Polish J. of Environ. Stud. Vol. 16, No. 2 (2007), 215-225

Original Research

Determining Temporary Odour Concentration under Field Conditions – Comparison of Methods

J. Kośmider, B. Krajewska

Szczecin University of Technology, Department of Technology and Chemical Engineering, Institute of Chemical Engineering and Environmental Protection Processes, 42 Piastów Avenue, 71-065 Szczecin, Poland

Received: March 28, 2006
Accepted: November 15, 2006

Abstract

The authors compared two methods of determining odour concentration under field conditions. Twelve series of odour measurements were carried out at a mink farm. Odour concentration was determined using a portable dynamic olfactometer (Nasal Ranger, St. Croix Sensory, Inc.) and by approximation using the psychophysical Weber-Fechner equation of *S*-log*Z* on odour intensity results. Odour concentrations were about 60 ou/m^3 for both methods. Values of the ratio $c_{od,WF}/c_{odNR}$ were in the range of (0.2-5), which satisfies the requirements of EN 13725.

Keywords: field olfactometer, odour intensity scale, n-butanol, Nasal Ranger, Weber-Fechner psychophysical law

Introduction

Legal protection of air quality at sensitive receptors requires unambiguous agreement on procedures for control, measurement and computation of results. For chemical substances there are standards appointed as a certain concentration level with an admissible frequency of excess. The standards are defined by order of the authorities together with recommended measurement methods. Measurements involve emission studies (analyses of compound concentrations in off-gases) and imission studies (analyses of ambient air at selected points of a monitoring network).

Solutions to problems concerning protection of odour quality of the ambient air seems to be more dubious. Familiarity with dependence of the quality and concentration of pollutants on the perceived odour has been limited so far. Even relatively good knowledge of composition of off-gases emitted from agricultural operations, food industries and other similar sources does not allow for forecasting odour annoyance at sensitive receptors [1, 2]. At present odour quality of the air, comprising of mixtures of many pollutants (very often not identified), can be determined only on the basis of olfactory signals analysis – thanks to biological and artificial noses.

An electronic nose is a measurement apparatus which is being used more and more often for solving various problems of environmental protection [3-14]. Its widespread use in networks for monitoring emissions and odour quality of the air, both in confined spaces and in the natural environment, is very likely in the near future. Until it happens it will be necessary to use standardized methods of sensorial analysis.

Sensorial analysis enables the determination of reproducible odour concentrations, odour intensity assessments, hedonic quality and other kinds of odours [15-25]. The correlations between results of chemical and sensorial analysis of samples of off-gases or ambient air at receptors and results of sociological studies on opinions of a sample of population of environmental quality and medical reports on health conditions are being searched for [26-31].

Determining odour concentration (c_{od}) using the method of dilutions is most often used from among numerous sensorial analysis methods. The measurement consists of determining the dilution ratio required for diluting the sample to such a degree that it stops being perceptible for half of a panel of assessors (dilution ratio $Z_{50\%}$). It means that a panel detection threshold is reached (c_{th} [ppm]). Under threshold conditions odour concentration is assumed to be equal to c_{od} = 1 ou/m^3 (one odour unit in a cubic metre). A value of c_{od} [ou/m^3] = c/c_{th}, numerically equal to $Z_{50\%}$, can be applied to each sample of a higher concentration.

Reaching a satisfactory reproducibility of sensorial measurements of odour concentration requires keeping strict records of adequate procedures. They are described in detail only in reference to organised emission sources (dynamic dilutions method of odour measurement). A selected panel of assessors of a specific smell sensitivity towards n-butanol (standard population) takes part in measurements conducted according to the European standard EN 13725 [25]. For each panelist a value of dilution factor Z_{ITE} (ITE -Individual Threshold Estimation) is calculated. This is the point at which they stop detecting the odour of a sample. Panel odour concentration values (c_{od} [ou$_E$ /m^3]) are calculated as geometrical means of at least four Z_{ITE}'s.

Once odour concentration of emitted gases is determined it is feasible to qualify a number of odour units introduced into the atmosphere in a unit of time – odour emission (q_{od} [ou/s]), if the off-gas volumetric flow (V [m^3/s]) is constant and given:

$$q_{od} = c_{od} \text{ [ou/m}^3] * V \text{ [m}^3\text{/s]}.$$

Procedures for determining odour emissions from diffuse or temporary and fugitive sources have not yet been standardized. At present they are the subject of intense studies. The most frequently used technique consists of wind tunnel systems. Odour concentration of air samples entering and exiting a confined space above a given section of an area source is evaluated (solid waste landfills, sewage settling ponds, surface of compost pile etc.) The technique enables the determination of odour emission factors from an area unit ([ou/s·m^2]) [32-36].

Odour emission values are used to make forecasts of odorant concentrations at receptors in the vicinity of emitters. For this purpose atmospheric dispersion computer simulations are carried out. Calculations are made using different process models and take into account local meteorological conditions (e.g. yearly average or seasonal wind rose) [37-40]. The calculation result is the probability of exceeding specific values of odour concentration, as indicated in appropriate national standards of odour quality of the ambient air [37, 41-48].

It is necessary to conduct experimental verification of computational results due to the utilization of simplified dispersion models. Typically, hourly averages of c_{od} are calculated. The measurement method described in EN 13725 cannot be utilized to capture events of low or instant odour concentrations. Temporary values of odour concentration are extremely important as air quality is assessed on the basis of maximal temporary odorant concentrations, instantly recognized with a sense of smell. In relation to this matter, studies aimed at standardisation of appropriate measurements procedures are being carried out.

Determination of temporary odour concentration can be conducted with:

- indirect method, on the basis of sensorial odour intensity assessments *in situ*, without sampling (extrapolation method) [49-51],
- method of dynamic dilutions to detection threshold, conducted *in situ* using a *Nasal Ranger Field Olfactometer* [52, 53],
- in compliance with a Japanese procedure called Triangle Odour Bag Method (Japan) [54-56].

