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Determination of odour emission rates emitted by active area sources and dispersion of odour concentration in the surrounding air

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Abstract

In this study, the area of a biofilter representing an active area source was sampled by taking 12 odour samples from the gaseous effluent and measuring the physical parameters of the source, so that we can obtain the odour emission rate (OER) specific to the source.

The odour sampling process is a crucial step in the assessment and monitoring of odour pollution.

Direct measurement of odour concentration in the ambient air is often not sufficient to determine whether an activity is responsible for producing olfactory discomfort to the receptors.

To observe the contribution of the source to olfactory pollution and air quality by estimating the odour concentration in the ambient air, the odour emission rate (OER) was taken into account, which is expressed in odour units per second (ou_E/s) and is obtained as the product of the odour concentration and the airflow rate associated with the source. The odour emission rate was entered into the dispersion program AERMOD for mathematical modelling. In order to estimate the odour concentration in the surrounding air in the adjacent areas to the sampled biofilter, 2 mathematical models were made to illustrate the odour concentration on the site and in its vicinity in the most unfavourable weather conditions „Highest values" and „98th Percentile" to illustrate the concentration in the surrounding air excluding the 2% unfavourable weather condition.

INTRODUCTION

While odorous compounds may not pose inherent toxicity or hazards to human health, their presence can adversely affect the psychophysical well-being and behaviour of individuals when exposed to them. In the past, odour emissions from industrial processes were commonly overlooked as an inherent aspect of the activity. However, over the last two decades, odours have emerged as a significant environmental concern, especially in connection with waste disposal or treatment facilities [1].

ISO 5492:2008 characterizes odour as an organoleptic attribute detectable by the olfactory organ, including its nerves, upon inhaling specific volatile substances. In simpler terms, odour can be described as the "perception of smell" or a sensory experience resulting from the stimulation of the olfactory sensory system. An odorant, on the other hand, refers to a substance that triggers the human olfactory system, leading to the perception of an odour. The complexity of odours arises from the interplay of various volatile chemical species, such as sulphur compounds (e.g., sulphides, mercaptans), nitrogen compounds (e.g., ammonia, amines), and volatile organic compounds (e.g., esters, acids, aldehydes, ketones, alcohols) [2].

Challenges associated with odour emissions frequently act as a constraining element in the establishment or expansion of composting and bio-stabilization plants. A valuable approach for assessing and predicting odour impact involves the use of odour emission factors (OER). These factors are constructed in a manner similar to emission factors for other pollutants or chemical compounds, establishing a correlation between the amount of a released pollutant into the atmosphere and the corresponding activity [1].

Odour characterization and measurement has become a particularly important concern in recent years as people become increasingly aware of the impact of these odours on air quality and public health. In recent decades, several techniques and methods have been developed and studied to address this problem [3].

This paper focuses on two essential aspects: determining the emission rate from active area sources and estimating the odour concentration in the ambient air through mathematical modelling using AERMOD View software and the steps are as follows:

- ➤ collection of gaseous samples at the chimney outlet of the hood to the atmosphere;
- ➤ olfactometric analysis of gaseous samples and determination of emission rates;
- ➤ estimation of odour concentration in the surrounding air by mathematical modelling of odour dispersion using the AERMOD View software platform [4].

A schematic overview of the steps used to determine the concentration of odour in ambient air for active area sources is illustrated in (Fig.1).
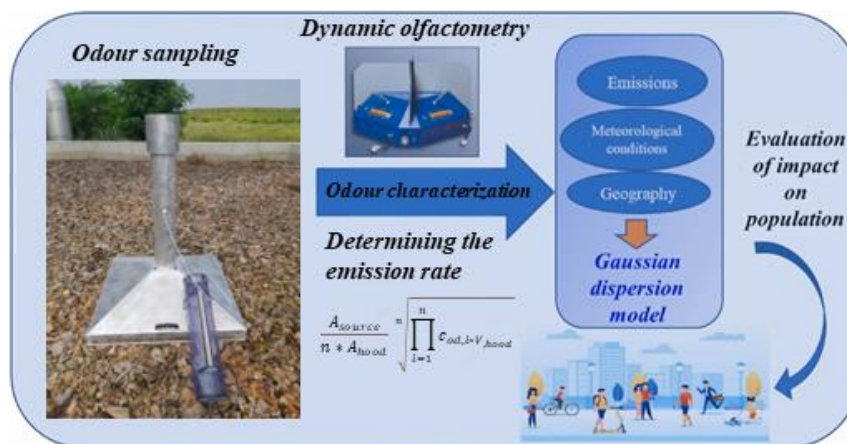

Fig. 1. Steps for determining the odour concentration in surrounding air [4]

Area sources play a crucial role in comprehensive air pollution models. The existing literature explores various methods for modelling the dispersion and determining the rate of emission from these types of sources. However, there is a lack of consensus on an approach that is both applicable to area sources of arbitrary types and efficiency [5].

