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Odour monitoring of small wastewater treatment plant located in sensitive environment

T. Zarra, V. Naddeo, V. Belgiorno, M. Reiser and M. Kranert

ABSTRACT

Small wastewater treatment plants are often localized nearby tourist areas. Odour emissions are a major environmental issue in these plants and are considered to be the main cause of disturbance noticed by the exposed population. Odour measurement is carried out using analytical or sensorial methods. Sensorial analysis, being assigned to the "human sensor", is the cause of a considerable uncertainty.

In this study, a novel procedure based on highly innovative analytical tool was used to identify and characterise the odour sources and the volatile substances that cause annoyance in a SWWTP located in a sensitive area, with the aim to remove the subjective component in the measure of the odours and define the induced impact. At the same time key odour compounds are detected, and the relationship between their concentration and the performances of the plant are investigated.

The sources and the main chemical substances responsible for the olfactory annoyances were identified. Results highlight the applicability of the highly innovative tool in odour emission monitoring. Around 39 different substances were detected, with almost half being smell relevant components as well as responsible. Dimethyl disulphide was identified as key compound connected to the efficiency of the process.

Key words | annoyance, dimethyl disulphide, GC-MS with ODP analysis, odour impact, volatile substances

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INTRODUCTION

Small wastewater treatment plants (SWWTP) localized in tourist areas have high difficulties related to the loads variability concentrated in a few months of the year and the simplicity of the processes implemented. At the same time, odours induced from SWWTP are considered to be the main cause of disturbance noticed by the exposed population (Frechen 1988; Bidlingmaier 1997; Stuetz & Frechen 2001), and have a relevant impact on tourism economy (Zarra 2007). Even though a real toxicological-sanitary risk is hardly ever associated with the odour impact from sources connected to the activities of wastewater management, due to the rarely dangerous nature of the smells as well as the generally very low concentrations, the collective imagination often associates the bad smell to conditions of "non healthy" air. In fact, a significance higher than the one related to more dangerous contaminants not directly perceptible with our senses, is often attributed to them (Frechen 1988; Kehoe *et al.* 1996; Gostelow *et al.* 2000; Stuetz & Frechen 2001). Odour emissions affect quality of life (Brennan 1993) leading to psychological stress and symptoms such as insomnia, loss of appetite and irrational behaviour (Wilson *et al.* 1980).

The particular and complex nature of the substances cause of the smell impact, their variability in time and related to the meteo-climatic conditions, and the subjectivity of the smell perception are the elements that delayed their regulation (Bidlingmaier 1997; Gostelow *et al.* 2000).

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There are few international laws that fix the limits of odour emissions from industrial sources and/or define criteria of quality related to the smell. In Europe Germany is the nation with most specific regulations well defined and based exclusively on the sensorial analysis (Frechen 2003; Both & Koch 2004). Only recently, the technical regulation EN 13725:2003 "Quality of air – measurements of smell concentration using dynamic olfactometry" has been approved in European limits, with the aim of making objective and quantifiable the intensity of an odour perceived from a group of detectors (panellists) that in a laboratory smell samples of air at different dilution ranges.

On the other hand, the definition of normative limits on the smell emissions is a hard problem to solve because of the difficulties related to the subjectivity of smell perception and the methods for determination of odours in the environment (Zarra *et al.* 2007). Odours are difficult to measure. A person's response to an odour is highly subjective - different people find different odours offensive, and at different concentrations. This is further complicated by the fact that many odorous emissions, including those from sewage treatment works, consist of many individual odorous components, and the overall odour of complex mixtures cannot easily be predicted. For these reasons, there is no universally accepted method for the quantification of odours, and odour measurement has often been regarded as an art as opposed to a science (Koe 1989; Jiang 1996).

