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Odour emission from primary settling tanks after air-tightening

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The purpose of the present article was to determine odour emission rate from primary settling tanks after hermetisation. The paper presents the results of the research on odour emission from four settling tanks, covered with self-supporting aluminium domes with a diameter of 52 meters, located on urban wastewater treatment plants, with the planned flow capacity equal to 200 000 m^3/day. Altogether, the olfactometry analysis of 189 samples of polluted air pulled from the domes with the use of an air blower which has efficiency of 12 000 m^3/h was conducted. The results of odour concentration measurements were in a range of approximately 10 800 to 763 600 ou_E/m^3. Average odour emission rate was equal to 102 $ou_E/(s \cdot m^2)$. The obtained value is much higher than the literature data, available for non-hermetised settlers only. This rate enables better estimation of the odour stream that has to be deodorised after sealing the settling tanks.

Keywords: odour emission, odour emission rate, air tightening, primary settling tank, wastewater treatment plant.

INTRODUCTION

Nowadays, technologies and installations that have the least possible impact on the environment are desirable[1–2]. One of the most onerous impacts is odorous impact[3–7]. Odour nuisance can be counteracted in various ways, such as: change of type of resources or technologies, modification of process parameters, increase of ejection point of polluted air to the atmosphere, hermetisation, deodorisation and also – in the case of new objects – proper localization[8–18]. The choice of the optimal solution is possible by modelling odorants dispersion. As a result of such calculations, the olfactory range of the installation impact can be estimated for the subject matter in question[19–23]. However, the use of deodorisation with a certain odour abatement efficiency is frequently the only possible solution.

There are various methods of deodorisation. The choice of the right one depends strictly on the parameters of the air stream to be treated, such as: volume flow, temperature, humidity or pollutant charge, as well as expected odour concentration reduction level[24]. In order to design a suitable deodorising installation, knowledge of the odour concentration in the treated stream is needed. This quantity can be estimated in two ways: by performing olfactometric measurements at the source of emission, or by using literature data – odour emission rates[25–29]. However, there are facilities, such as primary settling tanks that are a dominant source of odour nuisance generated by wastewater treatment plants, where determination of odour emission is problematic[30–34].

The primary settling tanks are the last stage of the mechanical wastewater treatment and are large, usually round or rectangular tanks with proper instrumentation, where sewage flows through. Their task is to remove easily falling suspensions (as a result of sedimentation) as well as suspensions lighter than water, which flow to the surface.

The primary settling tanks are diffusion sources, characterized by large surface and unorganized variable emission of pollutions. The size of this emission depends on numerous factors, such as: composition of wastewater, their turbulence, pH, temperature, size of mass exchange area (liquid – gas), and wind velocity over this surface[24, 31, 35–37]. Therefore, taking representative samples for olfactometric analysis is problematic[38–41]. The methodology for collecting samples to determine odour emission from surface sources is still not standardised. In practice, wind tunnels or shields are used to cover section of sewage surface, enforcing flow of known size underneath them (see Fig. 1). Samples of polluted air are taken at the outlet from the tunnel/shield, in a similar way as organised emission. Construction of tunnels and shields is varied, which can significantly affect the measurement results[39].

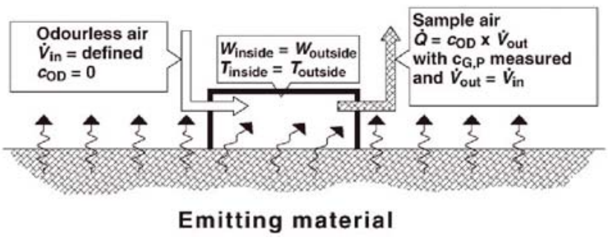

Figure 1. Principle of sampling on a passive surface source[24]

Literature data on odour emissions from primary settling tanks are few and far between. In 2004 Frechen published odour emission rates from primary settling tanks, relating to one m^3 of sewage area, at the level of 0.64 ou_E/s, and for weir – 2.14 ou_E/s (see Table 1)[24]. In 2015 Sówka, Sobczyński and Miller presented the results of odour emission measurements from the primary settler obtained in selected months, ranging from 30.9 $ou_E/(s \cdot m^2)$ to 72.9 $ou_E/(s \cdot m^2)$ (see Table 2)[42]. In turn, the Sobczyński, Sówka and Bezyk publication (also from 2015) presents 14 results of odour emission measurements from the primary settling tank (see Table 3), carried out in the period from October to February, whose average

