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Experimental Evaluation of Odour Emission Capacity across a Wastewater Treatment Process

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Odour emissions from wastewater treatment process (WWTP) are a relevant environmental issue, particularly in densely populated areas. However, the wastewater treatment process allows for a reduction in the pollutant load and a mitigation of the odour load of the wastewater itself. This study presents an experimental monitoring campaign aimed at assessing odour emissions associated with liquid wastewater streams and sludge in a municipal WWTP. Odour emission capacity (OEC) analyses are carried out on liquid effluents at different stages of the treatment process, alongside chemical characterisation and dynamic olfactometry. The approach enabled the evaluation of the distribution of odorous compounds throughout the treatment line and their potential contribution to emission fluxes. The results highlight a decrease in OEC between influent and treated effluent, with values decreasing from 10^5 ou_E/m^3 to 10^4 ou_E/m^3 in the liquid phase. Evaluating the odour rate (OR_L) of each sampling, the results show that the corresponding abatement efficiency is about 60%, alongside a redistribution of odorous compounds between the liquid and solid phases during treatment. Overall, the combined chemical and olfactometric data provide a coherent framework for interpreting odour emission patterns within the plant.

1. Introduction

Over the past decades, odour emissions have received increasing scientific and regulatory attention due to their impact on community well-being and quality of life. This phenomenon has been accompanied by the development of odour nuisance regulations at both national and international levels (Brancher et al., 2017; Zalin and Sironi, 2024). WWTPs remove pollutants from municipal and industrial effluents, thereby cleaning up receiving water bodies and protecting public health. However, these facilities are recognised as significant sources of odour emissions, causing nuisance to nearby communities, especially in densely urbanised areas (Zarra et al., 2014; González et al., 2022). Odours mainly arise from the presence and transformation of organic matter and reduced sulphur compounds during treatment processes. Typical odorants associated with WWTP emissions are sulphur compounds (like H_2S, methanethiol, dimethyl sulphide), indole, skatole and acetone (Czarnota et al., 2023). The complexity of biological, chemical, and physical mechanisms occurring in municipal wastewater treatment processes results in a highly variable distribution of odorous compounds between phases and across treatment stages. In this context, the biological treatment process involves the transfer and transformation of pollutants from the liquid phase to the solid phase, which may also influence the behaviour of odorous compounds during treatment. Along the different process units, WWTPs are equipped with odour prevention and abatement technologies to mitigate these impacts (Alfonsín et al., 2015; Du et al., 2024). In many cases, limited information is available on their actual performance, including the effectiveness of emission treatment systems and compliance with regulatory or environmental criteria (Toledo and Muñoz, 2025).
Although various studies have investigated emissions from specific WWTP units, integrated approaches combining chemical characterisation and dynamic olfactometry to assess odour emission potential in wastewater streams and sludge are still limited (Lehtinen and Veijanen, 2011; Barczak and Kulig, 2017).

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The characterisation of odour potential from sludge and liquid matrices is not straightforward, as odorous compounds are distributed between liquid and gas phases. In addition to field-based methods, such as hood-based techniques (e.g. wind tunnel, flux chamber), laboratory approaches can provide a valuable alternative for the characterisation of emission sources that are difficult to sample directly due to safety, accessibility, or logistical constraints typically encountered within the plants. The choice of the sampling method can significantly influence the estimated odour impact, as it directly affects the emission data used as input for dispersion modelling (Tagliaferri et al., 2020). Different approaches can be applied, including static headspace techniques, based on equilibrium partitioning, and dynamic methods such as OEC, based on the forced transfer of odorants to the gas phase (Jiang et al., 2017; Liu et al., 2022).