Nowadays, odour measurement is carried out using two different methods: analytical-instrumental and sensorial. With the sensorial techniques (dynamic olfactometry and/or sociological questionnaires) it is not possible to gather the substances composing the olfactory annoyance as well as their single concentrations. It is therefore not possible to have a measurement of the number of people exposed to the different chemical agents that can cause noxious effects as well as whether they are protracted over time and in what concentrations (Bidlingmaier 1997; Stuetz & Frechen 2001; Van Harreveld 2002). The principal source of uncertainty of the olfactometric method is the biological high variability of the olfactory sensibility. Even when performed according to the EN 13725:2003, the group of panelists does not necessarily represent a statistically representative sample of the exposed population, but only a group of subjects endowed with medium olfactory sensibility. Sensorial analysis, being assigned to the "human sensor", by its own nature not reproducible, is the cause of a considerable uncertainty, due to the unavoidable human component that interferes in the evaluation (Koster 1985; Sneath 2001).

Analytical measurements (GC-MS, colorimetric methods) concern the physical or chemical properties of the odorous compounds, although the most common measurement made by far is odorant concentration. Analytical measurements allow a preliminary screening of the existing substances, but do not allow to get information about the induced annoyance (Dalton 2002; Davoli 2004). From a GC-MS analysis it is possible to obtain indications on the numerous substances that constitute principally the odorous mixture. Therefore, it is possible to evaluate if substances indicating an inefficient process are present or not or to evaluate the efficiency of technological systems of odours mitigation as scrubbers or biofilters.

The scope of this study was to identify and characterise the odour sources and the volatile substances that cause annoyance in small wastewater treatment plants located in a sensible area, using a novel procedure based on highly innovative analytical tool, with the objective to remove the subjective component in the measure of the odours and define the induced impact. In the same time odour key compounds are detected, and the relationship between their concentration and the performances of the plant is investigated.

MATERIALS AND METHODS

Small wastewater treatment plant

The individuation of the main sources and chemical substances responsible of the olfactory annoyances have been carried out in full-scale SWWTP LFKW located at Stuttgart University (Baden Wuerttemberg Region, South-western Germany) (Figure 1).

The treatment plant is based on a conventional process scheme shown in Figure 2, and actually treats both domestic (University Campus and Büsnau town) and industrial discharges (Industrial and Laboratory Activities at University Area).

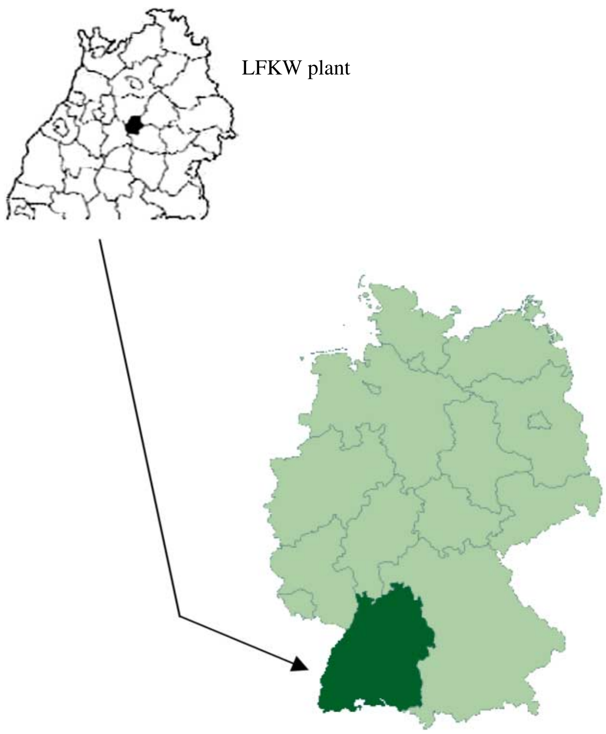

Figure 1 | Localization of the LFKW wastewater treatment plant in the Baden Wuerttemberg Region (Germany).

The LFKW plant is equipped with a odors abatement system (Dynamics biofilter). A brief characterization of the investigated SWWTP is showed in Table 1.

Odour emissions from wastewater treatment plant are essentially caused by the degradation of organic matter by microorganisms under anaerobic conditions. The development of anaerobic conditions in sewage is often referred to as 'septicity' (Gostelow & Parsons 2000).

