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# Development of an electronic nose to characterize odours emitted from different stages in a wastewater treatment plant

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ABSTRACT

Wastewater treatment plants have widely been described as a significant source of odour nuisance, which has led to an increase of neighbourhood complaints. Therefore, to mitigate the negative impact of odours, the detection and analysis of these emissions are required. This paper presents a measurement system based on an electronic nose for quantitative and qualitative odour analysis of samples collected from six different stages on a wastewater plant. Hence, two features vectors were performed in order to represent quantitative trends of the gaseous mixture sampled on the facility. In addition, odour fingerprints and a PCA were computed to discriminate odours from its sources and to detect relationships among the samples. This approach also comprises a dynamic dilution olfactometer. A PLS regression model was performed to predict the odour concentration by the electronic nose in term of odour units per cubic meter. The results show that the developed electronic nose is a promising and feasible instrument to characterize odours from wastewater plants.



## 1. Introduction

Malodorous released from wastewater treatment plants (WWTPs) can cause health problems, nuisance to the community and frequently neighbourhood complaints (Carrera-Chapela et al., 2014; Gostelow et al., 2001; Stuetz and Nicolas, 2001). Indeed, odours are recently considered as atmospheric contaminants (Capelli et al., 2013). The management strategies to mitigate odour nuisance entail monitoring, assessment and controlling the generated substances. However, this issue implies significant challenges because odours are complex gaseous mixtures, which can be found at low concentrations at ambient conditions. Odours also exhibit high variability over time, which can be related to weather conditions, effluent load characteristics and others specific features. The random and temporal population activities relative to sewage disposal can also influence over odour emission (Bourgeois and Stuetz, 2002; Frechen, 2004; Jeon et al., 2009; McGinley and McGinley, 2008; Muñoz et al., 2010; Stuetz et al., 1999a; Wilson, 2012). In addition to the complexity, smell perception involves a subjective interpretation that varies according to many factors. Therefore, to successfully assess odours emissions, the use of suitable measurement instruments is required.

There are different techniques to analyze gases and odours. Detectors and gases analysers provide information about specific gases concentration in the odorant mixture. The more complex gas chromatography coupled to mass spectrometers (GC-MS) (Chin et al., 2017), and also with sulphur chemoluminescence detector (Sun et al., 2014) can be used to identify and quantify potential odorant compounds, usually expressed in ppm or ppb. However, it

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is not possible to characterize an odour as a whole by only analysing its individual components (Blanes-Vidal et al., 2009; Qu et al., 2008; Stuetz et al., 1999a). This kind of measurements does not encompass the gas mixture interactions (suppression, synergism, hypo-additivity and linear sum), which might lead to uncertain environmental assessment. Moreover, the gases and their respective concentrations on the odorant mixtures cause different effects on human odour perception (Capurro et al., 2012; Kim and Kim, 2014; Kuebler et al., 2011). Despite that analyses by GC-MS provide accurate and reproducible measurements, the cost of the analyses and the restriction to perform measurements in the laboratory (not *in-situ*) are other drawbacks that constrain the use of GC-MS.

The terms odorant and odour must be explained. An odorant is a gaseous chemical component which stimulates the human olfactory system, while an odour is the sensorial response of the olfactory organ when sniffing certain volatile substances (Brattoli et al., 2011; Gostelow et al., 2001; Muñoz et al., 2010).

For odour measurements, the dynamic olfactometry is the more applied methodology (Capelli et al., 2008b). This technique employs an olfactometer combined with human assessors. An olfactometer is an instrument that performs controlled dilutions of a gaseous sample, then exposing them to the assessors panel and compute results. The assessors are certified experts with certain capabilities to sniff, previously selected through different tests. Then, the results of odour concentration are quantified in odour unit per cubic meter (O.U.$m^{-3}$). This measuring unit represents the number of dilutions with neutral air (odourless) that are necessary to the odorous sample achieves its odour detection threshold (the concentration at which there is a 50% probability of detectability by the human assessors) (Gostelow et al., 2001). For this reason, this technique is the more appropriate method to characterize the odours released to the atmosphere. Indeed, most environmental odour regulations in different countries and municipalities are based on the odour concentration in O.U.$m^{-3}$ (Brancher et al., 2017). Although, olfactometry is expensive, time-consuming, and presents lower repeatability and accuracy due to its subjective nature (Brattoli et al., 2011).

