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Comparison of Two Types of Field Olfactometers for Assessing Odours in Laboratory and Field Tests

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To determine odour concentrations in field conditions, portable dynamic olfactometers are used especially in North America, but those solutions are gaining popularity in Europe. This article compares results of using two field olfactometers for assessing odors. Nasal Ranger (NR) and Scentroid SM-100 has been used for determining dilution to threshold ratio (D/T) and, whereby, the odour concentration of gas samples. NR range is 2 D/T to 500 D/T, and Scentroid SM-100's is from 2 to 30,000. Under laboratory conditions, different concentrations of, inter alia, hydrogen sulphide as well as tetrahydrothiophene (used as an odorant in LPG) were tested. Concentrations of odorants were measured by gas chromatograph Photovac Voyager. Also, field researches were conducted – the paper compares those olfactometry field techniques used in wastewater treatment plant and municipal landfill. Statistical tests (i.e. test of the difference between the two means, statistical significance of differences, t-Student and Pearson's test as well as rang order correlations) were performed to determine the correlation between values obtained by NR and SM-100 olfactometers. Those instruments correlated well in the laboratory tests with very strong correlation factor values, wherein in most cases SM-100 results of D/T were higher than NR. In the field tests, correlation depended on the source of an odor. In present article, the correlation of higher range of D/T determined by two field olfactometers was checked – those values for hydrogen sulphide were between 2 and 500.

1. Introduction

Olfactometric methods could be divided into indirect (static) and direct (dynamic) olfactometry. Dynamic olfactometry is now a widespread and common technique for the quantification of odour emissions in terms of odour concentration (Munoz et al., 2010). It is based on air analysis directly from the source, whereas in the case of static olfactometry, the sample must be pressed into a suitable container and - in a second stage - be analyzed. To avoid adsorption processes or condensation during sample storage, it needs to use containers made of suitable materials. The main advantage of dynamic olfactometry is to minimize both the above cases, as well as the reaction between the chemical compounds during transport between the source of the odour and the research laboratory. If we consider the olfactometric analysis which requires the participation of a panel of experts, dynamic olfactometry has the disadvantage, that it is very expensive due to the necessity of probant's travel to the scene of odour event. Furthermore, there is a risk that the presence of test persons at the site can affect their responses - on the one hand due to the sample's origin awareness, on the other hand, the possibility of odour in the background. In some instances, field olfactometry may be used in conjunction with laboratory-based methods. For example, air samples from an odour souce may be collected and analyzed in an olfactometry laboratory to quantify source emission rates, while field olfactometry is used to assess odour transport in the surrounding area (Henry et al., 2011). Field olfactometry can be used as a proactive monitoring or enforcement tool for confident odour measurement at property lines and at locations throughout a neighboring community (Nicell, 2009). Field olfactometers are excellent for real-time analysis, but are limited due to insufficient dilution capabilities, panelists' accessibility to odour events, sample replication and sampling duration (Traube et al, 2011). Odour assessment by DDO (dynamic dilution olfactometry) is even more limited than field olfactometers due primarily to the loss of agricultural odorants in containers during

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storage (Traube et al., 2006, Parker et al., 2010) and large variability between odour panels. Also, Traube et al. (2011) mention other major limitations, i.e. the inability of odour standards used in DDO to model the characteristics or intensities of odours associated with animal feeding operations (AFO), difficulty in quantifying faint odours because of odours of the storage containers and differences introduced by sample collection techniques. The method of producing odour dilution ratios with the field olfactometer consists of mixing two “volumes” of carbon-filtered air with specific “volumes” of odorous ambient air (Pan et al., 2007). Measurement result in the field olfactometry is the degree of fragrant gas dilution, set by assessment at the time that the gas appears in the sensibility threshold. It's written as the ratio of the mixed gas streams D/T (Dilution-to-Threshold). Actually, two main instruments called Nasal Ranger (St. Croix Sensors, Inc.) and SM-100 (IDES Canada Inc.) are used. Those olfactometers, a simplified portable dilution devices, help to determine the odour levels and give a reading of the D/T ratio (Brandt et al., 2010, Benzo et al., 2012, Capelli et al., 2013) as well as may be a useful tool for downwind odour intensity measurement (Pan et al., 2007). Olfactometer Nasal Ranger is a lightweight, portable device with two replaceable filter cartridges with activated carbon for air purification. It includes built-in channel system for mixing and sharing gas streams - deliberate targeting known part of the inhaled air by bypassing filters. The control valve is used to adjust one of the eleven values of D/T (2, 4, 7, 15, 30, 60, 100, 200, 300, 400, 500) and to set the value of "blank", at which the researcher breathes by purified air stream. When measuring with the olfactometer Scentroid SM-100, the polluted air is diluted with technical air pumped from bottle. Scentroid patented valve allows to set it at 15 positions corresponding to fifteen values of D/T. The system of interchangeable plates with holes of different diameters allows for D/T in the range 2-30,000. During the measurement, as in the laboratory dynamic olfactometry, researchers increase the value of D/T (the share of fragrant air flow) until he achieve individual threshold of the odor.