In wastewater treatment plants, different diffusive and non-diffusive odour sources can be identified (Zarra 2007). Odours arise from several points at wastewater treatment facilities. One possibility is that odorous compounds are already present in the incoming wastewater and are released to the air during treatment activities. Another possibility is the formation of odorous compounds (Stuetz *et al.* 1998).

Odour monitoring

Samples of odour emissions were taken at seven different points of the plant during the period March–April 2006. Table 2 shows the position of the sampling points and the measurement program carried out over the testing period. 23 analyses were carried out.

In order to investigate the relationship between the identified odour key compound concentration emitted by the principal treatments of the plants, and their performances during sampling phases BOD_5, COD, pH, TS, TSS and temperature were also monitored.

Analytical methods

Air samples are taken using the 'lung' technique, whereby the sampling bag is placed inside a rigid container (length 685 mm, diameter 152 mm), and the container evacuated using a vacuum pump in accordance with EN 13725:2003. This method avoids contamination, which may arise from the direct use of pumps in the sampling line. Nalophan® sampling bags of 3 litres volume are used for the sampling.

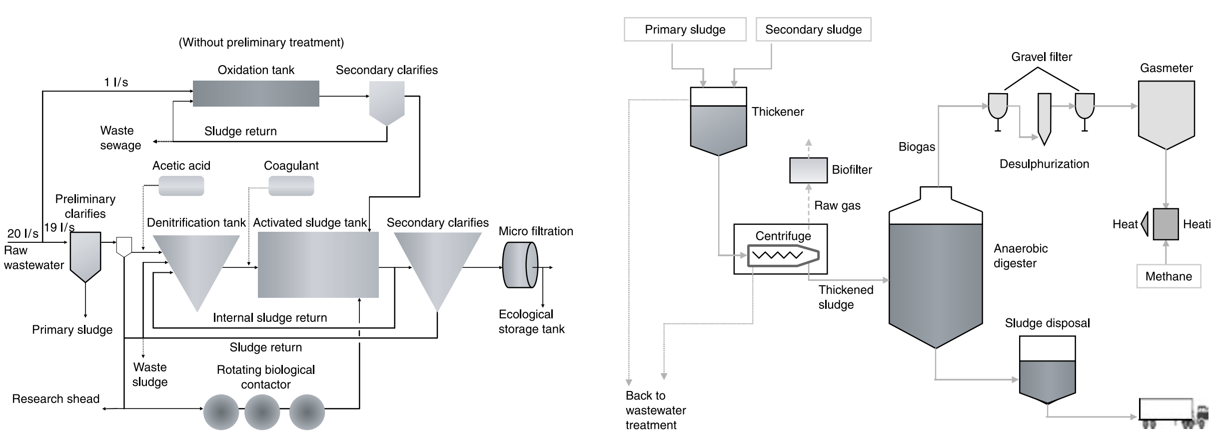

Figure 2 | Flow chart of the wastewater (left) and sludge (right) treatments at LFKW plant.

Table 1 | LFKW treatment plant characteristic

Parameter	Value
Flow rate	2,000 m^3/d
Average biogas production	47,000 m^3/year
Grit material production	18 t/year
Sand production	8 t/year
Dried sludges production	2,150 t/year
BOD_5	290 mg/l
COD	500 mg/l
Total N (mg/l as N)	50 mg/l
Total P (mg/l as P)	7.6 mg/l

Analytical measurement was carried out by GC-MS (Agilent Technologies Inc., 6890 and 5970 model) equipped with an odour sniffing port (ODP) (Gerstel) and a flame-ionisation detector (FID). This method combines both sensorial and chemical-physical measurement methods. Humidified air was combined with the hot GC effluent, before sniffing by an experienced "odour sniffer". To detect many of trace compounds from the gas samples, the compounds are enriched by adsorption. The concentration technique involved passing a volume of 2,000 ml of sample through a porous polymer trap (at rate of about 200 ml min^{-1}) that adsorbed the organic compounds in the sample. The polymer trap consisted of glass tube (175 mm long × 6 mm diameter) containing about 200 mg Tenax-TA®. The volatile compounds adsorbed on the Tenax-polymer were thermally desorbed into the gas chromatograph. Desorption was accomplished by purging the adsorbent with helium for approximately 15 minutes and collecting the compounds in a cooling trap at −100°C. When thermodesorption was completed, the trap temperature was rapidly raised to 280°C.

