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Precision of Odour Abatement Efficiency Determination in Changing Conditions

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In order to draw the right conclusions from olfactometric analyses as well as effectively prevent odour nuisance, taking into account confidence level of odour result is of great significance. Dependence of confidence interval for the expected value of odour abatement efficiency in determined conditions upon the number of observations is presented in The European Standard ‘Air Quality – Determination of odour concentration by dynamic olfactometry’ (EN 13725, CEN, 2003), which enables to plan the exact measurement session and establish the number of measurements to be conducted.

The objective of the research was to determine whether this dependence may also be applied in changing conditions. The effectiveness of six installations was assessed in the process of deodorization of waste gases characterized by the difficult to predict composition. Olfactometric measurements were performed in two large objects: wastewater treatment plant and manufacturing plant. Dry chemical sorption, a water scrubber and four plasma-assisted installations were examined. Nine observations (odour concentration measurements- in the crude and clean gas stream) were carried out for each installation.

The lung principle method was used for sampling, together with the application of dynamic pre-dilution with clean dry air. The measurements of odour concentration, made in accordance with the EN 13725 (2003) standard, conducted by the trained assessors, meet the selection criteria for the olfactory sensitivity. The samples were pre-diluted using the Strohlein olfactometer and odour concentration was measured using the Ecoma TO7 dynamic olfactometer.

The average efficiency of evaluated installations ranged between 9 and 78 %. The number of observations needed to obtain odour abatement efficiency of the desired confidence interval in real, changing conditions can be determined based on the European Standard. Nine observations were considered to be an optimal number of observations used for evaluating efficiency in changing conditions.

1. Introduction

The activity of municipal management, animal farms and manufacturing plants, are usually at the top of the list of air pollution complaints, mainly due to the odour impact. Whether these complaints are found to be justified, it can be determined by the field olfactometric inspection (Benzo et al., 2010; Kośmider and Krajewska, 2007; Zarra et al., 2010). If identification of the most troublesome emitter is possible, then it is also possible to calculate the level of waste gases deodorization - sufficient to eliminate odour nuisance (Bokowa, 2010). The problem arises, however, when it comes to the choice of installation,

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due to the insufficient and thus unreliable information about odour abatement efficiency, provided by both manufacturers and contractors of these installations as well as description of the evaluation methodology or simply not enough number of olfactometric measurements conducted.

According to the EN 13725 (2003) norm, determination of odour abatement efficiency (η_{od}) is based on determination of the relative difference in odour concentration in the crude and clean gas stream in determined conditions, using equation 1, or – 2 if a flow rate does not change as a result of deodorization

$$\eta_{od} = \frac{q_{od,crude} - q_{od,clean}}{q_{od,crude}} \tag{1}$$

$$\eta_{od} = \frac{c_{od,crude} - c_{od,clean}}{c_{od,crude}} \tag{2}$$

where q_{od} [ou_E/s] is the odour flow rate and c_{od} [ou_E/m^3] is the odour concentration.

The measurement of odour concentration should be conducted using the dynamic olfactometry by the panel of human assessors, meets the selection criteria for olfactory sensitivity. The confidence interval for an estimate of the expected value of the test results (m_D) is calculated, using the 3 formula.

$$\bar{y}_D - t \cdot \frac{s_D}{\sqrt{n}} \leq m_D \leq \bar{y}_D + t \cdot \frac{s_D}{\sqrt{n}} \tag{3}$$

where t is the Student's t-factor for $n = \infty$ (for 95 % confidence interval $t = 2$) and y_D is the average of the y_{iD} value that is the difference between the paired logarithms of odour flow rate of treated and untreated gas:

$$\bar{y}_D = \frac{\sum_{i=1}^{n} y_{i,D}}{n} = \frac{\sum_{i=1}^{n}\left(\log_{10} q_{od,clean} - \log_{10} q_{od,crude}\right)}{n} \tag{4}$$

where n is the number of paired odour concentration measurements. If a flow rate does not change as a q_{od} deodorization result, it can be replaced by the c_{od} in 4 formula.