Focusing on the OEC, this method, originally proposed by Frechen and Köster (1998) provides an estimate of the total amount of odorants that can be stripped from a liquid matrix under controlled conditions, expressed in ou_E/m^3_{liquid}. It is recognised as an experimental parameter for evaluating the odour potential of wastewater matrices (Frechen, 2009). In particular, the estimation of OEC along the treatment line provides valuable insights into odour generation and abatement dynamics. Despite not being directly adopted in regulatory frameworks, OEC can be applied for the comparison of different odour sources and as an input parameter for dispersion modelling (Frechen, 2004). Furthermore, it can support the definition of odour management strategies and regulatory criteria (Zarra et al., 2021). After its introduction in the 1990s, the method was subsequently incorporated into the German technical standard VDI Guideline 3885/1 (Frechen, 2012; VDI, 2017) and is now widely applied, while still being the subject of ongoing methodological developments. These include, for instance, the optimisation of stripping times and the use of controlled dilution approaches, aimed at improving measurement accuracy and extending its applicability to matrices other than water, such as hydrocarbon-based systems (Scolieri et al., 2022).

The present case study, carried out within the framework of the PRIN project "3D effect-based assessment of direct emissions for the eco-sustainability of wastewater management strategies (3D WWTP TOX)", aims to contribute to the application of OEC measurements in a municipal WWTP. In particular, the work focuses on evaluating the odour load associated with influent and treated effluent, as well as with the sludge produced during the treatment process. By integrating OEC measurements with chemical characterisation of the gas samples, the study seeks to improve the understanding of odour distribution and evolution throughout the WWTP treatment line, thereby supporting odour assessment and management.

2. Materials and methods

2.1 Case study description

The investigated WWTP is a full-scale municipal wastewater treatment facility, located in the North-East of Italy and serving a densely populated urban area, with a treatment capacity of approximately 410,000 population equivalents (PE), and treating both municipal wastewater and industrial effluents. The plant receives wastewater through three main sewer collectors, identified as 1M, 3M, and 8M, serving different urban and industrial catchment areas. Due to differences in elevation, the incoming flows are conveyed to the headworks through lifting systems before reaching the preliminary treatment stage. The main process units are equipped with odour control systems to mitigate emissions generated during treatment, including technologies such as chemical scrubber and a biofilter. The treatment process includes preliminary treatment (screening, grit and grease removal), followed by primary sedimentation and biological treatment based on an activated sludge process (pre-denitrification and nitrification), secondary clarification, chemical phosphorus removal, and disinfection. The sludge line includes thickening, anaerobic digestion, and dewatering. During these stages, pollutants are progressively removed from the liquid phase through transfer and transformation into the solid phase.

To better characterise the overall odour potential of liquid streams throughout the entire process, the sampling points were selected to represent the main process streams within the WWTP, as follows:

- the inlet of the three collectors (1M, 3M, and 8M), representative of the influent
- the discharge channel to the nearby river, representative of the treated effluent
- sludge collected downstream of the anaerobic digestion process, representative of digested sludge

For each sampling point, 1 L per sample was collected, using refrigerated automatic samplers and stored in LDPE containers to preserve sample integrity prior to analysis. Influent and treated effluent samples were analysed during two separate sampling campaigns (December 2024 and March 2025), while a single digested sludge sample was analysed (March 2025). Overall, a total of 5 OEC tests were performed.

The odour rate (OR_L) associated to each liquid flow was derived by combining OEC values with the corresponding liquid flow rates (Q_{liquid}), according to Equation 1, obtained from plant operational data: the influent and treated effluent flow rates were equal to 2,900 and 2,800 m^3_{liquid}/h, respectively, while a flow rate of

100 m^3_{liquid}/h was considered for the sludge line. OR_L values provide a useful parameter for the evaluation of abatement efficiency of entire system.

$$OR_L = Q_{liquid} \cdot OEC \quad (1)$$

2.2 OEC methodology

The OEC is typically determined using the stripping method originally proposed by Frechen and Köster (1998) based on dynamic olfactometry (CEN, 2022), and further described in VDI, 2017. The method involves transferring volatile odorants from the liquid to the gas phase by bubbling under controlled conditions. The gas phase enriched with volatile compounds is collected in 4 suitable sampling bags at predefined time intervals (i.e. 2 min, 6 min, 16 min and 32 min). Subsequently, the odour concentration of each gas sample is determined by dynamic olfactometry (Polvara et al., 2021).

In this study, the experimental procedure was adapted to account for operational constraints related to reduced sample volumes, thereby facilitating sample handling. The experimental setup and operating conditions adopted for the OEC measurements are detailed in the section 2.2.