Table 2 | Sampling points and measurements program

ID	No. of analysis	Location	Treatment
P1	3	Raw wastewater influent	Influent
P2	3	Grit	
P3	3	Preliminary clarifies	Wastewater
P4	4	Oxidation tank	
P5	4	Thickener	
P6	3	Centrifuge	Sludge
P7	3	Sludge disposal	

Table 3 | LFKW odour emission characterization

Class	Substances	Max concentration (mg/m³)
Sulphurous	Sulphur dioxide	0.67021
	Dimethyl disulphide	0.21259
	Dimethyl trisulphide	0.04549
Ketones	Acetone	0.46179
	2-Butanone	4.53781
	Acetophenone	0.58772
Aldehydes	Benzaldehyde	0.06699
	Trimethyl-benzaldehyde	0.06432
	Decanal	0.02146
	Nonanal	0.01982
Aromatics	Ethyl-benzene	0.01472
	Dimethyl-benzene	0.01767
	1-Ethyl-2-methylbenzene	0.01309
	1,3,5 Trimethylbenzene	0.00836
	p-Xylene	0.04724
	1,2,4-Trimethylbenzene	0.01055
	Benzene	0.02191
	Toluene	0.50921
Terpenes	Limonene	0.11463
	D-Limonene	0.02304
	α-Pinene	0.01314
Alcohols	2-Butoxy-ethanol	0.09634
	2-ethenyloxy-ethanol	0.04782
	2-Ethyl-1-ethanol	0.39902
Volatile fat acid	Acetic Acid	0.10511
	Butanoic Acid	0.02088
	Propanoic Acid	0.01128
Hydro-carbons	Texane	0.00382
	Undecane	0.00537
	Dimethyl-Undecane	0.01989
	Dodecane	0.00341
	Tetradecane	0.00476
	Methyl-cyclohexane	0.01257
	Tridecane	0.00404
	Octane	0.01301
	Nonane	0.01071
	Decane	0.00708
Others	Tetra-chloroethylene	0.01065
	Octamethyl-cyclotetrasiloxane	0.58773

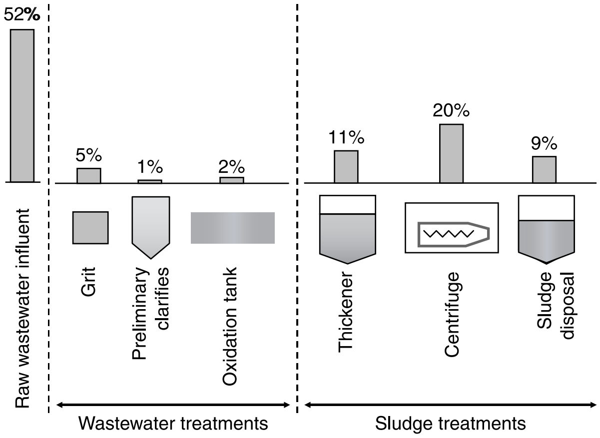

Figure 3 | Percentage of the potential odour impact at LFKW plant.

The results obtained were elaborated using a multi-varied statistical technique with the aim of identifying the most possible odour sources.

The substances with the lowest Odour Threshold (OT) and most prominent in the analyses are considered key compounds in this kind of process.

RESULTS AND DISCUSSION

Table 3 shows the substances detected of the LFKW plant located at Stuttgart University Campus and their maximum concentration. The results show the presence of a wide variety of organic sulphides and organic nitrogen-based compounds along with some oxygenated organic compounds and organic acids, mercaptans (R-SH) and amines.