The main purpose of this work is to apply currently available techniques to be able to accurately determine odour emission rates from active area sources (biofilters) and estimate odour concentration in ambient air by mathematical modelling using the rate of emissions as input data specific to the source. In this context, the paper proposes the implementation of the existing methods in the reference standard SR EN 13725:2022 for estimating the odour emission rate from active area sources, contributing significantly to the understanding and control of air quality, from the point of view of olfactory discomfort because it allows the measurement and direct assessment of odour impacts on the environment and public health.

These data can be used to develop new strategies to reduce odour emissions in order to improve air quality in regions affected by such sources that generate olfactory discomfort. This could have a significant impact on air quality management and environmental protection in the context of odour emissions from active area sources.

MATERIAL AND METHODS

Sampling method and analysis of odour concentration

Sampling of odour in this study was carried out in special nalophan bags, certified, using a vacuum sampling system type CSD-30 Olfasense with a capacity of 10 litter and a dedicated sampling hood with a covered surface of 1 m^2 (Fig. 2). This hood is pyramid shaped and merges into a cylindrical exhaust pipe. The length of the pipe being designed to be at least six times the inside diameter of the pipe [6]. To measure the physical parameters of the area source, the TESTO 480 analyser was used, which performs a variety of tasks and areas of measuring physical parameters and air quality, such as temperature, humidity, flow rate, carbon dioxide (CO_2) concentration [7].

During the sampling, it was considered that the velocity of the residual gases in the sampling plane of the hood chimney was higher than 0.008 m/s but not higher than 3 m/s in order to be determined using an appropriate measurement method, according to EN ISO 16911-1:2013 [8].

Sampling on area sources with outward flow can be carried out by using a static hood, which allows to isolate the sampling point from the external atmospheric conditions and to collect the emissions from a known surface portion in a sort of stack, which can be treated as a point source [3].

The method used to collect odour samples from the area of the biofilter, involved dividing its area into squares of equal size [3. Sampling began after the total volume of the hood had gone through five air changes at the sampling point [9].

The number of squares was chosen to cover at least 10% of the source's total area, and an odorant gas sample was taken from each square. The sampling strategy follows guidelines outlined in SR EN 13725:2022, which specifies different criteria based on the size of the sampled source, [9]:

- For sources with an active area of up to 100 m^2, the area is divided into sample cells of approximately 10 m2 each.
- For sources with an active area of more than 100 m^2 and up to 2000 m^2, the division involves 9 sample cells, with an additional cell added for every 100 m^2 of surface. All sample cells must be of similar size.
- For sources with an active area greater than 2000 m^2, a minimum of 30 sample cells is required, and it's crucial that all cells are of similar size.[9]

Recent research indicates that commonly used materials for odour sampling bags, including Nalophan™, Teflon™, or Tedlar™, exhibit significant diffusion coefficients, particularly concerning certain odorous substances [10].

The diffusion of specific molecules can be influenced by both intrinsic factors, like the thickness of the sampling bag, and extrinsic factors, such as the temperature and humidity during sample storage [11]. This phenomenon becomes crucial in sample preservation, particularly when dealing with emissions that contain substantial quantities of the hydrogen sulfide and ammonia, as seen in emissions from sources like biofilters, wastewater treatment plants, livestock, landfill, and foundries [12]. In such scenarios, it becomes essential to consider potential countermeasures, such as implementing specialized sampling approaches or materials, or reducing the storage duration [11].

In order to prevent condensation and adsorption of the samples, in this study, the samples were stored under controlled conditions of temperature and humidity for the entire duration of storage, in a climatic chamber and not exceeding 30 hours from the date of sampling until the analysis.

In Figure 2 is presented the equipment used to take odour samples and the volumetric flow measurement at a certain sampling point "i" used to determine the odour emission rate from the area of the biofilter was calculated by the equation 1, [9]:

$$V_i = (V_{duct,i} - A_{duct})/A_{hood} \tag{1}$$

where:

V_i is the outward flow velocity from the area source; $V_{duct,I}$ is the velocity measured in the outlet duct; A_{duct} is the area of the sampling plane in the outlet duct; A_{hood} is the area covered by the hood. In this study to determine source homogeneity, representative grid measurements of gas velocity and humidity were performed to distinguish between an active area source with homogeneous or inhomogeneous airflow [3].

