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Assessment of Odour Impact Range of Selected Waste Management Plant with the Use of Mathematical Tools (Model Tools)

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ABSTRACT

One of the many factors that can significantly affect the quality of human life in cities is odour pollution. The progressing industrialization mean that objects that can contribute to odour emission can be found in the immediate neighbourhood of the residential areas. The close proximity of such objects may contribute to odour nuisance. The scope of this work was to determine the extent of the odour impact associated with the functioning of the technological composting process for biodegradable waste at the Utilization Plant. In the study, biofilter and compost ripening area were considered as main odour emissions sources. The odour dispersion modelling from selected odour sources was performed with the use of Operat Fb software, the calculation scheme of which is consisted in the guidelines from the Regulation of the Minister of the Environment of 26 January 2010. The odour dispersion modelling was performed for two different scenarios. The first, representing the current state of the considered waste utilization plant and the second one represents the improvement option by applying encapsulation of the ripping area and the use of a biofilter with 98% efficiency. The calculations carried out showed a reduction of the odour concentration value in the second variant compared to the first variant. The odour emission from the waste utilization plant amounted to 2,027,100 ou_E/s in the first scenario while in the second variant – 52,569 ou_E/s. The highest obtained values of maximum annual average concentrations were 9,247 ou_E/m^3 for the first scenario and 874 ou_E/m^3 for the second scenario, respectively. The highest average concentration reacged 1,405 ou_E/m^3 for the first scenario and 181 ou_E/m^3 for the second scenario. The highest exceedance frequencies of are 100% for the first scenario and 99.7 for the second scenario. The reduction ratio for emission is 0.97%, for the maximum odour concentrations is 0.91% , the average annual odour concentrations is 0.87% and the frequency of exceeding the maximum odour concentrations is 0.003%. The application of the mathematical model allowed for the assessment of the reduction of the odour impact of the examined object and the validity of the applied method of reducing odour emissions.

Keywords: odour impact, modelling,

INTRODUCTION

The composting processes are considered as one of the most ecological methods of waste utilization. However, it they contribute to the deterioration of the environment by emitting unpleasant odours [Sówka et al. 2017, Kwarciak-Kozłowska and Bańska 2014, Byliński et al. 2019]. Composting is the aerobic degradation of organic matter that is transformed into a stable form through the process. The final products of composting processes are rich in mineral compounds, free of pathogenic microorganisms and can be used, for example, as an organic fertilizer [Kwarciak-Kozłowska and Bańska 2014]. The biological decomposition of organic matter occurs under controlled conditions with the use of microorganisms, which by taking oxygen, decompose organic matter with the release of carbon dioxide, water and heat. The heat is used to sanitize the composted material [Grag and Tothill 2009, Farrell and Jones 2009]. It is a multi-stage process including such activities as supplying raw material, its pretreatment, proper composting process, maturing process and storage. The emission of odours to the atmospheric air can take place at each of these stages. Maturation and proper composting phase are characterized by the greatest nuisance in terms of odour emission [Sówka et al.2017]. The composting process itself consists of 4 stages, depending on the temperature and the degree of acidification of the material being processed. Each of these stages may differ in the amount of odour emissions. Odour can be emitted from material used in composting process. Odour pollutants may also appear as a result of the metabolic processes of the microorganisms used in the process [Kwarciak-Kozłowska and Bańska 2014]. The main causes of odour emission in composting processes include insufficient aeration and excessive humidity, which may cause anaerobic conditions in the composting material [Sówka et al. 2017, Kwarciak-Kozłowska and Bańska 2014]. In addition, the emissions of odours also depend on the type of waste processed and on the technological aspects. In order to reduce the odour emission, the process should be carried out in closed reactors. They allow for easier control of the emitted pollutants. Running the process in an open area increases the odour emissions.

When managing odours from different sources, it is necessary to properly assess their environmental impact. It is a known fact that the odorous pollution can affect human life and decrease its quality [Capelli et al. 2013]. There are plenty of tools used in the evaluation of the odours emitted from different sources. Among them, we can distinguish the tools for mathematical modelling of dispersion of odorous pollution. These tools allow predicting how odours can spread from their sources [Pawnuk and Sówka 2019].

The main purpose of the work was to assess the extent of the odour impact associated with the composting process in a selected waste utilization plant, using model tools to predict the spread of odour pollution for the two assumed scenarios: the first representing the current state and the second, representing the improvement option by applying encapsulation of the ripping area and a biofilter.