The relation between m_D and the efficiency η_{od} shows the following equation:

$$\eta_{od} = 1 - 10^{m_D} \tag{5}$$

According to the EN 13725 (2003) standard, the width of confidence interval for the estimated η_{od} depends on the number of observations and expected value of efficiency. Figure 1 shows dependence of the 95 % confidence interval for the measured efficiency of deodorization upon the number of observations of odour abatement efficiency in determined conditions, calculated with the use of the laboratory precision $10^r = 3$. As shown in Figure 1, when the expected value of efficiency is unknown, nine observations are considered the optimal number of the paired odour c_{od} measurements (in the crude and clean gas stream) to establish the efficiency in determined conditions. More observations do not reduce the width of confidence interval significantly. The evaluation of efficiency based on fewer observations, often referred to in literature, imply a wide confidence interval, especially in the case of lower efficiency. The European Standard does not contain information about the way of analyzing cases where the source is unstable and emission is characterized by considerable and unpredictable time changes. In this paper confidence interval for the effectiveness of deodorization of waste gases, characterized by variable and difficult to predict composition, was investigated.

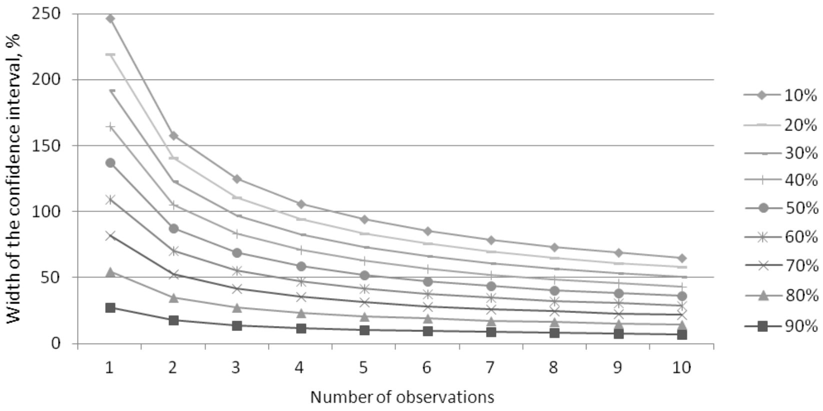


Figure 1: Dependence of the 95 % confidence interval for the expected values of odour abatement efficiency in determined conditions upon the number of observations (EN 13725, CEN, 2003)

2. Materials and methods

The olfactometric measurements were conducted in two large facilities in Poland - the mechanical-biological wastewater treatment plant with a comprehensive sludge management and pet food manufacturing plant with high variability of production during the day. The installations examined are presented in the following Table 1:

Table 1: Identification of source under investigation

Installation	Deodorisation method	Source	Flow rate, m^3/h
A	cold plasma	the primary sludge thickener	160
B	cold plasma	petfood production line	68 000
C	cold plasma	petfood production line	46 000
D	water scrubber	the thermal sludge drying stadion	8 200
E	cold plasma	the thermal sludge drying stadion	2 200
F	dry chemical sorption	the thermal sludge drying stadion	1 200

2.1 Sampling

The samples were collected to the bags made of polyethyleneterephthalate (Nalophan^{TM}) using the lung principle method. The *UPP-2* of *LAT* sampling system, allowing dynamic pre-dilution with clean dry air in the range from 2 to 24 times was used in sampling. This UPP system is a prototype tested by the *Laboratory for Odour Quality of the Air* in various conditions and facilities. This sampling system consists of three parts: control & executive element, sampling probe with a mixer and container where the sample is placed.

The stream of the ambient air inflowing to the control & executive element is cleaned and dried there and thereafter directed to the mixer of sampling probe, where it is mixed with the appropriate flow of odorous gas under investigation. The diluted sample is sucked into the bag, under the influence of vacuum in the container generated by the control & executive element. The dilution factor was controlled using a bubble flowmeter before and after sampling of each bag.

Sampling time of one bag lasted about 15 min for installation of ‘A’ and 5 minutes in other cases. A couple of samples before and after installation of a deodorizer were taken one after the other (at the shortest interval possible) in the case of A, B, C and two identical *UPP-2* sampling system in the case of D, E, F. Nine samples were collected for each installation. The linear velocity of gases was controlled before or after sampling of each bag. Conditioning bags were skipped due to high variation of conditions. A new bag and line with which the sample was directed into the bag were applied every time.