Homogeneous flow implies that the minimum and maximum measured flow velocities are at most a factor of two and inhomogeneous flow is consistent with a source where the minimum and maximum measured flow are greater than a factor of two calculated by the equation 2, [9]:

$$R_O = C_a/C_m \qquad\qquad\qquad (2)$$

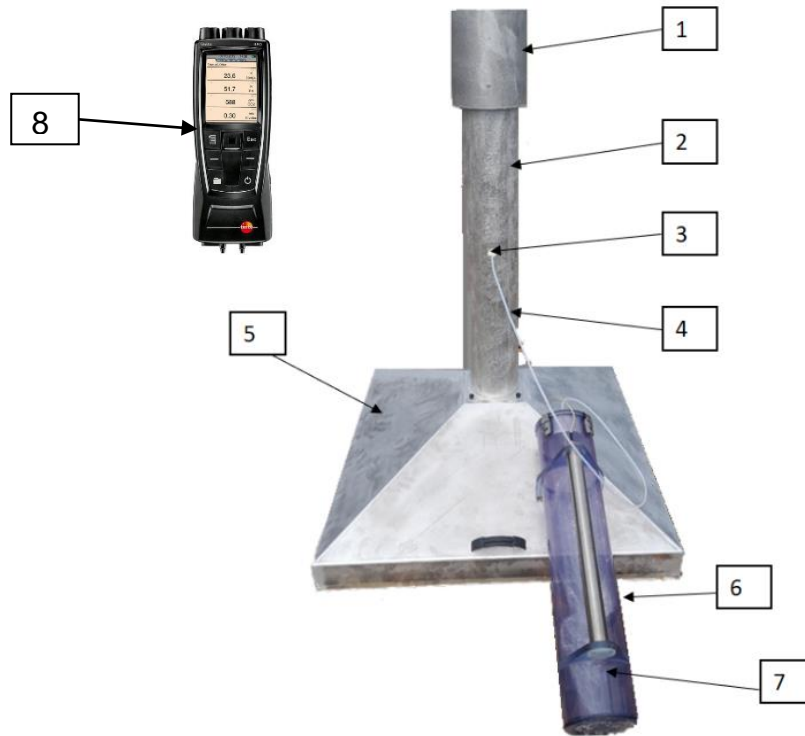where: R_O is homogeneity ratio; C_a is the concentration measured at a point, C_m is the average concentration.

Fig. 2. Equipment used for odour sampling from active area sources
where: (1) chimney collar, (2) outlet duct, (3) duct sampling/measurement orifice, (4) teflon tube, (5) surrounding apron, (6) depression pump, (7) recipient bag, (8) analyser testo 480.

If the ratio is equal to 2, then the indicator is twice higher or lower than the average, therefore the sampled source is an inhomogeneous one. And if the ratio is close to 1, then the indicator is almost equal to the average and therefore the sampled source it is a homogeneous one [9].
In order to ensure the homogeneity of the outward flow, other methods were researched for the evaluation of the exhaust air velocity distribution on active area sources, in order to identify the representative sampling sites. One of the methods is to introduce smoke or fog into the air flow emitted by the biofilter. Another innovative method for evaluating outflow conditions involves the use of infrared thermography to measure the temperature distribution over the area of a biofilter. This approach, in contrast to conventional methods of measuring the temperature at selected points, allows the simultaneous determination of the temperature for each point in the biofilter area [13].
After taking the samples, they were connected to the measuring device Olfactometer TO8 (fig.3) for the actual analysis. The odour concentration was determined by the delayed dynamic olfactometry method, in compliance with the provisions of the SR EN 13725:2022. Determination of odour concentration by dynamic olfactometry, is a method recognized at European level for determining the concentration and emission rate of odour into the air from fixed and area sources [9].
Odour concentration is expressed as odour units by volume (ou_E/m^3) and is numerically equal to the dilution factor of the sample required to reach the group-specific perception threshold, i.e. the minimum concentration perceived by 50% of the population of 1 ou_E/m^3 [9].

The SR EN 13725:2022 standardizes the determination of odour concentration by exposing a gaseous sample to a panel in varying dilutions. Odour concentration is measured in European Odour Units (ou$_E$), defined as the amount of odorants evaporated into 1 m^3 of neutral gas at standard conditions that elicits a physiological response equal to that produced by 1 European Reference Odour Mass (EROM) evaporated in 1 m^3 of neutral gas at standard conditions. EROM, the accepted reference for odour units, is equal to 123 μg of n-butanol when evaporated in 1 m^3 of neutral gas, it yields a concentration of 0.040 μmol/mol [9].