Table 1. Odour emission rates from the primary settling tanks according to[24]

Primary sedimentation	Odour emission rate [$ou_E/(s \cdot m^2)$]				No. of values [pcs.]	No. of WWTP [pcs.]
	Low	Average	High	Maximum		
surface	0.11	0.64	3.58	109.39	38	10
weir	0.35	2.14	13.16	20.44	22	7

Low – mean minus standard deviation; High – mean plus standard deviation; Maximum – maximum value obtained from the measurements; No. of values – number of values on the basis of which the mean was calculated; No. of WWTP – number of objects on the basis of which the research was conducted

Table 2. Odour emission rates from the primary settling tanks according to[42]

Month	May	June	July	August	October	December	February
Sewage temperature [°C]	16.3	17.2	20.4	20.6	19.7	16.7	15.4
Odour emission rate [$ou_E/(s \cdot m^2)$]	32.5	31.9	41.0	72.9	38.6	31.2	30.9

Table 3. Odour emission rates from the primary settling tanks according to[43]

Odour emission rate [$ou_E/(s \cdot m^2)$]													
40.6	28.5	68.5	28.5	44.9	43.4	13.6	18.8	23.0	10.6	24.9	20.9	7.9	8.8

value, related to 1 m^2 of the sewage area, is 22,8 $ou_E/(s \cdot m^2)$, and the minimum and maximum values of 7,9 $ou_E/(s \cdot m^2)$ and 68.5 $ou_E/(s \cdot m^2)$ respectively[43].

Differences in the above mentioned values of the odour emission rates from the primary settling tanks may have a significant impact on the values determined with their use. As a result, this may lead to an incorrect estimation of the odour impact range of the primary settling tanks or the size of the odour flow rate after settlers have been sealed air tight. The literature on the subject is missing information on odour emission from primary settling tanks after hermetization. In this work, the rate of odour emission from hermetized primary settling tank was estimated on the basis of a large set of results of olfactometric measurements conducted under real conditions.

OBJECT OF STUDY

The research was carried out on a mechanical – biological municipal wastewater treatment plant with an increased degree of biogen removal and full processing of sewage sludge. This treatment plant treats wastewater from both households and industrial plants (e.g. food industry, pharmaceutical industry, automotive industry, cosmetics industry, printing industry and chemical industry). Its designed capacity is 200 000 m^3/d. Four identical horizontal flow radial settlers with chain scrapers were tested (see Fig. 2). The technical parameters of each of the settling tanks are presented in Table 4.

Table 4. Technical parameters of the primary settling tanks on the basis of which the tests were carried out

PARAMETER	VALUE
Setller diameter	52 m
Depth	2–4.6 m
Active volume	3900 m^3
Average retention time for Qmax	1.03 h
Average retention time for Qśr	1.08 h
Maximum hydraulic load	1.78 $m^3/(m^2 \cdot h)$
Average hydraulic load	0.98 $m^3/(m^2 \cdot h)$

Settling tanks worked simultaneously. The wastewater was distributed evenly to them from the distribution chamber. These were the wastewater after the retention of larger solid contaminants on the screenings and removal of mineral suspended matter in sand traps.

RESEARCH METHODOLOGY

Measurements of odour emission from the settling tanks were carried out after their air tightening with the use of a „solid – self supporting" aluminium cover (see Fig. 3). The flow of the ventilation air from each of the settling tanks was 12 000 m^3/h. The measurments were carried out over a period of 6 years, starting in 2014, when the first two covers were installed. A total of 6 measurement sessions were conducted, one each in February (2015), and October (2017) and three each in September (2014, 2018 and 2019). The measurement sessions lasted from 2 to 4 days, depending on the number of settling tanks testet (see Table 5). Only one settling tanks was

Figure 2. Primary settling tanks before hermetization

Figure 3. Primary settling tanks after hermetization

Table 5. Characteristics of the measurement sessions

Measurement session	D [days]	PS [pcs.]	S [pcs.]	Atmospheric conditions								
				T [°C]			P [hPa]			H [%]		
				a	l	m	a	l	m	a	l	m
09.2014	2	2	18	17	13	21	-	-	-	86	61	98
02.2015	4	4	36	6	0.4	10	1003	988	1020	63	41	79
05.2015	3	3	27	16	12	20	1007	1005	1009	47	20	68
10.2017	4	4	36	11	8	20	1004	999	1011	93	57	100
09.2018	4	4	36	18	14	24	1011	1008	1018	70	36	100
09.2019	4	4	36	17	9	24	1005	999	1010	58	34	100

D – length of the measurement session, PS – number of settling tanks tested, S – total number of the samples taken, T – air temperature, P – atmospheric pressure, H – atmospheric humidity, a – mean value, l – minimum value, m – maximum value

assessed every day. Nine ventilation air samples were taken from each settling tank. Samples were taken at different times of the day, on average every 1,5 hours.