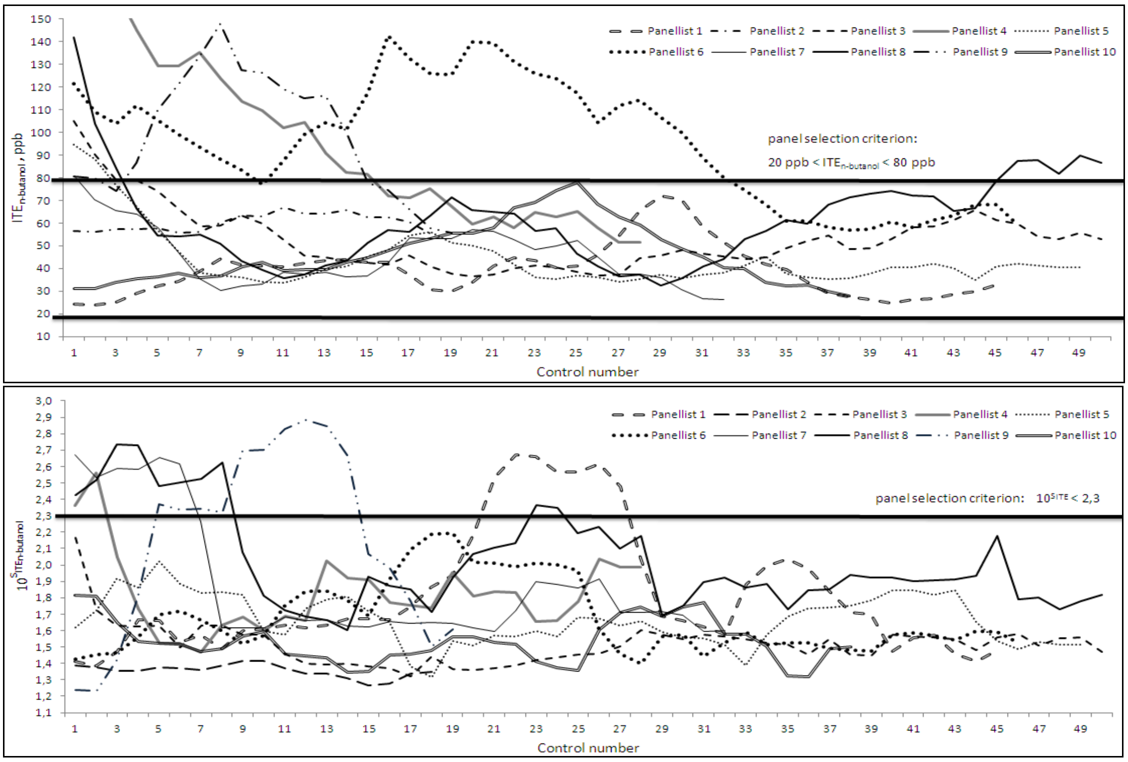


Figure 2: Control history of individual threshold estimate for n-butanol: $ITE_{n\text{-}butanol}$ (the geometric mean of 10 last measurements) of assessors (above) and the antilog of the standard deviation s_{ITE} control calculated using the logarithms (log_{10}) of the $ITE_{n\text{-}butanol}$ (below)

2.2 Determination of odour

The measurements of odour concentration were conducted according to the EN 13725: 2003 standard by the odour panel, whose members had been controlled for a period of time. The history of olfactory sensitivity of assessors participating in the measurement with the standard in the background is presented in Figure 2.

The olfactometric measurements of odour concentration c_{od} [ou_E/m^3] were conducted in the Olfactometric Mobile Laboratory of the Laboratory for Odour Quality of the Air. The conditions inside the laboratory were controlled (such as temperature, humidity and CO_2 concentration). The laboratory was installed beyond odour impact. The time between the sampling and the olfactometric analysis ranged from 1 to 6 h. Odour concentration was measured using the Ecoma TO7 dynamic olfactometer. A hundredfold, fiftyfold or twenty-fivefold pre-dilution (function of TO7) was used in the olfactometric analysis. When necessary, the samples were pre-diluted using the Strohlein olfactometer after transporting to the laboratory and before connecting to the TO7 olfactometer.