This determination of the odour concentration provides directly comparable data for different types of odour and can be used as inventory for dispersion models, to determine odour impact in terms of annoyance and to assess the efficiency of abatement measures [13].

Olfactometric analyses were conducted in conformity with the European Standard EN 13725:2022 An olfactometer model TO8, (Fig. 3) based on the 'yes/no' method, was used as a dilution device. This instrument with four panellists' places in separate open boxes. Each box is equipped with a glass sniffing port and a push button for 'yes' (odour threshold). The measuring range of the TO8 olfactometer starts from a maximum dilution factor of 76,000 with a dilution step factor of 2. All measurements were carried out within 30 h after sampling, relying on a panel composed of four panellists, adequately selected in conformity with SR EN 13725:2022 [14].

A dynamic olfactometer (Fig. 3) functions as a high-accuracy diluter, and the human nose, respectively a group of 4 odour assessors, are used as a detector.

Fig. 3. Dynamic olfactometer with 4 positions Olfasense TO8
used to determine odour concentration [6]

RESULTS AND DISCUSSION
Description of the active area source with outward air flow
Biofiltration is used in a varying gas concentration range, primarily for odour substances and VOCs; however, according to the literature, this technology is dedicated to low concentrations of pollutants and high gas flow rates [15].

Active area sources with outward air flow (biofilter) are aerated with waste air or gas conducted through the matrix below its surface by mechanical ventilation [16].

The biofilter is used to filter a variety of gaseous pollutants such as volatile organic compounds (VOCs), ammonia, hydrogen sulphide (H$_2$S), and other toxic chemicals or unpleasant odours [17].

From a technical point of view, a biofilter (Fig. 4) is a massive layer of moistened organic material through which the exhausted air flows slowly to be treated. It naturally contains a microflora that grows in suitable environmental conditions and adapts to degraded exhaust components.

The exhaust components are separated by adsorption to the filter material and dissolved in the contained moisture film as it flows through the organic bed. Dissolved air components reach the cells of microorganisms by diffusion and osmosis and degrade it into ecologically irrelevant compounds. The functionality of the biofilter essentially depends on the adsorption capacity of the biofilter and the biological activity of its bio-flora [18].
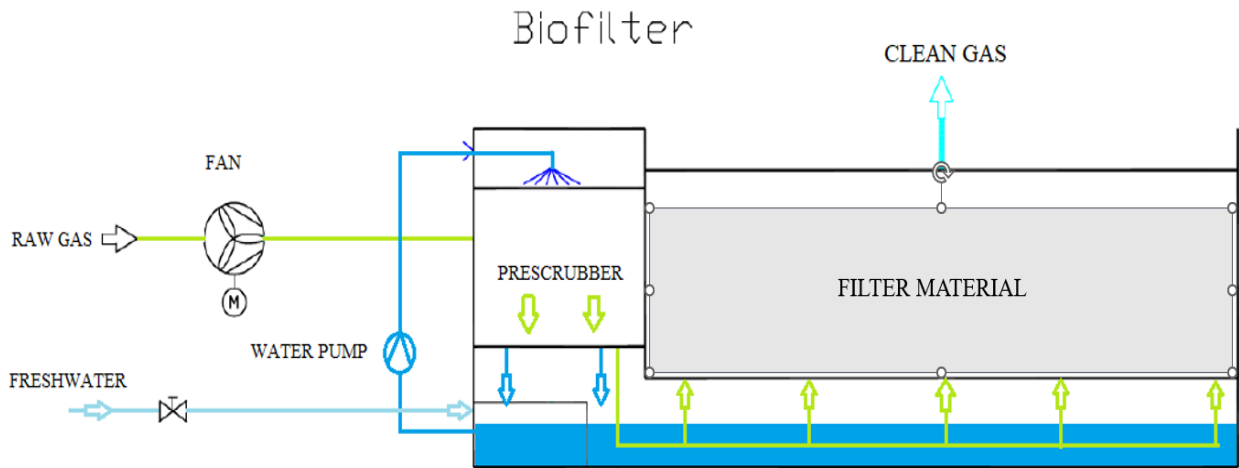
Fig. 4. Operating principle of a biofilter

Determination of emission rate (OER)

Direct measurement of the odour concentration in the ambient air is often not sufficient to establish an odour pollution level in the sensitive area. To determine whether an odour emission source produces olfactory discomfort to the population, the concentration and air flow associated with the odour emission source must be taken into account, these parameters are related to each other. The resulting parameter is the odour emission rate (OER), expressed in odour units per second (ou_E/s) and is obtained as the product of the odour concentration and the air flow rate associated with the source [19]. SR EN 13725 states that the volumetric air flow must be evaluated under normal conditions for olfactometry: 20 ºC and 101.3 kPa.

