Continuous monitoring of odours at a biofilter outlet

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ABSTRACT

The experience matured in the field of biofiltration applied to odour removal enabled to study the correlation between some of the characteristic parameters of the biofilter bed (e.g. T, RH, ΔP) with the emitted odour concentration. Today odour measurement can be performed only by classical olfactometry. Classical olfactometry is an expensive and time-consuming method that is not suitable for continuous monitoring as needed by operators of compost facilities. This paper describes the experimental approaches adopted for the development of a system for the continuous monitoring of odour emissions, i.e. an instrument for the repeated air analysis, capable of qualitatively and quantitatively recognizing odours.

This work shows the results of the first experiments carried out with the purpose of developing an electronic nose to be applied at a biofilter outlet for the real-time odour concentration measurement and for the detection of the exceeding of a given odour «alarm threshold».

1 INTRODUCTION

Biofiltration is a process commonly used for the removal of odorous compounds (Devinny *et al*., 1999). The biofilter efficiency depends on several key parameters such as the moisture content of the medium (Van Lith *et al.*, 1997; Leson and Winer, 1991; Quiniam *et al*., 1999; Krailas and Pham, 2002; Morales *et al*., 2003), temperature (Yang and Allen, 1994) and pH (Devinny *et al.*, 1999).

Typical organic media may be 40-80% water (by weight) when saturated. The recommended water content is commonly evaluated at 50% of the water-holding

capacity of the material. The rough surface and porosity provide extensive microbial habitats that may improve colonisation and bacterial diversity (Delhomenie *et al.,* 2002).

Most biofilters are colonised with mesophilic microbial communities, that is to say microbes that thrive at temperatures between 20 and 45°C (Darlington *et al.*, 2001). In general for this temperature range, enzymatic activity increases as a function of temperature.

Finally most biofilters are designed to operate in a near-neutral pH range (6-8) (Mac Nevin and Barford, 2001).

Also the nature of the packing material is of great importance for the service life of the biofilter, microbial growth, removal performance and operational cost. Thus, the choice of biofilter medium (size of particles and their organic or inorganic nature) is a fundamental factor in the successful running of biofilters (Krailis *et al.*, 2000; Tawil, 2001).

Biofilters are widely used as odour abatement systems at different kinds of industrial plants. Odour control at the outlet of biofilters is very important, especially in the case of municipal solid waste (MSW) treatment plants, because odour emissions from this kind of plants are subject to limits fixed by the competent authority. The efficiency of biofilters in odour removal can be evaluated by monitoring the above mentioned parameters or by the direct analysis of odour concentration. Dynamic olfactometry is the technique commonly used for odour measurements at biofilters inlets and outlets, but olfactometric analyses are expensive and time consuming, and they can't be carried out continuously.

The aim of this paper is to describe the approaches adopted for developing an electronic nose suitable for the continuous monitoring of the odour concentration at a biofilter outlet, with the purpose of getting over the discontinuity bound to dynamic olfactometry. Nonetheless, the development of such a system requires a validation, which might be achieved by the execution of periodical olfactometric analyses for verifying the instrument accuracy in odour concentration determination.

2 MATERIALS AND METHODS

2.1 Olfactometric analyses

The collection of samples to be analyzed by dynamic olfactometry on the biofilter outlet is carried out by means f a static hood, which has the function of isolating the sampling point from the external conditions, and to channel the air stream in a stack from where the sample is collected with a depression pump inside a Nalophan™ bag with a Teflon™ inlet tube (Bockreis and Steinberg, 2005) (Figure 1).

The odour concentration of the samples collected at the biofilter outlet is determined by dynamic olfactometry, in conformity with the European Norm EN 13725:2003.

The odour concentration is expressed in European odour units per cubic metre (ou_E/m^3), and it represents the number of dilutions with neutral air that are necessary to bring the concentration of an odorous sample to its odour perception threshold concentration. The analysis is carried out by presenting the sample to a group of selected panellists at increasing concentrations by decreasing serial dilutions, until the panel members perceive an odour that is different from the reference neutral air. The odour concentration is then calculated as geometric mean of the odour threshold values of each panellist, multiplied by a factor that depends on the olfactometer dilution step factor.

An olfactometer ECOMA model TO8, based on the «yes/no» method, was used as dilution device (Figure 2). This instrument with aluminium casing has 4 panellists places in separate open boxes. Each box is equipped with a stainless steel sniffing port and a push-button for «yes» (odour threshold). The measuring range of the TO8 olfactometer goes from a minimum dilution factor of 4(=2^2) to a maximum dilution factor of 65536(=2^{16}), with a dilution step factor 2. All the measurements were conducted within 30 hours after sampling, relying on a panel composed by 4 panellists. The odour concentration was calculated as geometric mean of the odour threshold values of each panellist, multiplied by $\sqrt{2}$.

Figure 1. Equipment for odour sampling at a biofilter outlet.

Figure 2. The ECOMA TO8 olfactometer.