SITE CHARACTERISTICS

The tested facility was a waste utilization plant. The plant area is about 72 hectares. Waste is collected from around 0.5 million people. The waste utilization plant serves 5 municipalities. The main purpose of the plant under study is a municipal waste management. The main technological elements in the plant are: a waste sorting plant, a waste composting system with biofilters, a landfill, a bioelectric plant and a sewage utilization plant. In addition, the plant also collects hazardous waste.

The considered plant is located in the suburbs of one of the major Polish cities. From the north, the plant borders with single service and commercial facilities. Near the eastern border of the plant, there is an express road, which is the main transport route. Additionally, a large service and commercial center is located about 170 meters from the eastern border of the facility. Further service

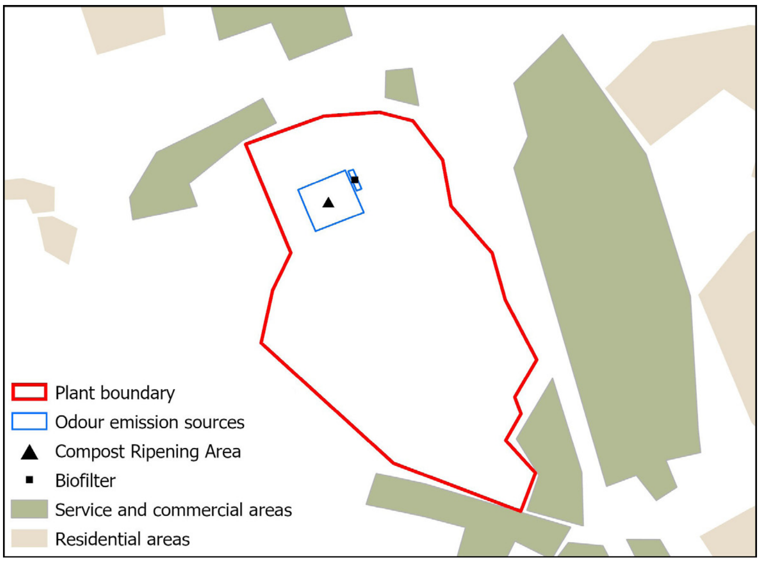

Fig. 1. The location of the plant under study

and commercial facilities are located south of the plant. The west side of the plant is surrounded by forest areas. The plant itself is surrounded by a greenery belt. The closest clusters of residential buildings are located about 750 meters east of the plant, 670 and 1,100 meters west, 860 meters south, 600 meters north-west. Figure 1 shows the location of the plant together with the nearest residential buildings and service, and commercial areas marked out.

In the municipal waste composting plant, there is a set of several objects including a closed composting building (in the tunnels an accelerated composting process is carried out through intensive aeration), a building designed for cleaning and deodorization of process air through the system of scrubbers, a compost ripening area and a biofilter for the purification of air.

The composting building consists of 14 compost tunnels, divided by concrete walls. Each tunnel is 48 meters in length and 5 meters in width and is equipped with a ventilation plate. The filling of tunnels is carried out by successive supply of waste at the entrance to tunnels. Loading organic waste intended for composting takes place using loading conveyors. After 12 tunnels (2 reserve and emergency tunnels), there is a phase of intensive composting lasting a minimum of 21 days. Following this period, the product is exported to the compost ripening area (open space), where it undergoes a maturing process lasting 8 ÷ 10 weeks.

On the ripening square, the compost is laid in piles which are 5 m wide and 2.4 m high. The area of the square is approximately 20,000 m^2. The exhaust air from the halls where the waste utilization process takes place is subjected to a deodorization process using three water scrubbers and a biofilter.

Two surface emitters were distinguished on the site: biofilter and prisms on the compost ripening area. Compost ripping area consists of 20 prisms located on the compost ripening area: 14 prisms created from the organic fraction sorted out from mixed municipal waste and 6 prisms created from wet waste.

RESEARCH METHODS

In order to determine the odour impact range of a selected waste utilization plant, two emission sources associated with the waste composting process have been identified at the first stage of research. The first of these included 6 biofilters that are used for air purification from the closed waste composting buildings. The second was the compost maturing area, where composting piles were stacked from two different materials – wet waste and the organic fraction sorted from mixed municipal waste. Both sources were classified as area sources.