The odour emission rate emitted by the sampled source is required to estimate the odour concentration in the ambient air and to establish the level of odour pollution using mathematical modelling.

In this study, the odour emission rate of a biofilter with an area of 120 m^2 was calculated using the calculation method from standard 13725:2022 [9].

To estimate the odour concentration in the surrounding air from a homogeneous source, it was necessary to calculate the odour emission rate (ou_E/s) according to equation (3) and the results obtained after the determinations are presented in Table 2.

The odour emission from active surface sources is calculated using the formula, [9]:

$$q_{od,clean} = \frac{A_{source}}{n*A_{hood}} \sqrt[n]{\prod_{i=1}^{n} c_{od,i} * V_{RH,293,hood}} \tag{3}$$

$q_{od,clean}$ is the odour emission of the source area (ou_E/s); A_{source} is the source area (m^2); A_{hood} is the sample hood surface (m^2); n is the number of sample cells sampled; $c_{od,i}$ is the odour concentration of the sample (ou_E/m^3); $V_{RH,293,hood}$ is the volume flow rate measured in the sampling hood (m^3/s), at standard conditions for olfactometry [9].

The results of the measurements performed for each cell are presented in Table 1 where C_{od} is the odour concentration of the sample (ou_E/m^3), temperature measured in degrees Celsius (ºC), atmospheric pressure (mbar), flow velocity (m/s), the product between the odour concentration and the normalized volumetric flow rate C_{od}, (i_vrh), the temperature expressed in degrees Kelvin (ºK), the volumetric flow rate (m^3/s) and the volumetric flow rate normalized to standard conditions for olfactometry (Nm^3/s).

Table 1. Measurement results for the 12 sampled cells

Cell	C_{od} ou_E/m^3	Temp. ºC	Press. mbar	Flow velocity m/s	product C_{od}, i_vrh	Temp. ºK	Volume flow rate m^3/s	vrh,293,hood Nm^3/s
1	460	30.1	1021	0.88	369.99	323.1	0.88	0.80
2	392	29.2	1022	0.93	334.47	322.2	0.93	0.85
3	385	30.5	1021	0.98	344.43	323.5	0.98	0.89
4	452	30.6	1021	1.03	424.87	323.6	1.03	0.94
5	512	30.9	1020	1.18	550.30	323.9	1.18	1.07
6	491	30.2	1021	1.23	551.82	323.2	1.23	1.12
7	612	30.4	1021	1.20	670.62	323.4	1.20	1.10
8	516	29.1	1020	0.95	448.99	322.1	0.95	0.87
9	495	29.8	1020	1.12	506.70	322.8	1.12	1.02
10	623	29.6	1021	1.17	667.26	322.6	1.17	1.07
11	555	30.3	1020	1.22	617.88	323.3	1.22	1.11
12	564	30.1	1021	1.19	613.44	323.1	1.19	1.09

According to Table 2, the area of the entire source (A_{source}), the area of the sampling hood (A_{hood}), the number of sampling points (n), and the odour emission rate obtained for the 12 sampling points ($q_{od, clean}$) is presented.

Table 2. The odour emission rate result for the active area source

Source values		Samples cells (n)	$q_{od, clean}$, ou_E/s	$Q_{od, clean}$ $ou_E/s*m^{-2}$
A_{source}, m^2	A_{hood}, m^2			
120	1	12	4941.896	41.182

The resulting of the emission rate for the entire area of the source is 4942 ou_E/s, respectively 41 $ou_E/s*m^{-2}$ for the area of 1 m^2. This odour emission rate was entered into the dispersion software for mathematical modeling to estimate the odour concentration in the surrounding air.

Weather data used for mathematical modeling

Validated weather data, provided by the National Meteorological Administration, were used to perform the mathematical modelling of odour dispersion in the surrounding air. The data characterize 6 weather parameters (temperature, pressure, humidity, cloudiness, wind speed and direction) being provided in the form of hourly averages, according to the requirements of the dispersion program.

The weather data were treated statistically with the "Aermet View" program to eliminate outliers and create the wind rose (Fig. 5), presented in "blowing from" format and represents the annual distribution of the wind direction. Generally, a homogeneous distribution of winds is observed, in all directions up to a level of 4÷5% with predominant directions from NE (10%) followed by E-SE (8%), without identifying a strongly dominant direction.