2.2 Development of a system for the continuous odour concentration determination

2.2.1 General principles

The development of this system is based on the use of an already existing technology, i.e. the electronic nose. The first prototype of electronic nose was described by Persaud and Dodd in 1982, and it consists of an instrument which comprises an array of electrochemical sensors with partial specificity and an appropriate pattern recognition system, capable of recognizing simple or complex odours. Even though electronic noses are studied since several years, most studies concern applications that are very different from the one proposed in this work. For these reasons, a complete re-design of the instrument is required in order to make it suitable for the specificities associated with the application in the environmental sector.

The work required for the development of a similar system is composed of two fundamental activities, which are strictly interconnected, i.e. the instrument design and the definition of its utilization procedures. The instrument design comprises the following aspects: the choice of the gas sensors; the implementation of a suitable software for the instrument operation and the data acquisition and processing, and finally the study of technical features which are needed in order to make the instrument usable not only in laboratory but also in the field. Parallel to the instrument design activity it is extremely important to define the electronic nose utilization procedures.

The use of an electronic nose provides to relate an unknown «match data set» to a «training data set» acquired by the instrument in the so-called «training» phase, during which a number of odorous samples are analyzed in order to create the database of odour concentration values used as a reference by the instrument for further odour concentration estimation. The principal utilization procedures to be defined concern therefore the instrument settings, the training methods and the data processing methods.

2.2.2 Electronic nose description

The instruments used for this study have been developed in collaboration with Sacmi s.c.a.r.l. and the Sensor Laboratory of the University of Brescia (Falasconi *et al*., 2005) (Figure 3).

Figure 3. Electronic nose used for the study.

The system includes a pneumatic assembly for dynamic sampling (pump, electro-valve, and electronic flow meter), a thermally controlled sensor chamber with 35 cm^3 of internal volume and an electronic board for controlling the sensor operational conditions. The electronic noses have been equipped with an array of six thin film MOS (Metal Oxide Semiconductor) sensors, which make the system sensitive to a large spectrum of volatile compounds, and a humidity sensor. For the analyses, the carrier flow rate was 150 cm^3 min^{-1} and the temperature of the sensor chamber was kept constant at 50°C.

2.2.3 Training for odour quantification

The quantification of odour concentration by means of an electronic nose requires a particular training: odorous gas samples must be diluted at different odour concentration values and analyzed in order to create a database that can be used for the estimation of the odour concentration of unknown air samples by interpolation of the training points. For this reason, after collection, the odour concentration of the samples is measured by dynamic olfactometry. Once the odour concentration of the samples is known, each sample is diluted at different odour concentration values, by means of the same dilution device used for the olfactometric analyses (olfactometer), in order to obtain samples with odour concentration values included in the typical odour concentration range of odorous ambient air (20-1000 ou_E m^{-3}) (Sironi *et al*., 2007).

2.2.4 Instrumental sensitivity towards odour concentration variations

In order to develop a system for the continuous monitoring of odours at a biofilter outlet it is necessary to evaluate its sensitivity towards odour concentration variations. For this reason, we are currently carrying out a set of experimental tests, in order to evaluate how different sensors respond at the analysis of odorous gas samples at different odour concentration values.

The instrumental sensitivity is tested using different typologies of odours: pure compounds and gas samples collected at biofilter outlets. As pure compounds, we decided to consider ammonia (NH_3) and hydrogen sulphide (H_2S), because these are the compounds for which an concentration limit is fixed by the competent authority at the outlet of biofilters installed at plants for the mechanical biological treatment of MSW.

3 RESULTS AND DISCUSSION

This paragraph reports the results of some of the studies conducted with the aim of developing an electronic nose suitable for the continuous monitoring of odours at a biofilter outlet. More in detail, the results reported concern the studies relevant to the experimental verification of the instrumental sensitivity towards odour concentration variations. It is worth to remember that this results are preliminary and therefore partial, because our work in this field is still in progress.

As mentioned in the previous paragraph, the sensitivity of different sensors is tested using samples of pure compounds and of gaseous mixtures collected at biofilter outlets.

As an example, we consider the tests conducted with a set of samples at different odour concentration values (22, 34, 44 and 110 ou_E/m^3) obtained by dilution of a

sample collected at the outlet of a biofilter installed at a plant for the mechanical and biological treatment of MSW.

Figure 4 shows the responses of a Nickel Oxide sensor (p-type) relevant to the analyses of the above mentioned samples. It is possible to observe that the amplitude of the response curves increases with the odour concentration values. Based on this observations it is possible to affirm that the studied sensor is sensitive even to very small variations of the odour concentration (*i.e.* 10 ou_E/m^3).