Between subsequent observations, atmospheric conditions were monitored with the use of Testo 400 meter and appropriate probes. Table 5 summarises the sampling atmospheric conditions, the average value (a) of the atmospheric pressure, temperature, humidity, and their lowest (l) and highest (m) values.

The „lung" method without pre-dilution was used for sampling. The sampling system consisted of a rigid container, in which the bag was placed, a control system producing a vacuum in the container and a probe in the form of a teflon tube with an inside diameter of 4 mm (see Fig. 4). Two probes were used alternately for each measuring point. Each probe was flushed with clean air before the next use. Samples were taken continuously for about 10÷20 minutes at a speed of about 50÷100 l/h. Each sample was taken into a new bag made of Nalophan film and a teflon tube with a stopper.

Figure 4. Sampling for the determination of odour concentration

Immediately after sampling, the samples were transported to the Mobile Olfactometric Laboratory, installed about 2 km from the research facility, where the olfactometric analysis was performed. During the measurements, environmental conditions, such as temperature and CO_2 concentration, in the laboratory were monitored. The determination of odour concentration (c_{od} [ou_E/m^3]) was carried out using the dynamic dilution method according to the EN 13725:2003 „Air quality – Determination of odour concentration by dynamic olfactometry"[25] using a TO7 (measurement sessions in 2014 and 2015) or TO9 (measurement sessions in 2017, 2018 and 2019) four-panelist station olfactometer. They were attended by an experienced odour panel with olfactory sensitivity to n-butanol controlled in accordance with the EN 13725 (the panelists conducted between several dozen to more than 2000 controls in their measurement history). A total of 18 panelists took part in the study. The yes/no method was used to present samples to the panelists. The samples were pre-diluted before connection to the olfactometer. Two odour concentration determinations were performed for each sample.

The results from all the settling tanks obtained during one measurement session were treated as one set of data, for which the average and 95% confidence interval were calculated. The confidence interval of the measured odour concentration for the measurement session was determined from the relationship:

$$\overline{y_w} - t \cdot \frac{s_r}{\sqrt{n}} \le m \le \overline{y_w} + t \cdot \frac{s_r}{\sqrt{n}}$$

where

y_w – average of the measurement results

m – expected value

t – Student`s factor for $n = \infty$ ($t \approx 2$ for 95% confidence interval)

n – number of observations (n depending on the measurement session)

s_r – standard deviation for precision measurement determined as a result of the international Proficiency Test of Olfactometry in a given year.

RESULTS AND DISCUSSION

The set of results of odour concentration (c_{od}) measurements in the ventilation air stream of the primary settling tanks after air-tightening, obtained in particular measurement sessions is shown in Fig. 5. The mean value of odour emission ($q_{od,mean}$ – geometric mean from n observations in a given measurement session) together with 95% confidence interval of the result obtained for particular measurement sessions is presented in Table 6.

Table 6. Results of the evaluation of the odour emission in individual measurement sessions

Measurement date	Number of observations (n [pcs.])	Odour emission, q_{od} [ou_E/s]				
		Minimum value ($q_{od,min}$)	Maximum value ($q_{od,max}$)	Mean value ($q_{od,mean}$)	95% confidence interval	
09.2014	18	160 046	637 710	327 595	274 160	391 445
02.2015	36	197 735	319 086	246 956	217 739	280 093
05.2015	27	92 785	241 616	143 051	123 694	165 437
10.2017	36	36 083	210 907	106 828	94 897	120 258
09.2018	36	148 534	2 545 213	456 433	403 636	516 135
09.2019	36	42 042	724 769	180 682	170 396	191 590