A YES/NO mode was used in the measurements. A decreasing geometric sequence with the common ratio 2, created by the consecutive Z values was presented to the odour panel. A sequence of decreasing dilutions was disturbed by the presentation of random blanks. During the measurement, presentation of a dilution series to the odour panel was repeated three times. At least two measurements were performed for each sample. One sample was analyzed at intervals of 30 to 60 minutes. 6 to 9 samples were analyzed per day. The total number of analyses conducted was 256.

According to the EN-13725 (2003) standard, correspondence of the results with the screening panel criterion was tested and ca. 3.9 % results were rejected upon verification.

2.3 Estimation of dependence of the confidence interval of odour efficiency on the number of observations

The results of odour concentration measurements collected from the inlet and outlet of the installations in varying conditions were used to evaluate dependence of the confidence interval for the effectiveness (n_{od}) on the number of measurements. For each installation, 8 – 9 calculation variants were conducted differing in the amount of the data collected. The data included the results of observations - variant 1 – 1st, variant 2 – 1st and 2nd, …, variant 9 – 1st, 2nd …, 9th. Temporary values of deodorisation effectiveness (n_{od}) and confidence intervals were calculated in accordance with Equation 3 - 5.

3. Results and discussion

Figure 3 presents the results of odour concentration measurements in samples collected from the inlet for the installations examined. Figure 4a and figure 4b shows the results of evaluation of deodorisation effectiveness for different calculation variants. Dependence of the confidence interval on the number of observations presented in Figure 5 is similar to the one presented in Figure 1, which means that appendix H of the EN 13725 (2003) standard may be used in planning a measurement session to evaluate the effectiveness of deodorisation techniques.

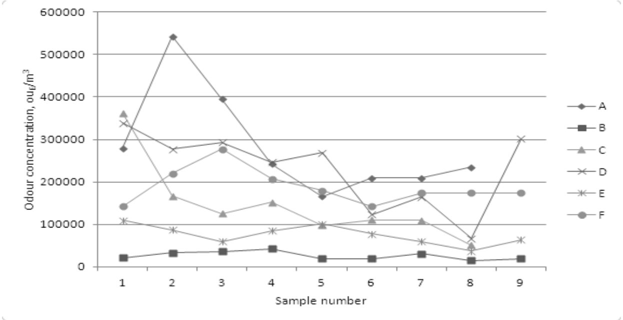
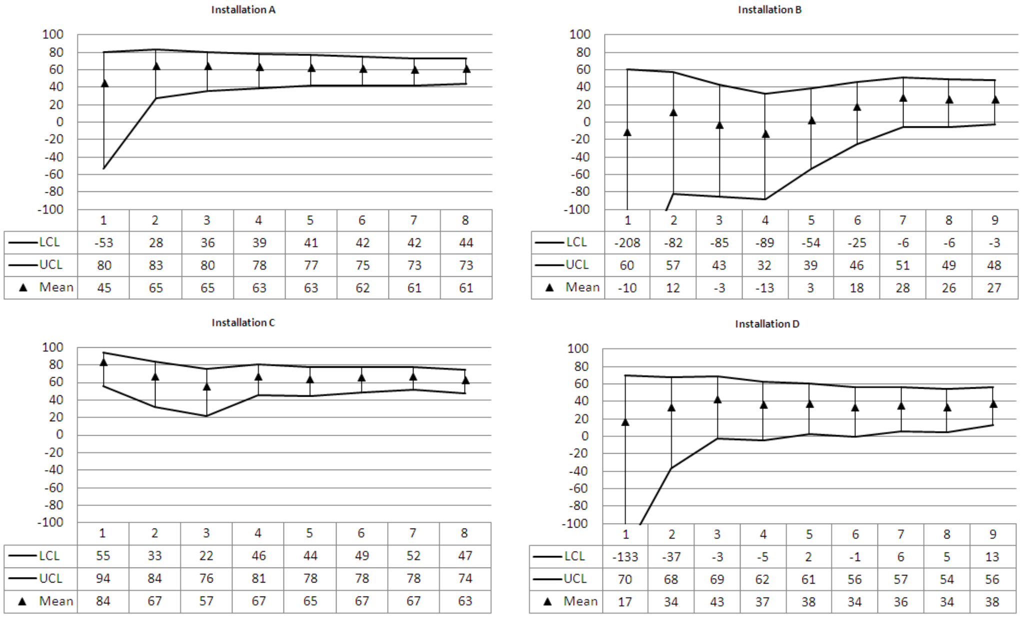