2.3 Experimental set-up and operative conditions

The implemented experimental procedure was adapted from Scolieri et al., 2022, with modifications aimed at reducing the required sample volume. In particular, the liquid sample volume was reduced from 30 L to 1 L, with a corresponding adjustment of the stripping gas flow rate from 3,000 L/h to 100 L/h in order to maintain the degree of turbulence within the range 90 h^{-1}÷110 h^{-1} (Frechen, 2012).

For the influent stream, the three liquid samples associated with the collectors were homogenised in equal proportions to obtain a 1 L composite sample representative of the overall influent.

The stripping was performed using a laboratory-scale setup consisting of a glass bubbler connected to a mass flow controller supplying nitrogen at 100 L/h. The outlet gas was collected in Nalophan™ bags. Gas samples were collected at predefined time intervals (i.e. 2 min, 6 min, 16 min and 32 min) and analysed both by dynamic olfactometry and with a chemical characterisation. Short sampling time (i.e. < 30 s) was adopted to characterise specific temporal stages of volatile organic compounds (VOCs) volatilisation during the stripping process, consistent with standard requirements for sampling bag filling times, which aim to preserve the representativeness of the collected gas samples. For this reason, a dilution step was introduced downstream of the stripping unit: the outlet gas stream (100 L/h) was dynamically diluted with an additional nitrogen flow (900 L/h), resulting in a total flow rate of 1,000 L/h. The measured odour and chemical compounds concentrations were corrected by applying the corresponding dilution factor (i.e. 10), and OEC values were calculated accordingly. In addition to odour concentration (C_{od}), the first OEC gas sample collected during each experimental test (i.e. at 2 min) was chemically characterised, in terms of VOCs, using TD-GC-MS/FID/PFPD analysis to support the interpretation of OEC results. The first gas sample was selected because it is generally characterised by the highest concentration of stripped volatile compounds, enabling a more robust comparison among the investigated matrices (Polvara et al., 2025). As discussed in previous studies, this configuration allows to specific detection and quantification of organic compounds via FID analysis, sulphur compounds through PFPD, and compound identification via MS analysis by comparing generated spectra with MS library references. An aliquot of the gas sample was directly collected from the same Nalophan™ bag used for the determination of C_{od} and sent to a thermal desorber to preconcentrate the analytes present on a cold trap ('TO-15/TO-17 Air toxics', Markes International Ltd).

2.4 Standard OEC measurement

The OEC was evaluated based on the odour concentration of the gas phase generated during the stripping of the liquid sample, following the approach proposed by Frechen (2012). The OEC value was calculated according to Equation 2:

$$OEC = \int \frac{(C_{od}(t) - C_{100})}{V_{liquid}} \cdot dV_{N_2}(t) \quad (2)$$

where $C_{od}(t)$ is the measured odour concentration at time t, corrected for the applied dilution factor (i.e. 10), C_{100} is the reference lower threshold of odour concentration (i.e. 100 ou_E/m^3), V_{liquid} is the volume of analysed liquid and $dV_{N2}(t)$ is the infinitesimal volume of nitrogen supplied at time t. The OEC value corresponds to the area between the experimental curve and the lower integration limit, which was determined by numerical integration of the experimental data, for instance using the trapezoidal rule. During the present test the odour concentration never do not fall below the threshold value C_{100}. Therefore, in accordance with Frechen (2012), an additional area was estimated by linear extrapolation of the concentration curve in the linear domain.

3. Results

The temporal profiles of odour concentration obtained during the OEC lab tests for analysed liquid samples are reported below. Figure 1a and Figure 1c present refer to influent and effluent samples, respectively, with the green curve corresponding to the first sampling campaign (December 2024) and the blue curve to the second sampling campaign (March 2025). Figure 1b shows the profile obtained for the digested sludge sample.