The odour emissions based on determination of odour concentrations have been estimated using odour emission factor Fqod, $ou_E/(s*m^2)$ [Zespół Pracowni Zapachowej Jakości Powietrza, 2014]

In order to determine the odour impact of the tested object, the obtained concentration and emission results were used to perform mathematical modelling of simulating the odour dispersion. The Operat Fb software was used to forecast the spread of pollutants from the analysed sources, in accordance with the Polish reference model contained in the guidelines in the Regulation of the Minister of the Environment of 26 January 2010 on the reference value for some substances in the air [Regulation of the Minister of Environment 2010]. The basic equation (1) that is used to determine the odour concentration in receptor points is based on a Pasquill formula.

$$S_{xyz} = \frac{E_g}{2\pi\bar{u}\sigma_y\sigma_z} * \exp\left(-\frac{y^2}{2\sigma_y^2}\right) * \\ * \left\{exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right]\right\} * 1000 \quad (1)$$

where: S_{xyz} – concentration of the substance/odour in the air averaged over 1 hour (µg/m3; ouE/ m3),
E_g – maximum emission of gaseous substance (mg/s; ou_E/s),
σ_y – horizontal atmospheric diffusion coefficient (m),
σ_y – vertical atmospheric diffusion coefficient (m),
$\bar{u}$ – 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).

For the purpose of calculations, the permissible frequency of exceeding odour concentration equal to 1 ou_E / m^3 was set at 3%. [Polish Ministry of Environment, 2009]

The odour dispersion modelling was performed for two different scenarios. In the first scenario (scenario 1), the current state of the plant was taken into account in odour dispersion modelling. The second scenario (scenario 2) assumes the reduction of odour emissions by including all processes related with composting of waste. The gases from the hermetic ripping area will be directed to a biofilter that works with 98% efficiency.

RESULTS AND DISCUSSION

Scenario 1

The parameters of the considered emitters (biofilter and the compost ripping area) are presented in table 1.

The results of odour dispersion modelling, including the results of the maximum odour concentration, frequency of exceedance and average annual odour concentration calculations, for the scenario 1 are shown in Figures 2–4. In order to examine the potential impact on residential areas, location of nearest buildings (A1-A7 on the figures below) was included in odour dispersion modelling.

The analysis of the results pertaining to maximum odour concentrations distribution (Figure 2) showed that the highest value in this case occurs inside the plant boundary in the compost ripening area (X = 1700, Y = 1800) and equals to 9,247 ou_E/m^3. The values of odour concentration outside the plant reach high values, especially in the case of service and commercial areas and residential buildings (from below 500 to around ca. 100 ou_E/m^3). For the points representing the nearest residential building, the highest and the lowest values were obtained at point A3 (213 ou_E/m^3) and A7 (93 ou_E/m^3), respectively.

Figure 3 shows the frequency of exceeding the maximum odour concentration. The highest frequency of exceedance was found inside the border of the plant (X = 1650, Y = 1700). At this point, the value reached 100%. In the case of residential buildings, the exceedance frequencies of the permissible level were obtained at each considered points. The highest value was found at point A4 (22.42%), while the lowest at point A2 (6.71%).

The highest value of average annual odour concentration (Fig. 4), as in the previous case, was reported inside the plant boundary (X = 1700, Y = 1800) and is equal to 1,405 ou_E/m^3. In the case of residential buildings, highest value was found at point A4 and is equal to 5.16 ou_E/m^3.

Scenario 2

As an opportunity to reduce the plant's odour impact on the environment, application of all processes related to waste delivered to the plant was proposed. It was assumed that an important role in this scenario is played by the biofilter, which purifies the air from the composting building. Table 2 presents the emitter characteristics assumed in scenario no. 2.

The distribution of maximum odour concentration obtained from modelling in the second scenario is presented in Figure 5. The highest value in the case of scenario 2 was found inside the plant boundary (X = 1750, Y = 1900) and equals to 874 ou_E/m^3, which is significantly lower in comparison to the first scenario (almost 11 times lower). In general, when analyzing the odour concentration distribution in the scenario 2, the odour concentrations outside the plant boundaries were also significantly lower (from ca. 30 ou_E/m^3 to below 5 ou_E/m^3). For additional receptor points (residential buildings), the odour concentration obtained values were also lower. In this case, the

Table 1. Emitter characteristics (scenario 1)

The name of the emitter	Quantity	Total area, m^2	Odour emission factor Fqod, $ou_E/(s*m^2)$	Emission ou_E/s	Flow rate V m^3/s
Biofilter	1	900	25	22,500	0.016
A prism from the organic fraction	14	9,100	99	900,900	0.00568
A prism from the wet waste	6	3,900	283	1,103,700	0.00446
Total		13,900	–	2,027,100	–