We can see the presence of weak winds, with speeds between 0.5÷2.1 m/s, covering approximately 65.4% of the year, according to (Fig. 6). Winds with higher intensity are rarer, being present in a percentage of approximately 24.9% for the range 2.10 ÷3.60 m/s and 4.8% for the range 3.60 ÷ 5.70 m/s; high and very high-speed winds have a low occurrence frequency, below 1%. The average wind speed for the entire monitored interval is 1.53 m/s, and the percentage of hours of atmospheric calm is 4.45%, respectively 390 hours.
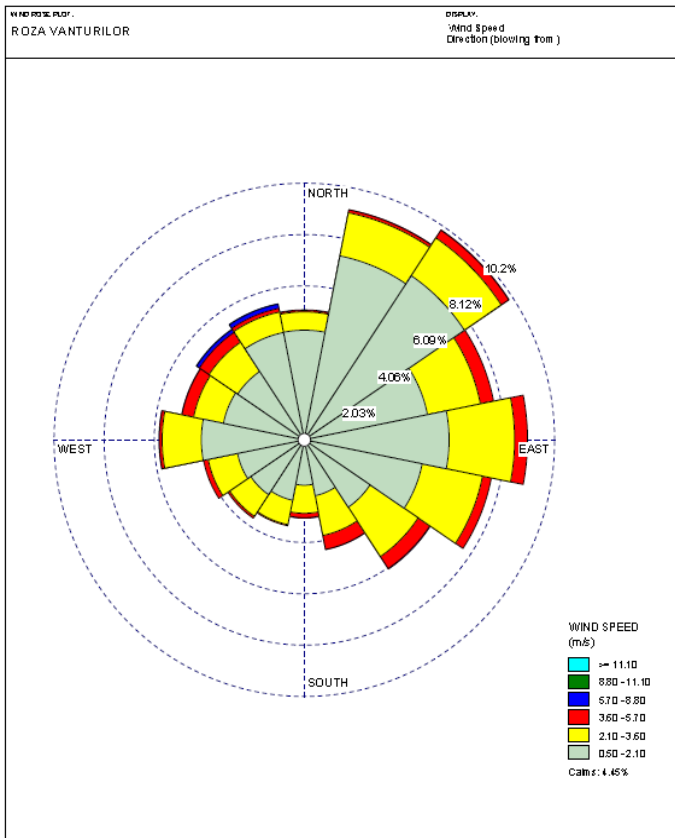
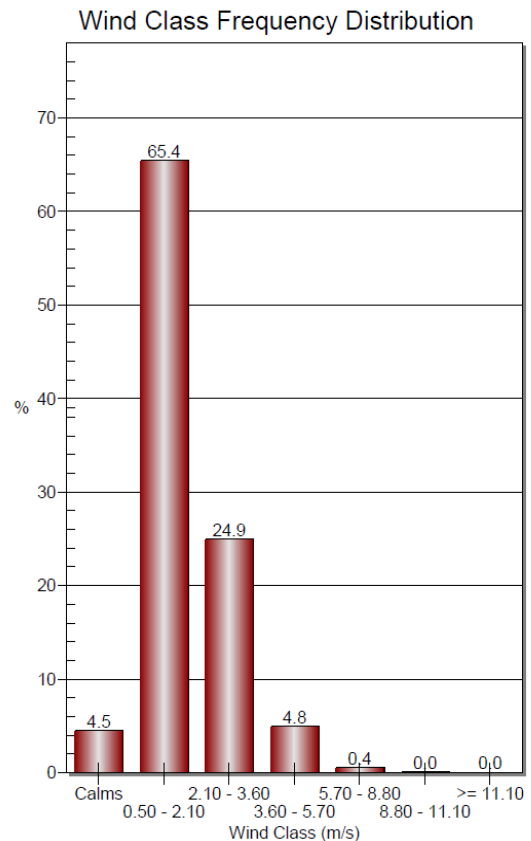**Fig. 5**. The wind rose specific to the zone

Fig. 6. Frequency distribution of wind speed, by classes

Estimation of the odour concentration in the surrounding air

Estimation of the odour concentration in the surrounding air was made carried out using the dynamic olfactometry method for measuring odour concentrations at the source, determining the emission rate generated by the source and mathematical modeling of the odour dispersion [20] using the "Aermod View" software, being an atmospheric dispersion model based on the turbulence structure of layers of the atmosphere and scaling concepts, including the treatment of multiple point sources at ground level and allows the creation of representative graphic models for locations and objects considered sources (point, linear, area, volume, etc.) [21].

According to the SR EN 13725 standard, the minimum odour concentration perceived by 50% of the population is 1 ou_E/m^3. Thus, at a theoretical level, we can consider that the smell is olfactory perceptible at concentrations above 1 ou_E/m^3, although at this concentration only part of the population presents a biological response, without being able to characterize the nature of the smell.