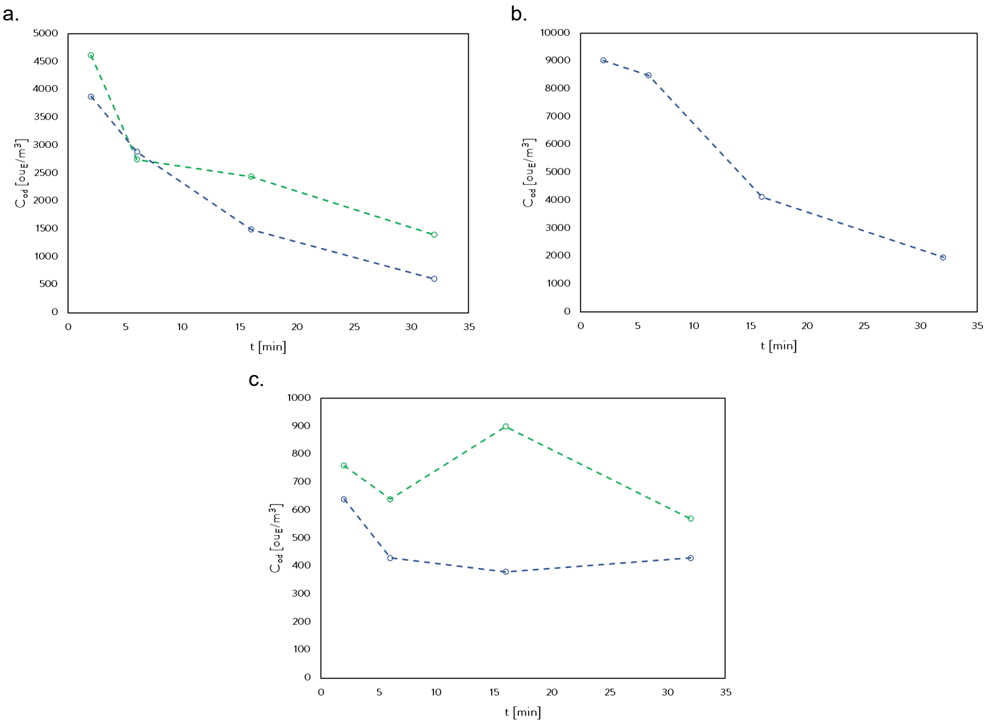

Figure 1: Odour concentration trend during OEC lab tests: (a) influent; (b) digested sludge; (c) effluent

Table 1 reports the OEC values calculated according to the method described above and the corresponding OR_L values, obtained from the product of OEC and the respective flow rates of the investigated streams, as defined in section 2. For treated effluent sample of second campaign, OEC value was not calculable (NC), as defined by the Frechen method.

Table 1: OEC and OR_L values obtained for analysed liquid samples

N°	Campaign	Liquid typology	OEC [ou_E/m^3_{liquid}]	OR_L [ou_E/s]
1	Dec 2024	Influent	$1.0 \cdot 10^5$	$8.1 \cdot 10^4$
2	Mar 2025	Influent	$9.9 \cdot 10^4$	$8.0 \cdot 10^4$
3	Mar 2025	Sludge	$2.9 \cdot 10^5$	$8.1 \cdot 10^3$
4	Dec 2024	Effluent	$2.9 \cdot 10^4$	$2.3 \cdot 10^4$
5	Mar 2025	Effluent	NC	NC

The obtained results show that the OEC values of the influent samples are comparable, in agreement with the temporal profiles of odour concentration. While the sludge sample exhibits higher OEC values than the influent, the corresponding OR_L is approximately one order of magnitude lower due to the lower flow rate associated with the sludge line. Regarding the treated effluent samples, the evaluation of OEC was not always feasible. The temporal profiles of odour concentration are less well-defined and exhibit limited variation compared to those observed for influent and sludge samples, reflecting the lower odour load of the treated wastewater. The odour concentration values reported in Figure 1 are already corrected for the applied dilution factor. Consequently, the measured odour concentrations associated with the treated effluent were very low, remaining below the reference threshold of 100 ou_E/m^3 adopted in the OEC method. This combination of low odour concentration levels and dilution reduced the sensitivity of the method, preventing the identification of a well-defined