In fact, of around 39 different substances detected in the mixture by the GC-MS with ODP, almost half were found to be smell relevant components as well as responsible for the typical smell of wastewater treatment plants.

Dimethyl disulphide was the volatile substance with the lowest Odour Threshold and most detected in the plant and for this considered the odour key compound. The high concentration (0.21259 mg/m^3) of these substance was detected at the thickened sludge.

Figure 3 shows the detected sources of odorous substances emissions at small wastewater treatment plants and their ranking for potential impact.

The results shows that the major contribute to odour impact are coming directly from raw wastewater influent. After this, sludge handling activities are the sources of odorous compounds that generated the main annoyance.

Figure 4 shows the percentage composition of the odour emissions for each source treatment unit monitored; in the plot were neglected both hydrocarbon and aromatic compounds.

The analysis between the detected concentration of dimethyl disulphide during the sampling program and the efficiency of the each treatment unit of the LFKW plant in terms of BOD_5 removal show how there is good linear correlation (65%). High BOD produce development of anaerobic conditions in sewage (Gostelow & Parsons 2000).

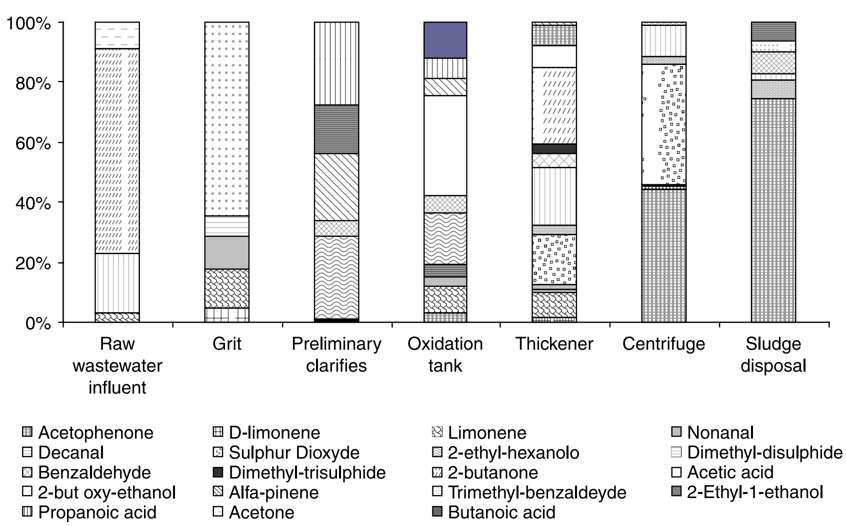

Figure 4 | Percentage composition of odour emissions for each monitored source treatment unit.

CONCLUSIONS

Odours induced by small wastewater treatment plant are considered to be the main cause of annoyance noticed by the exposed population.

The evaluation and characterization of the odours emissions have been applied to the case study of a SWWTP LFKW located at Stuttgart University (Baden Wuerttemberg Region, Southwestern Germany): 39 different substances were detected in the treatment phases. Almost half were found to be smell relevant components as well as responsible for the typical smell of wastewater treatment plants. The major contribute to odour impact are coming directly from raw wastewater influent (52%). After this, sludge handling activities (40%) are the sources of odorous compounds that generated the main annoyance.

Dimethyl disulphide is identified as key compound connected to the specific treatment process. She was the volatile substance most detected in the plant, with a average concentration of 0.152 mg/m^3; the high concentration (0.213 mg/m^3) of these substance was detected at the thickened sludge. Moreover, the study highlights the relationship between key compound concentration and the performance of the treatment phases of the plant, analysed in terms of BOD_5 reduction. The concentration of dimethyl disulphide decreases whit the reduction of BOD_5.

The results show a new way that scientific research could be carried out in order to both identify and characterize odours impact as well as monitor the efficiency of plants.

Results obtained by GC-MS with ODP port analysis indicated the potential role of the technique in the study of environmental engineering plants, while highlighting the need for a more comprehensive analysis suite.

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