In order to estimate the odour concentration in the surrounding air in the adjacent areas to the sampled biofilter, 2 mathematical models were made to illustrate:

- The odour concentration on the site and in its vicinity in the most unfavorable weather conditions – „Highest values";
- The odour concentration on the site and in the surrounding areas corresponding to the „98th Percentile";

The 1st Highest Values function (Fig. 7) involves the presentation on the dispersion map of the highest value estimated at ground level, in the form of an hourly average, in the most unfavorable meteorological dispersion conditions. The maximum value obtained on the entire dispersion map is 53.9 ou_E/m^3 and is recorded on site, in the sampled source area.

The 98th Percentile function (Fig. 8) reflects the highest concentration encountered in 98% of the one-year period, i.e. in 8584 hours. This value represents an hourly average. In 175 hours (2%) of the year the concentrations are higher than this value, largely due to weather conditions unfavorable

to dispersion. The maximum value obtained in this situation on the entire dispersion map is 26 ou_E/m^3 and is recorded on site, in the sampled source area.
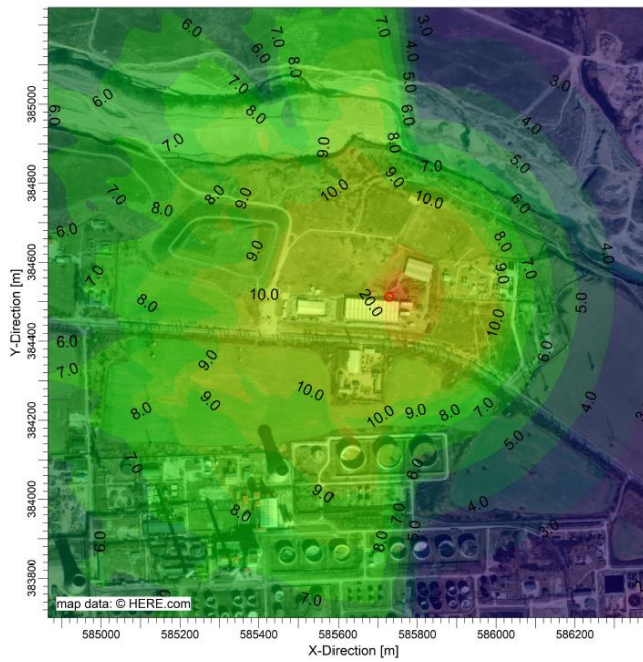

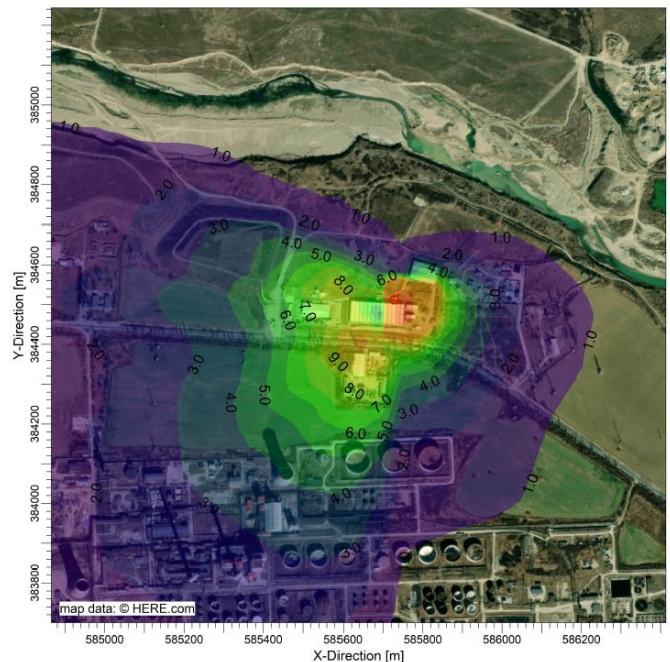**Fig. 7.** Average of the highest values, averaged over 1 hour (1st Highest Values)

Fig. 8. Hourly average of the highest values averaged at 1 hour in 98% of cases within a year (Percentile 98)