The triangle Odour Bag Method makes it possible to assess temporary odour concentration of ambient air samples of relatively small capacities – many times smaller than the one indispensable for the procedure of dynamic dilutions. A diluted sample together with two other samples of pure air is presented to assessors (at least six people) who are asked to assess odour and indicate the one odorous sample. Utilising the method of static dilutions, this produces a very precise selection of dilution factors and a very economical management of a sample delivered to a laboratory.

The extrapolation method (described below) has been successfully used at Szczecin University of Technology for many years. Most importantly, it is suitable for determining odour concentration of samples with a significant odour intensity.

The Nasal Ranger field olfacometer utility range has not been evaluated in interlaboratory comparison studies yet (only publications of producers are available).

The aim of this study was to compare results obtained by means of Nasal Ranger with those obtained using the extrapolation method.

Literature Review

Determination of Odour Concentration on the Basis of Odour Intensity

Odour intensity is quantified with a sensorial method on the basis of a set of assessments from a panel as big as it is practically justifiable. There are various sorts of point, verbal and graphical scales and scales of standards [20, 21, 24, 53, 57].

German Standard VDI 3882 [20] describes in detail a 7-point odour intensity scale (Table 1). The scale is used in Europe and Australia during field observations which are carried out for 30-minute periods. The odour intensity is then recorded every 10 seconds.

In American guidelines (ASTM E544-99) [24, 53] a method of appointing odour intensity with n-butanol references was described. During measurements the smell of an odorous sample or of the ambient air is compared with Odor Intensity Referencing Scale (OIRS).

Table 1. German VDI 3882 odour intensity scale.

Odour intensity	Intensity level
Extremely strong	A
Very strong	B
Strong	C
Distinct	D
Weak	E
Very weak	F
Not perceptive	G

Table 2. Example of Odor Intensity Referencing Scales (OIRS).

Odour intensity level	Concentration of n-butanol [ppm]		
	12-point scale	10-point scale	5-point scale
1	10		25
2	20	24	75
3	40	48	225
4	80	96	675
5	160	192	2025
6	320	384	
7	640	768	
8	1280	1536	
9	2560	3072	
10	5120	6144	
11	10240		
12	20480		

OIRS reference scales are prepared dynamically or statically. The two types of OIRS scales are prepared in such a way that n-butanol concentrations form a geometric sequence in successive references. In most scales a geometric progression of 2 is used; however, there are scales in which a geometric progression of 1.5 or 3 is used. Table 2 shows the n-butanol concentration of references forming a 12-, 10- and 5-point scale.

The set of n-butanol references of c_0, c_1, c_2, c_3, …, c_N concentrations making a geometric sequence of X progression can be considered as a linear scale of odour intensity. It results directly from the classic Weber-Fechner law [25, 49, 53, 57, 58]:

$$S = k_{WF} \cdot \log c_{od} = k_{WF} \log (c/c_{th}) = k_{WF} \log c - k_{WF} \log c_{th} \quad (1)$$

where: S – odour intensity, c_{od} [ou/m^3] – odour concentration (number of odour units [ou] in a cubic metre), k_{WF} – Weber-Fechner coefficient, c – odorant's concentration [ppm], c_{th} – odour detection threshold of an odorant [ppm].

If odorant's concentrations of the successive references are equal to:

$$c_0, \quad c_1 = c_0 \cdot X, \quad c_2 = c_1 \cdot X = c_0 \cdot X^2, \; \dots \;, c_N = c_0 \cdot X^N \quad (2)$$

then an arithmetic sequence of odour intensity values corresponds to them:

$$S_0 = k_{WF} \cdot \log c_{0;}\, S_1 = S_0 + k_{WF} \cdot \log X;\; S_2 = S_0 + 2\, k_{WF} \cdot \log X; \dots \quad (3)$$
$$\dots;\; S_N = S_0 + N \cdot k_{WF} \cdot \log X$$

where: X – dilution factor (geometric progression of a concentration sequence); S_0 and c_0 – odour intensity and odorant's concentration in the basic sample; S_1, S_2, …, S_N and c_1, c_2, …, c_N – odour intensity and odorant's concentration in successive references.

Odour intensity assessment of a sample (of the ambient air) using OIRS consists of indicating the reference with an equally strong odour. According to ASTM the reference is conventionally indicated by appointing an approppriate value of n-butanol concentration [ppm].

Using values of $c_{butanol}$ [ppm] instead of proper literal symbols of the references, their numbers or verbal descriptors of the strength of sensation, facilitates passing on of information about the odour strength between experts. It allows for unambiguous description of the strength of sensation without any additional explanations concerning the sort of scale which was utilized. Unfortunately, it causes misunderstandings at the same time, suggesting that odour intensity of n-butanol (strength of perception, S) is numerically equal to its concentration value (magnitude of olfactory stimulus, $c_{butanol}$ [ppm]). One may feel inclined to apply the symbols of S and $c_{butanol}$ alternatively in psychophysical equations, which leads to incorrect conclusions concerning the mathematical functions combining the strength of sensation with the magnitude of stimulus.

At Szczecin University of Technology (Laboratory for Odour Quality of the Air) there are two kinds of odour intensity scales [49, 51, 59, 60]:

- a point scale (scale A) with verbal descriptors: 0 – undetectable odour, 1 – weak odour, 2 – significant odour, 3 – strong odour,
- a scale of references (scale B), which is formed by a set of aqueous n-butanol solutions whose concentrations form a geometrical sequence of a constant progression of $X = 20/7$.

References are marked with successive numbers (NoB1, NoB2, …), rising along with the rise of water-dilution factor of the basic solution of n-butanol.