2. Purpose and scope of the research

The purpose of the research was to evaluate the use of two types of field olfactometers to study the odour concentrations in laboratory conditions and on the selected object and its comparative analysis. Comparative analysis of the Nasal Ranger and Scentroid SM-100 olfactometers included the appointment of odour concentrations of the following compounds: hydrogen sulfide and tetrahydrothiophene. The gas contained the above-mentioned compounds was diluted with clean air in the tedlar bags and subjected to examination by field olfactometers. The concentration of the compounds was determined using a gas chromatograph Photovac Voyager. As Munoz et al. (2010) mentioned, odorous emissions from sewers and wastewater treatment plants (WTP) are a complex mixture of volatile chemicals that can cause annoyance to local populations, resulting in complaints to wastewater operators. Due to the variability in hedonic tone and chemical character of odorous emissions, no analytical technique can be applied universally for the assessment of odour abatement performance. Sensory analysis of odors in WTP allows the sensorial component of odors to be evaluated both qualitatively and quantitatively using the human nose as the detector (Munoz et al., 2010). Therefore these techniques measure the total effect of the target WTP's odour on human perception (Gostelow et al., 2001). So, in addition, the determinations of odour concentration on selected municipal wastewater treatment plant had been made.

3. Test compounds

Tetrahydrothiophene – THT (C_4H_8S) is an organic compound used for odorant gas network. It comes from a group of cyclic thioethers with high volatility. It is a colorless liquid with a characteristic odour and very intense. (DJChem, 2014). The lower limit odour is 3.7 $mg \cdot m^{-3}$ and the same compound is three times heavier than air. THT is highly irritating to the skin and mucous membranes. For too long inhalation by humans causes respiratory irritation, congestion in the lungs, headache, dizziness, nausea and palpitations. In larger doses, causes hyperactivity, liver damage, until ultimately leads to the death-like drug overdose. (MAK, 2011)

Hydrogen sulphide - H_2S is produced by anaerobic fermentation of manure, and high concentrations are toxic to humans and animals. A H_2S concentration of 50 ppm can cause dizziness, irritation of the respiratory tract, nausea, and headache. Death from respiratory paralysis can occur with little or no warning when exposed to concentrations exceeding 1,000 ppm (Ni et al, 2002) Hydrogen sulphide is a colorless, flammable gas with a characteristic odour of rotten eggs. It is produced both naturally and through human activity. Hydrogen sulphide is a gas and, therefore, inhalation is the most relevant route of exposure to humans. Acute inhalation exposure to low concentrations of hydrogen sulphide may result in irritation to the mucous membranes of the eye and respiratory tract. Acute exposure to high concentrations of hydrogen sulphide results in depression of the nervous system, loss of consciousness and respiratory paralysis. Other health effects have been reported, the most sensitive being the respiratory, neurological and ocular system (IPCS, 2003, ATSDR, 2006).

Although the odour threshold has been reported to be around 0.011 mg·m^{-3} (0.008 ppm) in naive subjects, olfactory paralysis occurs at greater than about 140 mg·m^{-3} (100 ppm). The loss of odour perception makes hydrogen sulphide especially dangerous since a few breaths at around 700 mg·m^{-3} (500 ppm) is lethal (IPCS, 2003). Hydrogen sulfide is commonly used as a surrogate of sewage gases (Wang et al., 2011)

4. Object of the study

Tests have been performed at the wastewater treatment plant purifying sewage flowing in the sewage distribution system and wastewater delivered by slurry tank fleet to the catchment point localized in the treatment plant. Sewage treatment plant works in a mechanical-biological system with biological dephosphatation, denitrification and nitrification of simultaneous chemical precipitation of phosphorus. It has one technological sequence, where waste, in the first phase, is subjected to mechanical methods of purification. In the second phase, occurs the biological purification in the dephosphatation chamber and four sludge chambers with the possibility of simultaneous removal of phosphorus - two of them together with the two secondary settlers are the emergency unit of the plant. From denitrification and nitrification chambers wastewater enters the radial secondary settling tanks, then discharged into a receiver. Excessive sludge retained in the primary and secondary clarifiers is subjected to mechanical and gravitational compaction and fermentation processes in the fermentation chambers. After that, sludge is discharged into reservoirs of digested sludge and goes to the drainage, drying and liming station. Treated sludge is exported to the storage square outside the plant. (Długosz and Gawdzik, 2012).