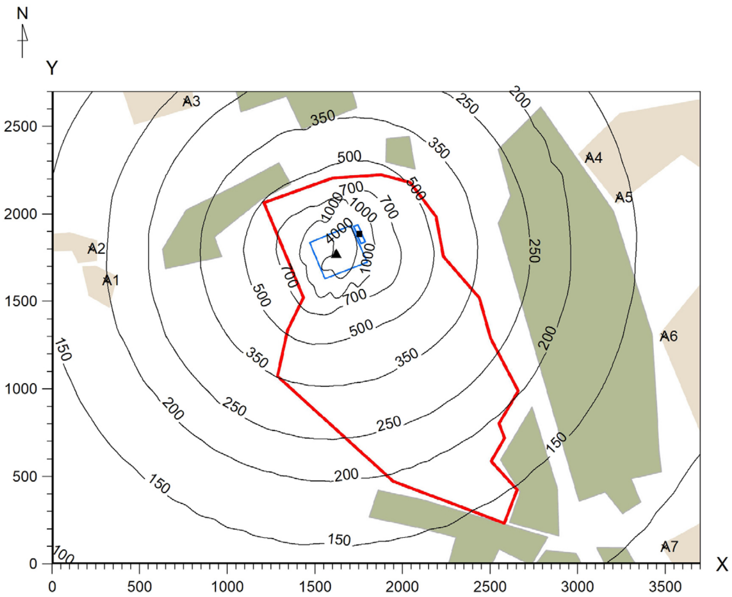

Fig. 2. The maximum odour concentrations obtained for scenario 1, ou_E/m^3.

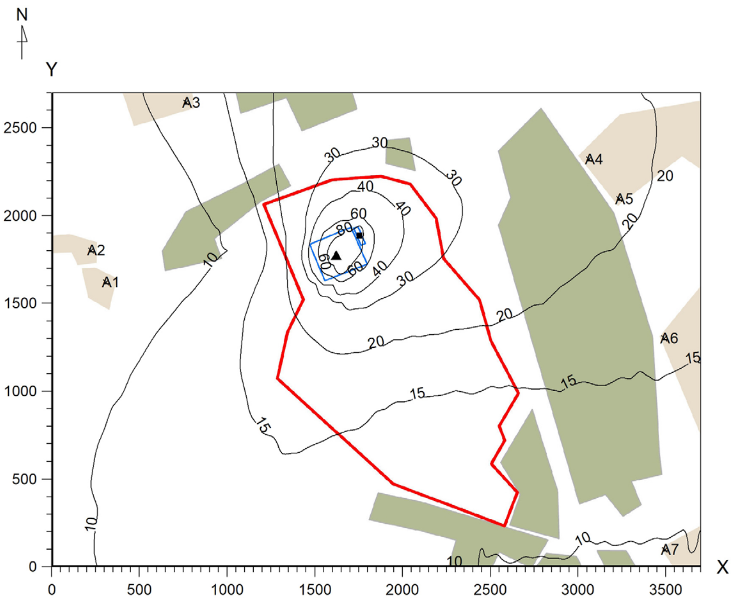

Fig. 3. The frequency of exceeding the maximum odour concentrations obtained for scenario 1 (exceedance of threshold of 3%), %.

highest maximum odour concentration was found at point A3 and is equal to 6.314 ou_E/m^3.

The calculations results pertaining to the frequency of exceeding the maximum odour concentration for scenario 2 are shown in Figure 6. The highest frequency of exceedance was found inside the plant boundary (X =1750, Y = 1900) and is equal to 99.70 %, while the permissible threshold level is 3%. In the case of residential buildings, the frequency of exceedance has not been noticed. The highest value obtained was found at point A4 and is equal to 2.61%.

The distribution of average annual odour concentration values is shown in Figure 7. The highest value of average annual odour concentration was reported inside the plant boundary (X = 1750, Y = 1900) and is equal to 181 ou_E/m^3 (almost 8 times lower than in the case of current state). In the case of residential buildings, highest value was found at point A4 and is equal to 0.14 ou_E/m^3.