The so-called electronic nose (e-nose) is another kind of instrument, which can be employed for odours assessment (Capelli et al., 2008b; Muñoz et al., 2010). The e-nose, in a simple way, mimics the mammalian olfactory system in term of sensory response and information processing (Arshak et al., 2004). These instruments mainly contain an array of sensors with cross-sensitivities, and an appropriate patterns recognition system capable of recognising simple or complex odours (Gardner and Bartlett, 1994). There are some relevant features that distinguish the e-noses regarding the rest of the gas/odour measurement systems: these concomitantly support gases and odours analyses, as well as temperature, humidity, wind velocity and others variables (Abdullah et al., 2012; Dentoni et al., 2012); allowing continuous monitoring of input odour data; and also performing both qualitative and quantitative analysis. For continuous odour monitoring can be used to estimate odour impact on the neighbourhood in real time, support rapid information for population, acquire data of high odour peaks over short time scales, capture of extreme odour events and even for a proactive purpose to detect odours before their impact on surrounding areas (Bourgeois and Stuetz, 2002; Capelli et al., 2008a; Purenne et al., 2007). A relate difficult from e-noses is that the non-specific gas sensors can respond to both odorous and odourless substances. In fact, this is a drawback of e-noses, not only for environmental odour applications. The low sensitivity of gas sensors to the odours threshold is another problem of e-noses (Boeker, 2014). However, to environmental odour analysis, these systems are an interesting choice, and they have been successfully applied in several assessments.

The development of an electronic nose comprises different stages that embrace the selection of the sensor array and the conditioning circuits, the processing and signal acquisition hardware as well as the signal processing, training and analysis of data. As concerning the selection of sensors, each sensor should maximize the overall sensitivity, providing different selectivity profiles over the range of application to the target odour (Phaisangittisagul et al., 2010). Then, a first step consists in obtaining several features from each sensor dynamic response, validating them and picking the main features which characterize the odours under study. This selection of the sensors strongly depends on the application, and it is needed when classification performance, cost, and technology limitations are issues of concern (Phaisangittisagul et al., 2010).

The next stages in processing the e-nose data include: data signal-pre-processing, feature extraction, feature selection, classification, regression, clustering, and validation. That way, several methods from statistical pattern recognition, artificial neural networks, chemometrics, and machine learning has been used to process electronic nose data (Gutierrez-Osuna, 2002).

Frequently, gas/odour monitoring systems only comprise one kind of measurement device. Nevertheless, it is also relevant to correlate outputs from different instruments. This integration usually provides more detailed and encompassed outcomes (Abdullah et al., 2012; Brattoli et al., 2011; Muñoz et al., 2010; Sohn et al., 2008). The analysis of environmental odours demands some difficult tasks. Hence, it can be supported by the combination of results from various measurement instruments, in order to obtain more representative data about substances evaluated. For instance, coupling olfactometry with GC-MS (GC-MS-O) allows the identification of odour-active compounds, which indicate the relevance of some gases as odorants. For this demand emerge another possibility, correlations between e-noses and olfactometry, which can allowed portable and fast odour analysis in term of odour concentrations. It can be used as a public tool to attend cases of complaints or to evaluate odour episodes that cause impacts on the populations (Brattoli et al., 2011; Purenne et al., 2007).

Several measurement instruments have been used for environmental applications (Alam and Saeed, 2013; Bootsmaa et al., 2014; Capelli et al., 2013; De Melo Lisboa et al., 2009; Wilson, 2012), including the assessment of odours emitted from WWTPs. There are reported e-noses responses correlated with olfactometry analysis to supply quantitative results from wastewater odours (Purenne et al., 2007; Zarra et al., 2014). Guz et al. (2015) performed a comparison of e-nose response to the standard physical-chemical parameters of treated wastewater, while Zarra et al. (2009, 2014) compared and evaluated different odour measurement methods for wastewater odours. Rajbansi et al. (2014) presented an assessment of odours from a sewage wastewater in terms of odour intensity by human assessors and GC-MS. A portable and commercial e-nose (PEN3) in conjunction with GC-MS was employed to discriminate between alkaline-stabilized biosolids treated at different doses (Romero-Flores et al., 2017). A sophisticated network of e-noses to quantify odours at Montreal WWTP was reported by Purenne et al. (2007). This system used correlations with olfactometry to calibrate the e-noses and also employed these results as input data to an atmospheric dispersion model.

Various e-noses have also been applied as a single instrument to wastewater odours assessment. Capelli et al. (2008a) proposed a system with three e-noses for continuous monitoring of environmental odours at specific receptors around a WWTP. In this approach was identified the major odour source in the facility and was also estimated the odour impact on the neighbourhood. The e-nose presented by Stuetz et al. (1999b) was able to discriminate odour samples from three different sources: raw sewage, settled