5. Results and discussion

5.1 Test compounds

Table 1 contains result of D/T and odour concentration of tetrahydrothphene (THT) in laboratory conditions.

Table 1. Results of THT odour concentration and D/T (means) in laboratory conditions (41 samples)

Odorant concentration		SM-100		NR	
ppm	mg·m^{-3}	D/T	Odour concentration ou·m^{-3}	D/T	Odour concentration ou·m^{-3}
0.298	1.07464	6	11	6	10
0.530	1.91128	6	12	7	11
1.021	3.68192	50	52	30	43
2.112	7.61627	60	70	45	58
3.312	11.9437	79	85	60	78
3.734	13.4655	144	162	100	142
4.168	15.0306	218	268	200	284
10.800	38.9468	265	276	200	284

To verify the hypothesis of equal average value of D/T at the 0.05 significance level, the difference between two averages test was performed. To search for homogeneity of variance, Levene's and Brown-Forsythe (B-F) tests were performed. Because the t-Student's test normality distributed traits assumption is not met, applied its nonparametric counterparts - U Mann-Whitney (U M-W) test and two-sample Kołmogorow-Smirnov (K-S) test. The results are summarized in Table 2.

Table 2: Homogeneity of variance and U Mann-Whitney as well as Kołmogorov-Smirnov tests

	SM-100			NR			p (one-sided test)	Variance homogeneity			
	mean	SD	n	mean	SD	n		p Levene	p B-F	p U M-W	p K-S
THT	99.6	94.9	41	77.8	75.9	41	0.13	0.07	0.27	0.46	> 0.10
H_2S	194.4	209.6	145	173.6	176.3	145	0.18	0.10	0.22	0.67	> 0.10

For the data D/T obtained during the determination of THT and H_2S using olfactometers NR and SM-100, Pearson correlation factor was calculated. Also, to determine the correlation between the values of D/T of THT and H_2S, obtained by olfactometers SM-100 and NR, Spearman R, Kendall's Tau Gamma rank correlation factors were used (Table 3).

Table 3: Results of correlation tests of D/T THT and H2S obtained using olfactometers NR and SM-100

Compound	Pearson correlation factor r(X, Y)	Determinant factor	Rank correlation factor		
			R Spearman	Tau Kendall	Gamma
THT	0.98	0.97	0.9791	0.9297	0.9429
H_2S	0.93	0.86	0.9606	0.8970	0.9245

5.2 Field tests

Table 4 contains meteorological conditions during field test on the water treatment plant. Results obtained during field tests of D/T determination by NR and SM-100 olfactometers in four series on the water treatment plant are placed in the table 5. In each series 24 points were examined.

Table 4: Meteorological conditions during examinations on 16.12.2013-17.01.2014

Date	Temperature °C	Humidity %	Wind speed $m \cdot s^{-1}$	Wind direction compass points	Cloudiness octants
16.12.2013	6,6-6,9	83-85	2.11-2.64	SW-W	8/8
4.01.2014	7,5-7,7	84-86	0.86-2.12	SW-S-W-SW	8/8
11.01.2014	5,0-5,3	85-87	4.83-5.30	W	8/8
17.01.2014	2,6-3,2	85-87	4.13-5.82	W	8/8

Table 5: Results of field tests of D/T range determination by NR and SM-100 in four series on WTP

Source of odor	Nasal Ranger		Scentroid SM-100	
	D/T	Odour concentration ($ou \cdot m^{-3}$)	D/T	Odour concentration ($ou \cdot m^{-3}$)
Raw wastewater	2-60	4-78	3-100	5-155
Scrats	0-30	2-43	1-34	3-40
Biogas container	7-30	16-31	6-23	9-24
Activated sludge	0-30	2-31	1-27	3-28
Excess sludge	2-30	5-43	2-44	4-45

For the data D/T obtained through the olfactometers NR and SM-100 for all series, the Pearson, R Spearman, Kendall Tau and Gamma correlation coefficients were calculated. Results are summarized in table 6. For each source of odors in wastewater treatment plants, statistical analyzes was performed.

Table 6: Correlation between D/T results obtained by NR and SM-100 for all series

Pearson	Spearman	Tau-Kendall	Gamma
0.89	0.91	0.82	0.92

In Table 7 are summarized results of the test difference between two averages, and tests of homogeneity of variance F, Levene and Brown-Forsyth.