Figures 9 and 10 show the odour dispersion diagrams in the surrounding air. These diagrams give us the opportunity to observe the evolution of the odour concentration plume, depending on the distance. In this case, in both scenario, 1st Highest Values and the 98th percentile, the odour concentration of 1 ou_E/m^3 can be sensed by the population from 1400 meters away.
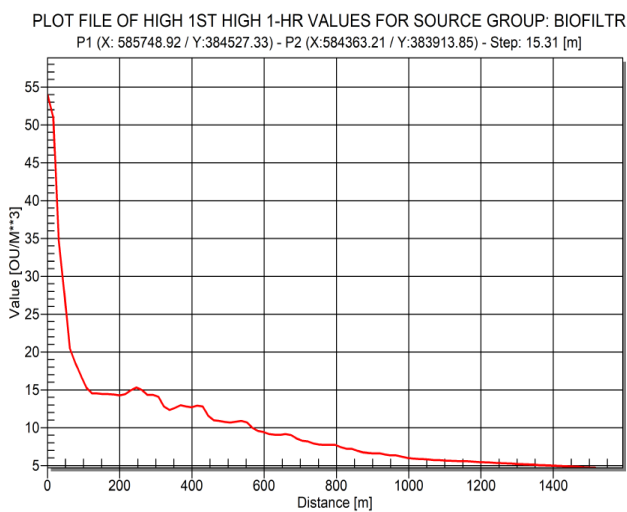

Fig. 9. Dispersion diagram for the highest values averaged at 1 hour (1st Highest Values)
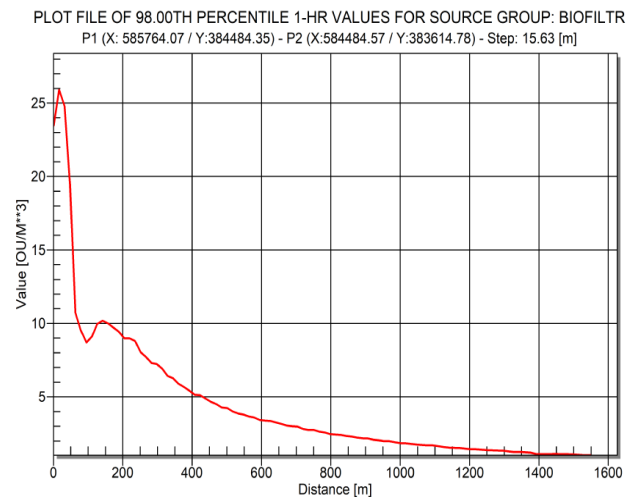
Fig. 10. Dispersion diagram for the highest values averaged at 1 hour in 98% of cases over the period of one year (Percentile 98)

We can also observe that in the case of simulation 1st Highest Values the odour concentrations at distances of 100 meters to 1000 meters from the site are in the range of $7 \div 15$ ou_E/m^3 and in case of the 98th percentile simulations the odour concentrations at distances covering between 100 and 1000 meters is in the range of $2 \div 10$ ou_E/m^3.

The national environmental regulations in force, from Romania Law no. 123/2020 for the amendment and completion of OUG no. 195/2005 on environmental protection, do not provide limit values for the odour concentration in the air [22]. The regulations for the application of this law are being approved and it is possible that they will introduce maximum permissible or recommended concentrations in the future. The only reference to the level of odour in the surrounding air can be found in STAS 12574/87 – Air quality conditions in protected areas regarding substances with unpleasant odours. For these compounds "it is considered that the emissions of strong-smelling substances exceed the maximum allowed concentrations, when in the impact area their unpleasant and persistent odour is olfactory perceptible"[23].

CONCLUSIONS

This paper provides an overview of the principles and methods used for odour sampling from active area sources, together with the determination of the odour emission rate that is relevant for this type of source. It should be emphasized that this study has applied existing methods and principles and is based on the latest research in the field that we have carried out. Sampling is an important issue in the characterization and measurement of odours and can affect the quality of measurements even more than the accuracy of the chosen analytical technique.

However, the contributions made in this paper highlight only the determination of the odour emission rate from active area sources in order to estimate the odour concentration in the ambient air and establish the level of odour pollution near the source. Great care must be taken in distinguishing this type of area source from other types of area sources, such as diffuse area sources or volume sources.

In the dispersion diagrams for both types of simulations, the odour concentrations in the surrounding air can be observed in relation to the distance from the source, in this sense we can conclude that the odour generated by this source can produce olfactory discomfort over a distance of 1000 meters in the worst weather conditions having a value of 7 ou_E/m^3 and in the case of the simulation with the 98th percentile function the odour concentration found at 1000 meters is 1 ou_E/m^3.

The specialized literature indicates a general range of $3 \div 5$ ou_E/m^3 for concentrations detected by the majority of the population and a range of $5 \div 10$ ou_E/m^3 for concentrations that lead to a state of discomfort. However, these intervals are not generally valid and depend on a multitude of factors such as: the sensitivity of each person, the character and intensity of the smell, the frequency, the location, etc.

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