC), the concentration of odour emissions increases. The correlation coefficient between the temperature and odour concentration stood at minus 0.91, showing a strong inversely proportionate relationship between the said values.
3. Detection of low concentrations of VOCs in odour samples analysed leads to the assumption that landfill odours are mostly caused by other chemical substances: aliphatic (fatty) acids, amines, ammonium, aromatic compounds, sulfur compounds (inorganic and organic).

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