The person assessing the odour smells the references in order of rising concentrations, starting from references indicated as odour free. They indicate two NoB values: one corresponding with an individual odour detection threshold of n-butanol (NoB_{zero}) and the other corresponding with the sample (NoB_{sample}). Given concentrations of n-butanol ($c_{butanol}$ [ppm]) are assigned to these values; however, they do not form the basis for calculations. Odour intensity *(S*) of an odourous ambient air sample is expressed conventionally as:

$$S = NoB_{zero} - NoB_{sample} \tag{4}$$

The result of assessments of temporary odour intensities of the ambient air allows for calculating the temporary value of c_{od} [ou/m^3] on the basis of Weber-Fechner equation (1). In order to carry out the calculations it is indispensable to determine Weber-Fechner coefficient (k_{WF}) typical for the analyzed pollutants mixture.

Weber-Fechner coefficient is determined experimentally as an angular coefficient of the $S = f(\log Z)$ straight line:

$$S_Z = S - k_{WF} \log Z \tag{5}$$

where: S – odour intensity of a sample of strong or at least significant odour, including the same pollutants as the ambient air, S_Z – odour intensity of samples diluted with odourfree air, Z – dilution factor.

Nasal Ranger Field Olfactometer

Nasal Ranger is a light, portable olfactometer (35.5 x 19 x 10cm, mass 0.91 kg), patented and produced by St. Croix Sensory (U.S. Patent No. 6.595.037) launched on the market in 2002. It was designed on the basis of results of work which has been sponsored since 1958 by the US Public Health Service. A device called a scentometer, produced by the Barnebey-Cheney Company, was its prototype [52, 53].

Nasal Ranger is a sort of a gas mask with an active carbon filter (two exchangeable filters of dimensions: diameter: 8.9 cm, height: 7 cm), in which a given part of the inhaled air can pass round the adsorption bed. The regulating valve allows for selecting one of six values of cleaned to crude air proportions ($V_{cleaned}/V_{crude} = 2, 4, 7, 15, 30$ i 60) and for setting the BLANK position (cleaning all inhaled air). According to the manufacturer the accuracy and reproducibility of dilutions are equal respectively to ±10% and ± 5%.

Within the device there is a sensor that senses inhaled air flow and is installed with an indicator which provides information when the recommended level of 16–20 dm^3/h is reached. However, conforming to the recommendation is very difficult (it requires intensive breathing for several minutes during the measurement), and it is questionable whether it is necessary.

After one minute of inhaling a portion of completely cleaned air (BLANK) an assessor gradually increases the part of the stream flowing round the filters. He registers the D/T value (Standard Dilution-to-Threshold Ratios) at which he can already smell the odour [52, 53].

Aim and Scope of Measurements

This work is aimed at verifying the compatibility of results of odour concentration measurements in the ambient air, obtained with two methods:

- on the basis of odour intensity assessments and Weber-Fechner coefficient determination,
- with a method of dynamic dilutions with the use of *Nasal Ranger Field Olfactometer*.

The measurements were carried out in the surroundings of a mink farm (4 thousand units of the basic herd) in the period between the beginning of July until the beginning of November (almost a complete animal cycle). Odour concentrations of ambient air inside the animal houses were determined. Collectively, 126 individual assessments were made, 63 with each of the compared methods. About 10-12 individual odour concentrations c_{od} [ou/m^3] were determined in each of 11 measurement series (two methods, 5-6 people).

Experimental Procedures

Measurement of Odour Concentration Using the Nasal Ranger

The same group of six people aged between 20-28 years old (3 women, 3 men) participated in most of the measurements. Sensitivity of their smell for the odour of n-butanol was not verified (rules of selection according to EN 13725 were not applied too).

During the measurements assessors walked into an animal house and at its central point made a measurement using the Nasal Ranger, St. Croix Sensory (information about its measurement precision is included in Table 3).

After adapting to the odour of the air coming through the filter (BLANK), settings of proportions of the cleaned stream ($V_{cleaned}$) to the uncleaned stream (V_{crude}), in the sequence of 60, 30, 15, 7, 4 and 2 with an intermediate BLANK position, were adjusted. The measurement was

Table 3. Calibration sheet of the utilized Nasal Ranger.

Dial D/T	Actual D/T	% Variance
60	58.98	-1.7%
30	30.22	0.7%
15	15.51	3.4%
7	6.88	-1.8%
4	4.09	2.3%
2	2.07	3.3%

stopped after the difference between the evaluated odour and BLANK was found. In this situation the ratio of the two mixed streams is equal to Dilution-to-Threshold Ratios ($V_{cleaned}/V_{crude}$ = D/T).

On the basis of the D/T value, individual assessments of odour concentration Z_{ITE} [ou/m^3] were calculated (analogical to the one determined in compliance with EN 13725 [25].

For this purpose two values of dilution factor (Z) were determined using the dependence:

$$Z = (V_{cleaned} + V_{crude})/V_{crude} = V_{cleaned}/V_{crude} + 1 \qquad (6)$$

The two values were, the value corresponding with the found D/T setting (YES, I can already smell the odour: Z_{YES} dilution) and the previous setting (NO, I still cannot smell the odour: Z_{NO} dilution). A geometrical mean of the values limiting the scope, which the real value is included within,

$$Z_{ITE} = \sqrt{Z_{YES} Z_{NO}} \qquad (7)$$

was calculated as an individual odour threshold estimate (Z_{ITE}).

In Table 4 there are D/T values settable with a Nasal Ranger listed with corresponding individual thresholds estimates (Z_{ITE}). It is necessary to explain an adopted method of interpretation of those situations where the maximal dilution possible to set ($V_{cleaned}/V_{crude}$ = 60) is not enough for one or two people, whilst the rest of the team indicate D/T value equal to 30 or less. It was assumed that the next dilution step exists and can be set with Nasal Ranger. Arbitrarily it was accepted that the ratio $V_{cleaned}/V_{crude}$ = 120 would be sufficient for all of the assessors.