decreasing trend and affecting the robustness of the numerical integration, resulting in non-calculable OEC values for the treated effluent samples.
From a chemical perspective, characterisation of the gas samples, with reference to the first sample collected during the stripping process (i.e. after 2 min), identified methanethiol among the main odour-active compounds, in terms of Odour Activity Value (OAV), in both influent and sludge samples, whereas it was not detected in the treated effluent. Given its very low odour threshold, i.e. $7.0 \cdot 10^{-5}$ ppm according to Nagata (2003) methanethiol is of particular interest from an odour-generation perspective, and its abatement during the process is therefore particularly significant in terms of odour reduction. This behaviour is consistent with the higher odour potential of influent and sludge and the lower odour potential of the treated wastewater and suggests preferential phase partitioning of odorous compounds.

4. Conclusions

The present study investigated the odour emission potential in a municipal WWTP using an adapted OEC method. The approach builds on the method proposed by Frechen, adapted according to approaches described in recent studies in the scientific literature. In particular, the method is applied with reduced sample volumes and adjusted gas flow rates. Chemical characterisation of selected gas samples is also performed to support the interpretation of the results. The results show a decrease in OEC values from influent to treated effluent, with an overall system efficiency of approximately 60%, derived from the corresponding OR_L values. Higher OEC values are observed for sludge ($2.9 \cdot 10^5$ ou_E/m^3_{liquid}), suggesting a redistribution of odorous compounds between the liquid and solid phases during the treatment process. This behaviour could be associated with anaerobic digestion processes and the generation of volatile sulphur compounds. Similar OEC values for sludge were reported by Frechen, supporting the interpretation that biological treatment processes may favour the accumulation of odour-active compounds in the solid phase. The analysis of temporal odour concentration profiles confirms the applicability of the method for influent and sludge samples. However, limitations are observed for treated effluent due to low odour concentrations and dilution effects, which may lead to values approaching or falling below the detection threshold of olfactometric analysis. These conditions reduce the sensitivity of the method and do not allow OEC values to be determined in some cases. The chemical characterisation identifies methanethiol as a key odour-active compound in influent and sludge samples, while it is not detected in the treated effluent, supporting the observed reduction of odour potential in the liquid phase. In view of this, future developments could focus on improving the applicability of the method under low odour load conditions by optimising liquid sample volumes and nitrogen flow rates, thus reducing dilution requirements while preserving the operational feasibility of the experimental setup.

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References

Alfonsín C., Lebrero R., Estrada J. M., Muñoz R., Kraakman N. J. R., Feijoo G., Moreira M. A. T., 2015, Selection of odour removal technologies in wastewater treatment plants: A guideline based on Life Cycle Assessment, Journal of Environmental Management, 149, 77-84, https://doi.org/10.1016/j.jenvman.2014.10.011

Barczak R. J., Kulig A., 2017, Comparison of different measurement methods of odour and odorants used in the odour impact assessment of wastewater treatment plants in Poland, Water Science and Technology, 75 (4), 944-951, https://doi.org/10.2166/wst.2016.560

Brancher M., Griffiths K. D., Franco D., de Melo Lisboa H., 2017. A review of odour impact criteria in selected countries around the world, Chemosphere, 168, 1531-1570. https://doi.org/10.1016/j.chemosphere.2016.11.160

CEN, 2022, EN 13725:2022 - Stationary source emissions - Determination of odour concentration by dynamic olfactometry and odour emission rate, Brussels

Czarnota J., Masłoń A., Pajura R., 2023, Wastewater Treatment Plants as a Source of Malodorous Substances Hazardous to Health, Including a Case Study from Poland, International Journal of Environmental Research and Public Health, 20 (7), https://doi.org/10.3390/ijerph20075379

Du H., Wang Z., Sun Y., Shan K. J., 2024, An Overview of the Progress made in Research on Odor Removal in Water Treatment Plants, Water, 16 (2), 280, https://doi.org/10.3390/w16020280

Frechen F. B., Köster W., 1998, Odour emission capacity of wastewaters - standardization of measurement method and application, Water Science and Technology, 38 (3), 61-69, https://doi.org/10.1016/S0273-1223(98)00451-X