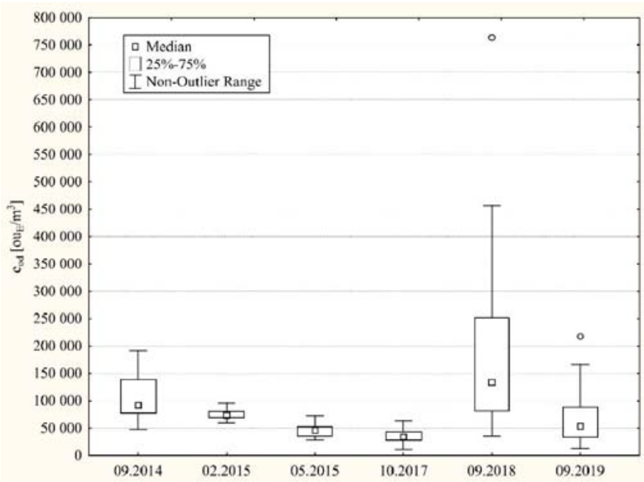

Figure 5. Distribution of odour concentration measurement results obtained in individual measurement sessions

Table 6 also shows the lowest ($q_{od,min}$) and the highest ($q_{od,max}$) value of odour emission recorded in particular measurement sessions.

The results obtained confirm high variability of odour concentration in the ventilation air stream of the primary settling tanks after air-tightening. Both the highest values and the highest spread of the results were obtained in September 2018. This may be related to weather conditions and the associated residence time of the wastewater in the settling tanks. The period preceding the session was characterized by low precipitation and relatively high temperatures (see Table 7). In turn, the lowest values were obtained in October 2017, the period with the most rainfall. Therefore, it can be assumed that the more wastewater is diluted by precipitation and stays shorter in settling tanks, the lower the odour emission from the primary settling tanks. In addition, it can be noted that the higher the temperature of the atmospheric air, the greater the variation in odour concentration in the air discharged from the settling tanks. However, determination of this relationship is a separate research topic.

Table 7. Characteristics of atmospheric conditions for the week and month preceding a given measurement session[44]

Measurement date	Average air temperature [°C]		Total rainfall [mm]	
	weekly	monthly	weekly	monthly
09.2014	12.5	15.6	8.9	43.5
02.2015	1.8	0.5	0.0	17.7
05.2015	12.5	12.1	4.1	28.8
10.2017	10.9	12.0	17.6	51.7
09.2018	17.2	18.7	4.9	13
09.2019	13.7	18.3	3.8	41.7

weekly – covers 7 days before the end of a given measurement session; monthly – covers 30 days before the end of the measurement session

Table 8 shows the average values of odour emission rates from the primary settling tank after air-tightening (together with the 95% confidence interval of the result), calculated for individual measurement sessions. These ratios are expressed in odour units per second and related to 1 m^2 of sewage area. The average value of the rate for the whole set of data collected during six measurement sessions (total of 189 values) was 102 $ou_E/(s \cdot m^2)$. The rate corresponding to the highest recorded value of the odour concentration in this set is 1200 $ou_E/(s \cdot m^2)$. The values obtained differ significantly from the literature data[24, 42, 43], determined on the basis of studies carried out in open primary settling tanks (without air-tightening). It is therefore confirmed that for the determination of odour emissions from large surface sources (such as settling tanks), the method of sampling for olfactometric analysis is important. Therefore, the rates determined for this source before air-tightening cannot be used to estimate the size of the polluted odour stream, emitted from the primary settling tanks after air-tightening. It is necessary to apply the rate relating to air-tightened settling tanks.

Table 8. Odour emission rates from the primary settling tanks after air-tightening

Measurement date	Odour emission rate [$ou_E/(s \cdot m^2)$]		
	Mean value	95% confidence interval	
09.2014	154	129	184
02.2015	116	103	132
05.2015	67	58	78
10.2017	50	45	57
09.2018	215	190	243
09.2019	85	80	90

CONCLUSIONS

Primary settling tanks are an important source of odour nuisance at wastewater treatment plants. One of the ways to reduce this nuisance is hermetization of the settling tanks and deodorization of the ventilation air. When estimating the amount of pollutants in the air to be treated, rates related to the settling tanks after air-tightening should be used. Using the values set for open tanks, the projected emissions may be significantly underestimated in relation to the actual ones, and this may result in an inefficient installation of the air purification plant of the air discharged from the settling tanks. The average odour emission rate of the primary settling tanks after air-tightening is 102 $ou_E/(s \cdot m^2)$. The minimum value recorded during the tests is 17 $ou_E/(s \cdot m^2)$ and the maximum one is 1200 $ou_E/(s \cdot m^2)$. Higher values and higher variability of emissions were observed in the case of measurement sessions characterized by lower precipitation and higher temperatures.

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