The value of odour concentration c_{od} [ou/m^3] was calculated as a geometrical mean of a set of threshold estimates (Z_{ITE}) collected on one day (series of single measurements):

$$c_{od}[ou/m^3] = \sqrt[n]{\prod^{n} Z_{ITE}} \qquad (8)$$

Determination of Odour Concentration on the Basis of Odour Intensity

Samples of 20 dm^3 capacity were taken from the animal cages located in the centre of the animal house. Bags made of NALOPHAN foil and the sampling System E (Stroehlein) were used. All the bags were thoroughly conditioned in order to avoid errors caused by pollutants' adsorption on the surface of the foil.

Part of the collected sample was used to obtain three additional samples – diluted with odourless air to various degrees. Dilutions were made with a static method preserving the step of 2-3 (example: dilution of a basic sample about 3, 9 and 18 times).

Five to six people assessed odour intensity of four collected samples, for one odour concentration determination (c_{od} [ou/m^3]). The n-butanol scale of odour intensity standards was utilized. It was prepared in Erlenmayer flasks of 50 cm^3 capacity each. Gradually diluting successive solutions a constant progression 20/7 was preserved (7 cm^3 of diluted solution, 13 cm^3 of distilled water).

A result of **a single odour intensity assessment** (S) was calculated according to equation 4, after the indication of a "threshold reference" (NoB$_{ZERO}$) and a reference corresponding with the sample (NrB$_{sample}$).

An individual threshold estimate (Z_{ITE}) was calculated using the Weber-Fechner equation (equation 5). The empirical Weber-Fechner coefficient (k_{WF}) was determined with a linear approximation of odour intensity (S_Z) dependence on the logarithm of dilution factor (log Z) of a sample diluted with pure air. The approximation was carried out separately for each individual threshold estimate Z_{ITE} (values of k_{WF} were determined separately for each assessor and each sample).

A single odour concentration measurement consisted of determining five or six Z_{ITE} values. These were calculated on the basis of 20-24 single odour intensity assessments (5-6 people, four samples of a different dilution factor).

Odour concentration (c_{od} [ou/m^3]) was calculated as a geometrical mean of at least four "valid" values of Z_{ITE}

Table 4. Method of determination of an individual threshold estimate on the basis of results of D/T determinations.

Measurement result		Dilution factor Z		
D/T ($V_{cleaned}/V_{crude}$)$_{YES}$	($V_{cleaned}/V_{crude}$)$_{NO}$	Z_{YES}	Z_{NO}	Z_{ITE}
60	120	61	121	86
30	60	31	61	43
15	30	16	31	22
7	15	8	16	11
4	7	5	8	6
2	4	3	5	4
0	2	1	3	2

(equation 8). The criterion of Z_{ITE} "validity" was defined on the basis of EN 13725 (retrospective screening). The result of an individual determination was not taken into account when it was five times higher or five times lower than the value of the geometrical mean.

Results

Results of odour concentration measurements ($c_{od,NR}$ [ou/m^3]) carried out with Nasal Ranger in the animal houses that had minks inside are shown in Fig. 1 (results of panel measurements on the background of individual estimates). Table 5 includes a list of results of odour intensity assessments (*S*), carried out simultaneously, at the animal cages.

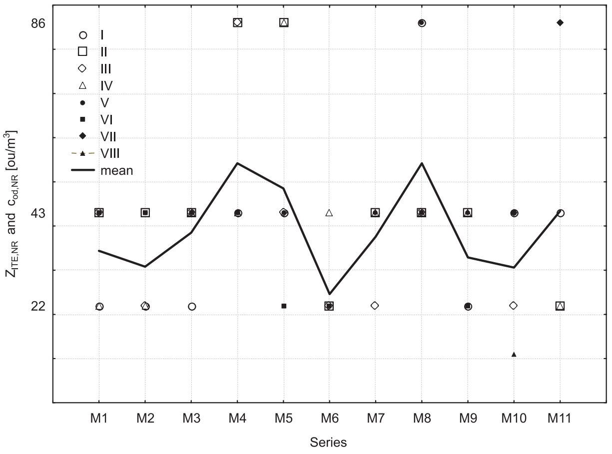

Fig. 1 Values of odour concentration determined with use of a Nasal Ranger ($c_{od,NR}$ [ou/m^3]) in the air inside an animal house on the background of individual estimates ($Z_{ITE,NR}$); M1, M2, M3, … – measuring series 1, 2, 3…; I–VIII – symbols of a participant of the measurement.

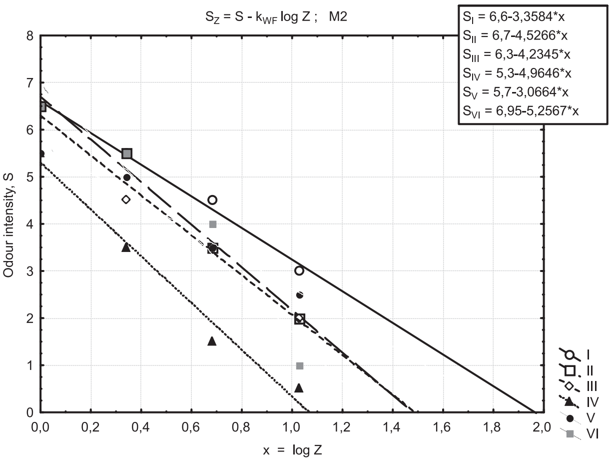

Fig. 2 Dependence of odour intensity of the air in vicinity of cages with minks on the factor of dilution (*Z*) with pure air. An example concerning measurements carried out by the assessors I-VI within the M2 series

Results of odour concentration $c_{od,NR}$ [ou/m^3] measurements conducted using Nasal Ranger were analysed from the point of compliance with the criterion of retrospective screening defined in EN 13725 [25]. According to the standard, these assessors, whose estimates are more than five-times higher or smaller than a geometrical mean, should be excluded from the panel. A mean value calculated after the exclusion is recognized as an odour concentration. One can find that all quotients lie within the scope of 0.5-2.0, significantly narrower than the admissible (0.2-5.0). That means that there is no reason to reject any individual estimates.