Frechen F. B., 2004, Odour emission inventory of German wastewater treatment plants - Odour flow rates and odour emission capacity, Water Science and Technology, 50 (4), 139-146, https://doi.org/10.2166/wst.2004.0244

Frechen F. B., 2009, 10 Years of OEC Measurement: Methodology, Application, Results and Future Development, Odour and VOCs: Measurement, Regulation and Control, Kassel University Press Kassel, 9-17

Frechen F. B., 2012, Evaluation of OEC Data for Preparation of the New VDI Guideline 3885/1, Chemical Engineering Transactions, 30, 19-24, https://doi.org/10.3303/CET1230004

González D. Colón J., Sánchez A., Gabriel D., 2022, Multipoint characterization of the emission of odour, volatile organic compounds and greenhouse gases from a full-scale membrane-based municipal WWTP, Journal of Environmental Management, 313 (March), https://doi.org/10.1016/j.jenvman.2022.115002

Jiang G., Melder D., Keller J., Yuan Z., 2017, Odor emissions from domestic wastewater: A review. Critical Reviews in Environmental Science and Technology, 47 (17), 1581-1611, https://doi.org/10.1080/10643389.2017.1386952

Lehtinen J., Veijanen A., 2011, Odour monitoring by combined TD-GC-MS-sniff technique and dynamic olfactometry at the wastewater treatment plant of low H2S concentration, Water, Air, and Soil Pollution, 218 (1-4), 185-196, https://doi.org/10.1007/s11270-010-0634-3

Liu L., Abdala Prata Junior A., Fisher R. M., Stuetz R. M., 2022, Measuring volatile emissions from biosolids: A critical review on sampling methods, Journal of Environmental Management, 317 (May), 115290, https://doi.org/10.1016/j.jenvman.2022,115290

Nagata Y., 2003, Measurement of Odor Threshold by Triangle Odor Bag Method, Odor Measurement Review, 118-127

Polvara E., Spinazzè A., Invernizzi M., Cattaneo A., Sironi S., Cavallo D. M., 2021, Toxicological assessment method for evaluating the occupational risk of dynamic olfactometry assessors, Regulatory Toxicology and Pharmacology, 125 (May), https://doi.org/10.1016/j.yrtph.2021.105003

Polvara E., Legnani V., Invernizzi M., Sironi S., 2025, Olfactometric and Chemical Characterisation of Gaseous Emission from Crude Oils. Molecules, 30, 1136, https://doi.org/10.3390/molecules30051136

Scolieri G., Invernizzi M., Sironi S., 2022, Estimation of the Odour Emission Capacity of High-load Wastewater, Chemical Engineering Transactions, 95 (April), 109-114, https://doi.org/10.3303/CET2295019

Tagliaferri F., Invernizzi M., Sironi S., Capelli L., 2020, Influence of modelling choices on the results of landfill odour dispersion, Detritus, 12, 92-99, https://doi.org/10.31025/2611-4135/2020.13998

Toledo M., Muñoz, R., 2025, Odour prevention strategies in wastewater treatment and composting plants: A review, Journal of Environmental Management, 375 (November 2024), https://doi.org/10.1016/j.jenvman.2025.124402

VDI, 2017, VDI 3885. Olfaktometrie. Messung des Geruchsstofiemissionspotenzials von Flüssigkeiten, 1-21, Düsseldorf

Zalin M., Sironi S., 2024, New Guidelines in Italy for the Regulation of Odour Emissions, Chemical Engineering Transactions, 112 (June), 13-18, https://doi.org/10.3303/CET24112003

Zarra T., Cimatoribus C., Oliva G., Belgiorno V., Naddeo V., 2021, Proactive approach for odour emissions characterization in wastewater treatment plant by H2odour system, Chemical Engineering Transactions, 85 (January), 37-42, https://doi.org/10.3303/CET2185007

Zarra T., Reiser M., Naddeo V., Belgiorno V., Kranert M., 2014, Odour emissions characterization from wastewater treatment plants by different measurement methods, Chemical Engineering Transactions, 40 (Special Issue), 37-42. https://doi.org/10.3303/CET1440007