Figure 3: Odour concentration in samples collected from the inlet for the installations



	1	2	3	4	5	6	7	8
LCL	-53	28	36	39	41	42	42	44
UCL	80	83	80	78	77	75	73	73
▲ Mean	45	65	65	63	63	62	61	61

	1	2	3	4	5	6	7	8	9
LCL	-208	-82	-85	-89	-54	-25	-6	-6	-3
UCL	60	57	43	32	39	46	51	49	48
▲ Mean	-10	12	-3	-13	3	18	28	26	27

	1	2	3	4	5	6	7	8
LCL	55	33	22	46	44	49	52	47
UCL	94	84	76	81	78	78	78	74
▲ Mean	84	67	57	67	65	67	67	63

	1	2	3	4	5	6	7	8	9
LCL	-133	-37	-3	-5	2	-1	6	5	13
UCL	70	68	69	62	61	56	57	54	56
▲ Mean	17	34	43	37	38	34	36	34	38

Figure 4a: Results of evaluation of deodorisation effectiveness for different calculation variants for installation A (top left), B (top right), C (down left) and D (down right)

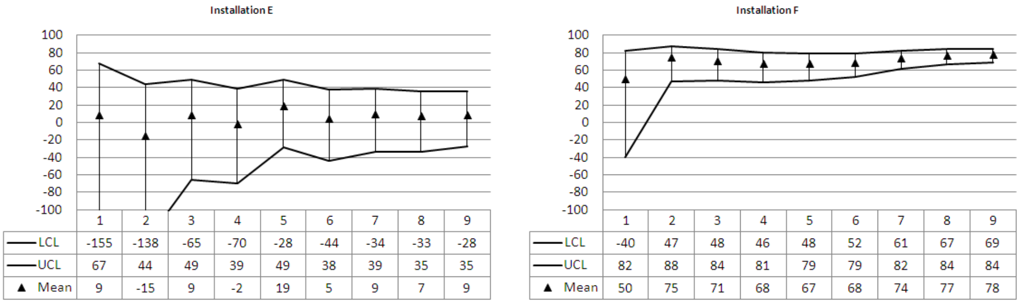


Figure 4b: Results of evaluation of deodorisation effectiveness for different calculation variants for installation E (left), F (right)

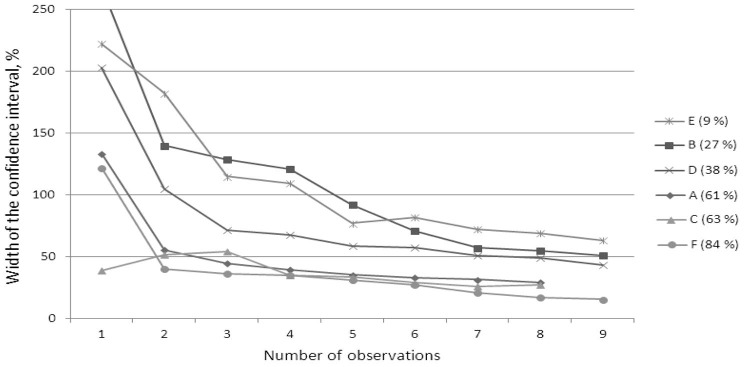


Figure 5: Dependence of the 95 % confidence interval for the measured efficiency of deodorization on the number of observations

4. Conclusion

It can be concluded that 9 observations is the optimal number for research facilities characterized by varying conditions. Fewer measurements imply a wide interval of confidence, which may result in making wrong decisions concerning the avoidance of odour nuisance.

The basis for making investment decision in choosing a particular deodorising installation should be assurance of achieving effectiveness, which should be confirmed by the olfactometric measurements conducted in a similar object together with provision of confidence intervals for this value. This is important as the assessment of a range of odor impact, determined on basis of the average value of effectiveness, may vary, if the real effectiveness is at the lower value of the confidence interval.

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