Table 5. Results of determinations of odour intensity of the air inside an animal house.

Series	Individual odour intensity assessments								Odour intensity, arithmetical mean, *S*
	S_I	S_{II}	S_{III}	S_{IV}	S_V	S_{VI}	S_{VII}	S_{VIII}	
M1	7.5	7.5	4	7	5	5	-	-	6.0
M2	6.5	6.5	6.5	5.5	5.5	6.5	-	-	7.5
M3	5.5	6	4	5	5	7	-	-	6.5
M4	6.5	7	4	5.5	4.5	6.5	-	-	6.5
M5	8	7.5	7	5.5	4.5	7	-	-	6.5
M6	7	6.5	4.5	6	6	7	-	-	6.5
M7	8	6	4.5	6.5	6	-	-	-	6.2
M8	7.5	7.5	5	7	6	6.5	-	-	6.5
M9	7.5	7	-	6.5	6	7	-	-	6.8
M10	7	-	4.5	-	5.5	6.5	5.5	6	5.8
M11	6.5	5	-	6.5	7	-	5.5	-	6.1

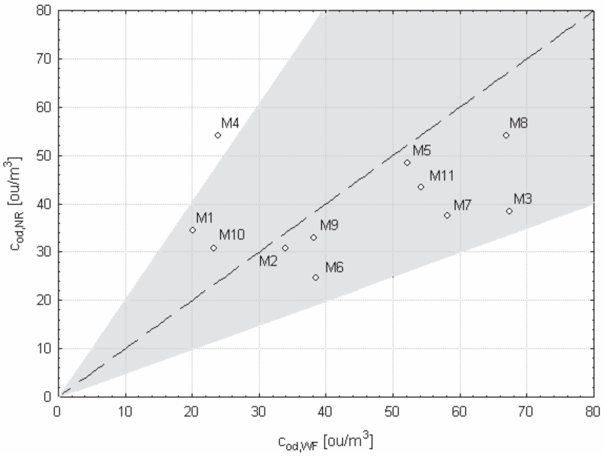

Fig. 3 Comparing results of odour concentration measurements c_{od} [ou/m^3] conducted with use of Nasal Ranger ($c_{od,NR}$) and n-butanol odour intensity scale $c_{od,WF}$); M1, M2, M3 – symbols of measurement.

Table 6. Results of odour concentration determinations ($c_{od.WF}$ [ou/m^3]) on the basis of odour intensity assessments.

No.	Series	Assessor	S	k_{WF}	Z_{ITE}	$c_{od,WF}$ [ou/m^3]	Z_{ITE} / $c_{od,WF}$	
1	2	3	4	5	6	7	8	
1	M1	I	8.2	5.78	26.2	20.2	1.30	
2		II	8.0	6.28	18.8		0.93	
3		III	4.1	3.02	22.0		1.09	
4		IV	7.6	6.03	18.2		0.90	
5		V	5.6	4.27	19.9		0.98	
6		VI	5.3	4.27	17.4		0.86	
7	M2	I	6.6	3.36	92.3	33.9	2.7	
8		II	6.7	4.53	30.2		0.89	
9		III	6.3	4.23	30.7		0.91	
10		IV	5.3	4.96	11.7		0.34	
11		V	5.7	3.07	72.3		2.13	
12		VI	7.0	5.26	21.0		0.62	
13	M3	I	5.1	1.70	1054.2	106.5 67.4	9.89	–
14		II	5.6	2.42	211.3		1.98	3.14
15		III	3.9	2.43	39.7		0.37	0.59
16		IV	5.1	3.15	42.7		0.40	0.63
17		V	4.8	2.57	76.2		0.72	1.13
18		VI	6.8	4.00	50.8		0.48	0.75
19	M4	I	7.1	4.97	26.4	23.9	1.11	
20		II	7.0	4.39	39.6		1.66	
21		III	4.3	3.51	16.9		0.71	
22		IV	5.6	4.83	14.6		0.61	
23		V	4.5	2.93	34.7		1.45	
24		VI	6.4	4.84	20.8		0.87	
25	M5	I	8.3	4.29	84.8	52.2	1.63	
26		II	7.5	3.72	101.5		1.95	
27		III	7.1	4.15	50.5		0.97	
28		IV	5.9	4.57	19.7		0.38	
29		V	4.8	2.86	46.4		0.89	
30		VI	7.1	4.15	50.5		0.97	
31	M6	I	7.2	4.53	39.0	38.5	1.01	
32		II	6.5	3.80	50.0		1.30	
33		III	4.3	2.78	35.5		0.92	
34		IV	6.0	3.80	36.9		0.96	
35		V	5.9	3.94	31.4		0.82	
36		VI	6.8	4.24	40.4		1.05	
37	M7	I	8.1	4.00	105.5	58.2	1.81	
38		II	6.1	3.28	71.8		1.23	
39		III	4.8	2.71	58.7		1.01	
40		IV	6.6	4.00	44.5		0.76	
41		V	5.9	3.86	33.8		0.58	