The calculations carried out showed a reduction of the odour concentration values in the second variant (scenario 2) compared to the current state (scenario 1). The comparison of results

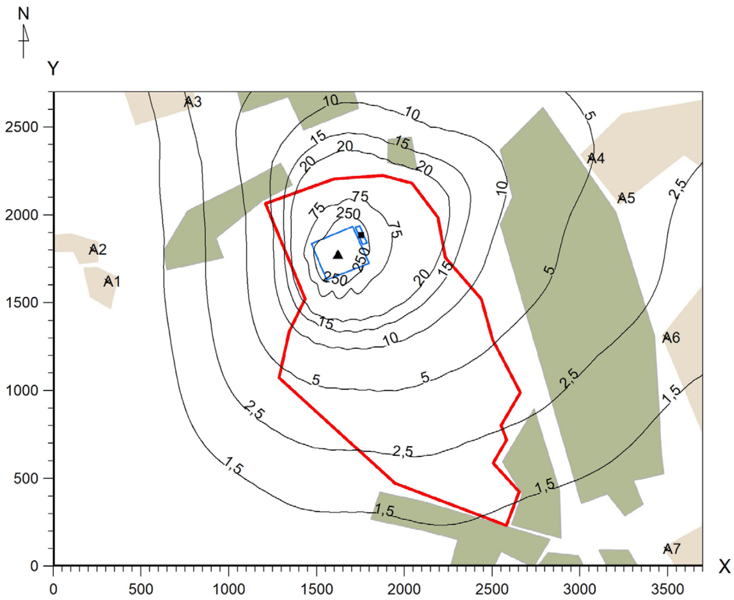

Fig. 4. The average annual odour concentrations obtained for scenario 1, ou_E/m^3.

Table 2. Emitter characteristics (scenario 2)

The name of the emitter	Quantity	Total area, m^2	Odour emission factor Fqod, $ou_E/(s*m^2)$	Emission ou_E/s	Flow rate V m^3/s
Biofilter	1	900	25	52,569	0.016

obtained for both scenarios is presented in table 3. The highest values of maximum annual average concentrations are 9,247 ou_E/m^3 for the first scenario and 874 ou_E/m^3 for the second scenario, respectively. The highest average concentrations are 1,405 ou_E/m^3 for the first scenario and 181 ou_E/m^3 for the second scenario. The highest values of the frequency of exceedances are 100% for the first scenario and 99.7 for the second scenario.

The reduction ratio for emission is 0.97%, for the maximum odour concentrations is 0.91%, the average annual odour concentrations is 0.87%. The frequency of exceeding the maximum odour concentrations is 0.003%.

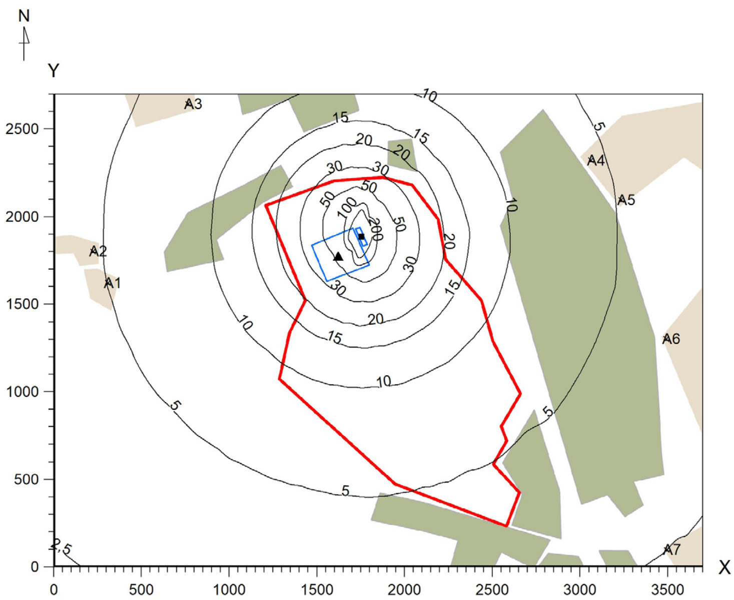

Fig. 5. The maximum odour concentrations obtained for scenario 2, ou_E/m^3.