Table 7: Results of difference between two averages and tests of homogeneity between the determinations of D/T in different sources (bold: p<0.5)

Source of odors	SM-100			NR			p (one-sided)	Variance homogeneity		
	mean	SD	n	mean	SD	n		p F	p Levene	p Brown-Forsythe
Raw sewage	26.7	23.2	84	20.9	16.3	84	**0.03**	**0.001**	**0.04**	**0.03**
Scrats	15.2	11.8	30	14.2	12.2	30	0.39	0.85	0.98	0.89
Excess sludge	15.7	11.5	20	13.7	8.5	20	0.27	0.19	0.13	0.27
Activated sludge	9.7	8.4	44	7.8	6.6	44	0.12	0.11	**0.02**	0.24
Biogas container	15.4	5.1	12	14.2	6.1	12	0.31	0.57	0.70	0.93

Because the assumption of normal distribution of the survey was not met (coefficient of Shapiro-Wilk was, depending on the source of, 0.000-0.0291) Mann-Whitney U and Kołmogorow-Smirnov tests were used. Results are summarized in table 8.

Table 8: Correlation between D/T results obtained by NR and SM-100 for different types of sources

Source of odors	Correlation coefficient			
	Pearson	R Spearman	Tau Kendall	Gamma
Raw sewage	0.89	0.92	0.84	0.94
Scrats	0.91	0.92	0.82	0.91
Excess sludge	0.92	0.88	0.76	0.89
Activated sludge	0.82	0.86	0.73	0.83
Biogas container	-0.05	0.02	0.03	0.04

McGinley and McGinley (2003) compared the Barnebey Sutcliffe Box Scentometer (BS) and the Nasal Ranger (NR) in and environmentally controlled room. Newby and McGinley (2004) compared NR, BS and laboratory-based olfactometry for assessing odour in the field. They found no significant difference between BS and NR at a 95% confidence interval and a Pearson correlation coefficient of 0.82 (Henry et al., 2011). Also, Henry et al (2011), in comparison between NR and dynamic triangular forced-choice olfactometry (DTFCO), the Mask Scentometer and an odour intensity reference scale (OIRS) studied the NR D/T ratio between 0 to 60.

Bokowa (2012) compared the results for the ambient odour concentrations measured by different techniques: Scentroid SM-110, NR, ambient sampling with odour panel evaluations and source sampling with dispersion modelling analysis. She found that Scentroid results were generally higher (24-38%) than the results obtained by the traditional odour panel evaluations using a dynamic olfactometer with eight panelists. There were a very good correlation between the results obtained by the Scentroid SM-110 and the traditional odour evaluations using a dynamic olfactometry, whereas the Nasal Ranger results were significantly lower. Bokowa (2012) also wrote, that there is up to 38% difference between results obtained by SM-110 and standard dynamic olfactometry with high odors in the range of 2,000 to 4,000 ou.

6. Conclusions

This article discusses the results of studies comparing the D/T obtained using two types of field olfactometers SM-100 and Nasal Ranger. For this purpose, odorimetric tests of two odorants: H_2S and THT as well as examinations in the sewage treatment plant were performed. On the basis of statistical tests, it was found that there is no evidence to reject the null hypothesis of equal average values of D/T obtained during THT and H_2S research using the above olfactometers. Variations of the results are homogeneous. There is no reason to reject the hypothesis of a lack of significant difference between D/T obtained by NR and SM-100, and these results are not significantly different. The value of the Pearson correlation coefficient indicates a strong linear relationship (correlation very high) between indicated parameters. Similar results were obtained in the case of research on wastewater treatment plants, taking into account, inter alia, and various sources of odors. Studies have shown, however, that the hypothesis of homogeneity of variance should be discarded for the results of the odorometric analyzes of raw sewage and activated sludge. Despite this, there is no reason to reject the hypothesis of a lack of significant difference between D/T. Tested variables showed very high value of the Pearson correlation coefficient - based on the tests performed it can be concluded, that the results of odorometric examinations using two types olfactometers are highly consistent. Any differences are primarily attributable to the uncertainty measurements performed by Nasal Ranger olfactometer. Apart from the fact that the accuracy and reproducibility of the dilutions is 10% for D/T = 2-60 and 5% for D/T = 60-500, is that - due to step between the values of the ratio of the purified and unpurified air - determination uncertainty. This may explain the phenomenon observed by Bokowa (2012) of the value of D/T obtained by Nasal Ranger were lower than those obtained in the tests stationary olfactometry.

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