Table 6. continued

1	2	3	4	5	6	7	8
42	M8	I	7.7	3.58	144.3	66.9	2.16
43		II	7.4	3.73	98.7		1.47
44		III	5.1	3.30	34.8		0.52
45		IV	7.0	4.87	27.7		0.41
46		V	6.1	3.30	69.9		1.04
47		I	6.8	3.45	93.4		1.40
48	M9	I	7.6	4.74	39.9	38.2	1.05
49		II	6.9	3.73	72.4		1.90
50		IV	6.7	4.45	31.9		0.83
51		V	6.0	4.17	28.2		0.74
52		VI	7.1	4.74	31.3		0.82
53	M10	I	7.0	4.88	27.7	23.3	1.19
54		III	4.3	3.43	17.7		0.76
55		V	5.4	3.87	24.6		1.06
56		VI	6.5	4.30	32.1		1.38
57		VII	5.9	4.26	24.9		1.07
58		VIII	6.9	5.68	16.6		0.71
59	M11	I	6.8	3.61	76.7	54.3	1.41
60		II	5.4	3.93	23.5		0.43
61		IV	6.4	3.39	77.2		1.42
62		V	7.1	3.65	86.5		1.59
63		VII	5.4	3.39	39.2		0.72

M1, M2, M3, … – measuring series 1, 2, 3…; I–VIII – symbols of a participant of the measurement. k_{WF} – Weber-Fechner coefficient. Z_{ITE} – individual threshold estimate. $Z_{ITE}/c_{od.WF}$ – panel screening parameter (the basis for retrospective screening)

Values of odour concentration $c_{od,WF}$ [ou/m^3], determined on the basis of Weber-Fechner law were calculated using the equations of $S_Z = f(\log Z)$ straight lines, incorporating the data enclosed in Table 7. The example presented in Fig. 2 illustrates the mutual location of the straight lines determined on the basis of individual odour intensity assessments in one of measurements sessions. It proves that individual values of Weber-Fechner coefficient are varied to a great degree – on the day the measurements were recorded they lay within the scope of $k_{WF} = 3.05–5.26$ (an analysis of a long-term variability of this parameter was not included in this work).

The variability of individual values of k_{WF} significantly influences the variability of individual estimates of odour concentration calculated as an antilogarithm of S_0/k_{WF} quotient (Table 6, column 6). Nevertheless the data that did not comply with the retrospective screening criterion was in only one measurement session (session M3, assessor I). After excluding the incompliant data it was possible to obtain such sets of $Z_{ITE,WF}$ values which, after dividing them by the average value, gave the values of the ratio within the scope of 0.34–3.14 (scope 25%-75%: 0.76–1.38; the admissible scope according to EN 13725: 0.2–5.0).

Comparison of odour concentration values $c_{od,NR}$ [ou/m^3] and $c_{od,WF}$ [ou/m^3] is presented in Fig. 3. It states that most of the measurement points lie within the scope limited with straights of $c_{od,NR} = 2\,c_{od,WF}$ and $c_{od,NR} = c_{od,WF}/2$. Only one point (session M4) lies outside of the area limited with the lines. Such level of compatibility is satisfactory. Accuracy of olfactometric measurements is directly connected with the utilized dilution step, and in the case of both compared methods it was approximately equal to 2 (results can be equal only to discrete values: 86, 43, 22, 11, 6, 4 and 2).

The distribution of most of the measurement points below the $c_{od,NR} = c_{od,WF}$ straight is difficult to explain. It is possible that odour materials which are used in Nasal Rangers (e.g. material of a mask, gaskets) could have masked the evaluated air odour.

Another probable reason of delays in smell reactions on increasing odorants concentration in the air stream inhaled using Nasal Ranger is the necessity of focusing on a permanent control of magnitude of the stream. It does not conform to the spirit of EN 13725, according to which full concentration of the odour assessed should be ascertained by assessors.

Recommendation that the stream inhaled through a carbon filter should be equal to 16-20 dm^3/min raises additional doubts. Such intense breathing is inconvenient. Introducing a requirement difficult to fulfill as it is not justifiable according to EN 13725. According to the standard, panelists should breathe calmly, fully concentrating on perceived olfactory stimuli. Using a large stream of evaluated gas ensures that even a deep breath-in does not cause dilution of the air in the port with the ambient air.

Conclusions

1. Odour concentration values determined using Nasal Ranger olfactometer were smaller than 60 ou/m^3 and proved to be compliant with the results obtained on the basis of odour intensity assessments to a satisfactory degree (utilizing n-butanol scale and Weber-Fechner law).
2. Precision of measurements conducted with a field olfactometer can probably be increased by exchanging some parts of the Nasal Ranger with odourless ones.
3. Precision of measurements conducted with use of field olfactometer can probably be enlarged by not conforming to requirements concerning intensity of breathing through the filter. This will allow assessors to fully concentrate on olfactory sensations, and additionally will increase the time of using the filter to the moment of bleeding.