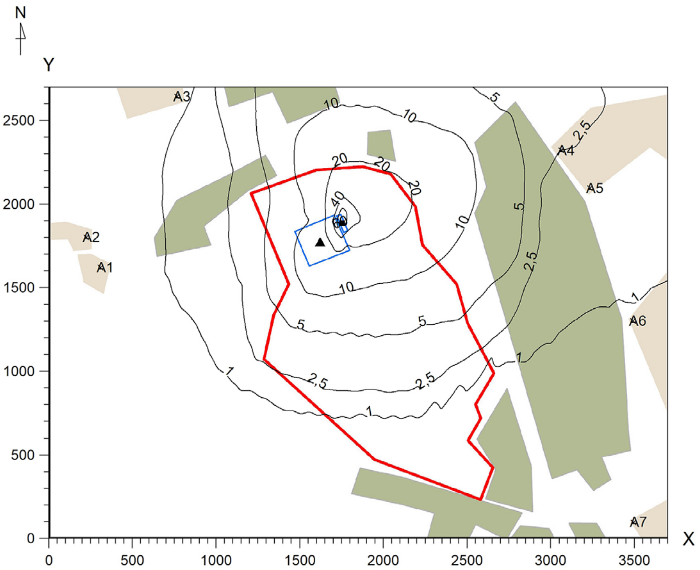

Fig. 6. The frequency of exceeding the maximum odour concentrations obtained for scenario 2 (exceedance of threshold of 3%), %.

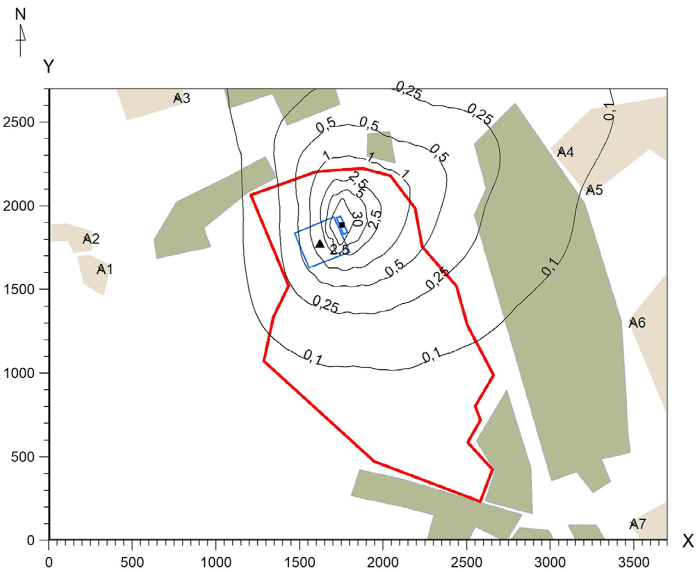

Fig. 7. The average annual odour concentrations obtained for scenario 2, ou_E/m^3.

The comparison of the results of calculating odour concentrations at additional receptor points is presented in Table 4. The highest values of maximum annual average concentrations were noticed at A3 and are 213 ou_E/m^3 for the first scenario and 6.3 ou_E/m^3 for the second scenario, respectively. The highest average concentration values occur at point A4 and amounts to 5.16 ou_E/m^3 for the first scenario and 0.15 ou_E/m^3 for the second scenario. The highest value of the frequency of exceedances occurs at point A4 and is 22.42% for the first scenario and 2.61% for the second scenario.

CONCLUSIONS

Mathematical modeling is one of the most economical methods to assess the odour range and impact of waste utilization plants. The application of this type of tools can be particularly useful in situations where it is important to assess the effectiveness of the selected method to reduce odour emissions and thereby mitigate the odour impact of the selected installation or facility emitting odours. However, it should be emphasized that good quality of input data is necessary for reliable assessment of the odour range with the use

Table 3. Comparison of results obtained for the scenario 1 and scenario 2

Parameter	Scenario 1	Scenario 2	Reduction ratio [%]
Emission [ou_E/s]	2027100	52569	0.97
Max. odour Conc. [ou_E/m^3]	9247	874	0.91
Annual Avg. Conc. [ou_E/m^3]	1405	181	0.87
Freq. of. exc. [%]	100	99.7	0.003

Table 4. The results of calculations of odour concentrations for points representing the nearest buildings

Name of point	Scenario 1			Scenario 2		
	Max. odour Conc. [ou_E/m^3]	Annual Avg. Conc. [ou_E/m^3]	Freq. of. exc. [%]	Max. odour Conc. [ou_E/m^3]	Annual Avg. Conc. [ou_E/m^3]	Freq. of. exc. [%]
A-1	197	0.93	7.28	4.98	0.02	0.18
A-2	185	0.82	6.71	4.84	0.02	0.17
A-3	213	2.56	11.88	6.31	0.04	0.50
A-4	172	5.16	22.42	5.44	0.15	2.61
A-5	157	3.61	21.60	4.91	0.09	1.59
A-6	129	2.05	16.27	3.71	0.05	0.80
A-7	93	0.94	10.00	2.57	0.02	0.40

of model tools, including the value of emissions and meteorological parameters, the variability of which in time combined with complex topography may cause underestimation or overestimation of concentration values at receptor points.

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