References

1. RAPPERT S., MÜLLER R. Odor compounds in waste gas emissions from agricultural operations and food industries. Waste Management. **25**, 887, **2005**.
2. GOSTELOW P., PARSONS S.A., STUETZ R.M. Odour measurements for sewage treatment works. Water Res. **35** (3), 579, **2001**.
3. BOCKREIS A., JAGER J. Odour monitoring by the combination of sensores and neural networks. Environmental Modelling and Software. **14** (5), 421, **1999.**
4. BOHOLT K., ANDREASEN K., DEN BERG F., HANSEN T. A new method for measuring emission of odour from a rendering plant using the Danish Odour Sensor System (DOSS) artificial nose. Sensors and Actuators B. **106**, 170, **2005**.
5. ROMAIN A.C., GODEFROID D., NICOLAS J. Monitoring the exhaust air of a compost pile with an e-nose and comparison with GC–MS data. Sensors and Actuators B. **106**, 317, **2005**.
6. DI FRANCESCO F., LAZZERINI B., MARCELLONI F., PIOGGIA G. An electronic nose for odour annoyance assessment. Atmospheric Environment. **28** (1), 1225, **1994**.
7. STUETZ R. M., ENGIN G., FENNER R. A. Sewage odour measurements using a sensory panel and an electronic nose. Water Science and Technology. **38** (3), 331, **1998**.
8. SCHÜTZ S., SCHÖNING M.J., SCHROTH P., WEIß-BECKER B., KORDOS, P., LÜTH H., HUMMEL H.E. An insect-based BioFET as a bioelectronic nose. Sensors and Actuators B. **65**, 291, **2000**.
9. GOPEL W. Chemical imaging I: Concepts and visions for electronic and bioelectronic noses. Sensors and Actuators B. **52**, 125, **1998**
10. SOHN J. H., SMITH R. J., YOONG E. Process studies of odour emissions from effluent ponds using machnie-based odour measuremenst. Atmospheric Environment. **40**, 1230, **2006**.
11. SZCZUREK A., MACIEJEWSKA M. Relationship between odour intensity assessed by human assessor and TGS sensor array response. Sensor and Actuators B. **106**, 13, **2005**.
12. YAMANAKA T., NAKAMOTO T. Real-time reference method in odor blender under environmental change. Sensor and Actuators B. **93**, 51, **2003**.
13. ISHIDA H., TOKUHIRO T., NAKAMOTO T., MORIIZUMI T. Improvement of olfactory video camera: Gas/odor flow visualization system. Sensors and Actuators B. **83**, 256, **2002**.
14. ISHIDA H., NAKAMOTO T., MORIIZUMI T., KIKAS T., JANATA J. Plume-tracking robots: a new application of chemical sensors. Biol. Bull. **200**, 222, **2001**.
15. ISO 6658:1998. Sensory analysis – Methodology – General guidance. l "#" PN-ISO 6658:1998. Analiza sensoryczna Metodologia Wytyczne ogólne.
16. ISO 5492:1997. Sensory analysis – Vocabulary (PN-ISO 5492:1997. Analiza sensoryczna Terminologia).
17. ISO 5496:1997. Sensory analysis – Methodology – Initiation and training of assessors in the detection and recognition of odours. (PN-ISO 5496:1997. Analiza sensoryczna – Metodologia – Wprowadzenie i szkolenie oceniających w wykrywaniu i rozpoznawaniu zapachów).
18. ISO 8589:1998. Sensory analysis – General guidance for the design of test rooms (PN-ISO 8589:1998. Analiza sensoryczna – Ogólne wytyczne dotyczące projektowania pracowni analizy sensorycznej).
19. VDI 3881. Blatt 1: Olfaktometrie. Geruchsschwellenbestimmung; Grundanforderungen; Blatt 2. Olfaktometrie; Geruchsschwellenbestimmung; Probenahme; Blatt 3. Olfaktometrie; Geruchsschwellenbestimmung; Olfaktometer mit Verdünnung nach dem Gasstrahlprinzip; Blatt 4. Olfaktometrie; Geruchsschwellenbestimmung; Anwendungsvorschriften und Verfahrenskenngrößen
20. VDI-Richtlinien 3882, Blatt I: VDI 3882 Blatt 1. *Olfaktometrie; Bestimmung der Geruchsintensität / Olfactometry. Determination of Odour Intensity*, Pub. Verein Deutscher Ingenieure, Dusseldorf. **1992**
21. VDI 3940. Bestimmung der Geruchsstoffimmission durch Begehungen; Blatt 1: Bestimmung der Immissionshäufigkeit von erkennbaren Gerüchen; Rastermessung; Blatt 2: Fahnenmessung, Pub. Verein Deutscher Ingenieure, Dusseldorf.
22. NVN2820. Air Quality. Sensory Odour Measurement using an Olfactometer. The Measurement of odour Threshold value. Netherlands Normalization Institute. Delft, The Netherlands, **1990**.

23. ASTM E679-91. Determination of Odor and Taste Threshold by a Forced-Choice Ascending Concentration Series Method of Limits.
24. ASTM E544-99(2004). Standard Practices for Referencing Suprathreshold Odor Intensity. **2004.**
25. EN 13725 (2003). Air quality – Determination of odour concentration by dynamic olfactometry (PN-EN 13725 (U): Jakość powietrza. Oznaczanie stężenia zapachowego metodą olfaktometrii dynamicznej).
26. SCHIFFMAN S. et al. The effect of environmental odors emanating from commercial swine operations on the mood of nearby residents. Brain Research Bulletin. **37** (4), 369, **1995**.
27. WINNEKE G., NEUF M., STEINHEIDER B. Separating the impact of exposure and personality in annoyance response to environmental stressors, particularly odors. Environ. Int. **22**, 73, **1996**.
28. BURLINGAME G. A. Odor profiling of environmental odors. Water Science and Technology. **40** (6), 31, **1999**.
29. KL**(AE)**BOE R., KOLBENSTVEDT M., CLENCH-AAS J., BARTONOVA A. Oslo traffic study – part 1: an integrated approach to assess the combined effects of noise and air pollution on annoyance. Atmospheric Environment, **34** (27), 4727, **2000**.
30. LUGINAAH I.N., TAYLOR S.M., ELLIOTT S.J., EYLES J.D. Community responses and coping strategies in the vicinity of a petroleum refinery in Oakville, Ontario. Health and Place. **8** (3), 177, **2002**.
31. DE BRUYN G., VAN ELIT T., KEGELS J. Case study: Intensive odour study at a non-ferrous metal plant in Belgium. 2nd. IWA International Workshop and Conference on Odour & VOCs. Singapur, 15-17.09.**2003**.
32. CARPENTIERI M., CORTI A. ZIPOLI L. Wind tunnel experiments of tracer dispersion downwind from a small scale physical model of a landfill. Environ. Modell. and Softw. **19**, 881, **2004**.
33. SIRONI S., CAPELLI L., CENTOLA P., DELROSSO R., IL GRANDE M. Odour emission factors for assessment and prediction of Italian MSW landfills odour impact. Atmospheric Environment. **39**, 5387, **2005**.
34. SOHN J.H., SMITH R.J., HUDSON N.A., CHOI H.L. Gas sampling efficiencies and aerodynamic characteristics of a laboratory wind tunnel for odour measurement. Biosystems Engineering. **92** (1), 37, **2005**.
35. KAIYUN J., KAYE R. Comparison study on portable wind tunnel system and isolation chamber for determination of VOCs from areal sources. Water Science and Technology. **34,** 583, **1996**.
36. LEYRIS C., GUILLOT J.-M., FANLO J.-M, POURTIER L. Comparison and development of dynamic flux chambers to determine odorous compound emission rates from area sources. Chemosphere. **59** (3), 415, **2005**.
37. SCHAUBERGER G., PIRINGER M., PETZ E. Separation distance to avoid odour nuisance due to livestock calculated by the Austrian odour dispersion model (AODM). Agriculture, Ecosystems & Environment. **87** (1), 13, **2001**.
38. SARKAR U, HOBBS S.E., LONGHURST P. Dispersion of odour: a case study with a municipal solid waste landfill site in North London, United Kingdom. J. Environ. Manage. **68** (2), 153, **2003**.
39. SHERIDAN B.A., HAYES E.T., CURRAN T.P., DODD V.A. A dispersion modelling approach to determining the odour impact of intensive pig production units in Ireland. Bioresour. Technol. **91** (2), 145, **2004**.
40. JANES K. R., YANG S. X.,. HACKER R. R. Pork farm odour modelling using multiple-component multiple-factor analysis and neural networks. Applied Soft Computing. **6**, 53, **2005**.
41. KRAJEWSKA B., KOŚMIDER J. Standardy zapachowej jakości powietrza. Ochrona Powietrza i Problemy Odpadów, **6**, 181, **2005.** [in Polish]
42. FUJITA H. Environmental Odour Management in Japan, Environmental Odour Management, International Conference. Cologne, pp 71-76, **2004.**
43. MAHIN T. D. Measurement and Regulation of Odors in the USA, Odor Measurement Review, Office of Odor, Noise and Vibration Environmental Management Breau, Ed. Environment. Min. Japan, pp 62-67, **2003.**
44. DRAGT J. Regulations in the Netherlands, and some practical experience, Semin. ODOURS'93: Odours – Control, Measurement, Regulations, Świnoujście 1993, pp 63-74, Ed. EKOCHEM, Szczecin, **1993**.
45. Ferstellung und Beurteilung von Geruchsimmision (Geruchsimmisions Richtlinie). Ministerium fur Umwelt, Raumordung und Landwirtschaft des Landes Nordheim- Westfalen, **1993**.
46. PRINZ B. Odours. Regulations in Germany, Semin. ODOURS'93: Odours – Control, Measurement, Regulations, Świnoujście 1993, pp 42-53, Ed. EKOCHEM, Szczecin, **1993**.
47. KNAUER W. Experience with the odour control policy in Germany, Semin. ODOURS'93: Odours – Control, Measurement, Regulations, Świnoujście 1993, pp 54-62, Ed. EKOCHEM, Szczecin, **1993**.
48. VAN BROECK G., VAN ELST T., NIEUWEJAERS B. Recent Odour Regulation Developments in Flanders: Ambient Odour Quality Standards Based on Dose-Response Relationship. Water Science and Technology. **44** (9), 103, **2001.**
49. KOŚMIDER J., MAZUR-CHRZANOWSKA B., WYSZYŃSKI B. Odory, Wyd. Naukowe PWN S.A., Warszawa, **2002.** [in Polish]
50. KOŚMIDER J. Problemy normalizacji oznaczania stężenia odorów. Normalizacja. **1**, 8, **2000**. [in Polish]
51. KOŚMIDER J., KRAJEWSKA B. Odor Air Quality Standards and Precision of Odor Intensity Assessments. Polish Journal of Environmental Studies, **13**, Suplement III, 87, **2004**.
52. MCGINLEY C. Standardized Odor Measurement Practices for Air Quality Testing. Symposium on Air Quality Measurement. Methods and Technology—2002. pp 13-15, San Francisco, **2002**.
53. A Detailed Assessment of The Science and Technology of Odor Measurement; pp 69, Prepared by: St. Croix Sensory, Inc., 30

June 2003; P.O. Box 313, 3549 Lake Elmo Ave. N. Lake Elmo, MN 55042, 1-800-879-9231; stcroix@fivesenses.com (http://www.pca.state.mn.us/publications/p-gen2-01.pdf).

54. IWASAKI Y., ISHIGURO T. Measurement of odor by triangle odor bag method (I). Japan Society Atmospheric Environment. **13** (6), 34, **1978**.
55. NAGATA Y., TAKEUCHI N. Measurement of odor threshold by triangle odor bag metod. Bulletin of Japan Enviromental Sanitation Center, **17**, 77, **1990**.
56. UENO H., HIGUCHI M., TATSUICHI S., IWASAKI Y., NISHIKAWA J. Effect of panel performance on olfactometry. Environmental Odour Management, Cologne, 18.11.**2004.**
57. RUCH F. L., ZIMBARDO P. G. Psychologia i życie. Wyd. Nauk. PWN. Warszawa, **1996.** [in Polish]
58. KOŚMIDER J. Projektowane standardy zapachowej jakości powietrza i możliwości oceny skutków wprowadzenia regulacji. Ochrona Powietrza i Problemy Odpadów. **3**, 77, **2005.** [In Polish]
59. KOŚMIDER J., WYSZYŃSKI B. Relationship between odour intensity and odorant concentration: logarithmic or power equation. Arch. Ochr. Środ. **28 (1),** 29, **2002.**
60. KOŚMIDER J., SOSIALUK M. Odour of acetone according to psychophysics laws. OLFACTORY BIORESPONSE III, P12, Drezno, December 2-5, **2003.**