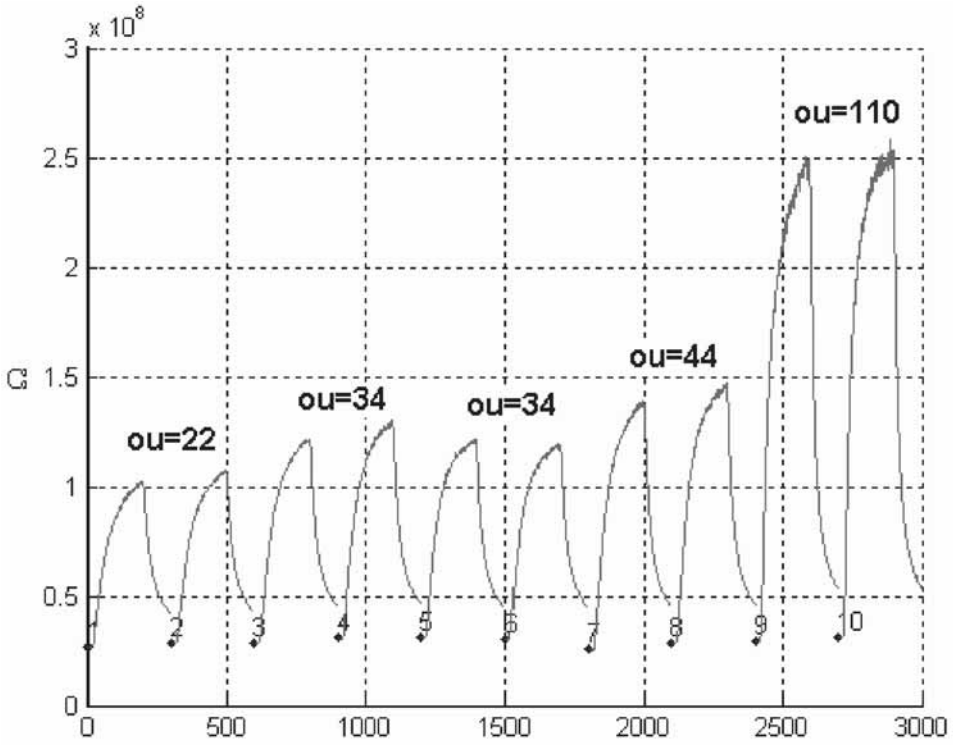

Figure 4. Response curves relevant to the analysis of gas samples at different odour concentration values.

Figure 5 shows a PCA relevant to the same test. It is possible to observe that the odour concentration values grow along the dircetion of the first principal component.

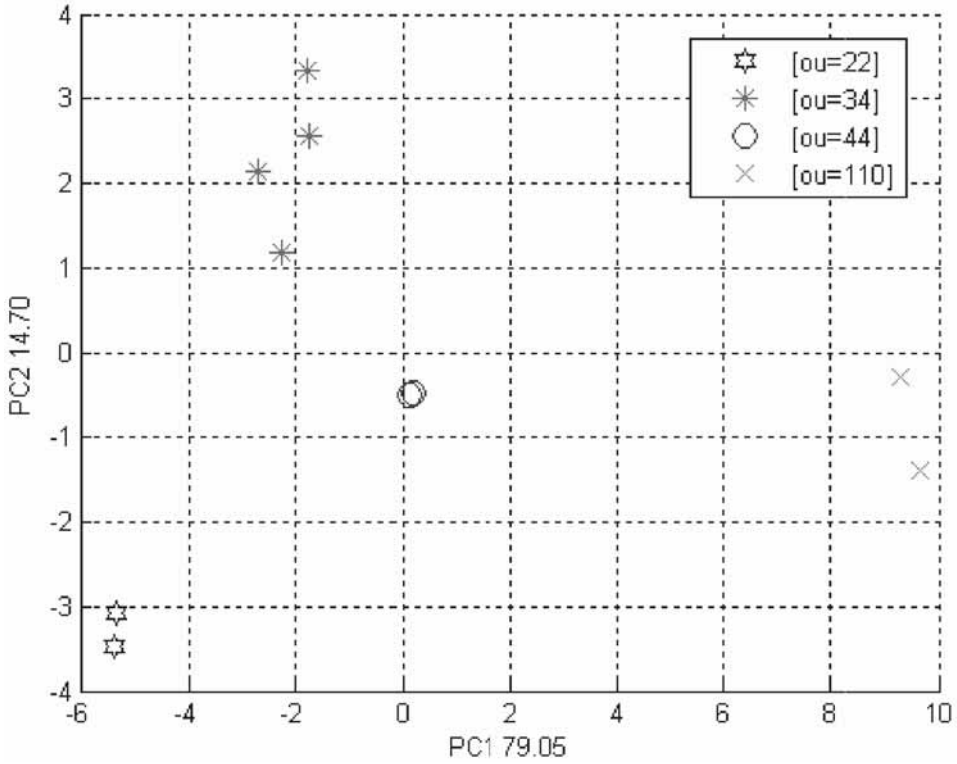

Figure 5. PCA relevant to the analysis of gas samples at different odour concentration values.

The data relevant to the analyses of the samples at different odour concentration values obtained by dilution of a sample collected at a biofilter outlet can be splitted in two, a test training set composed by 5 measures, and a test match set composed by the remaining 5 measures. The obtained test training set is used as a reference for the estimation of the odour concentration values of the test match set, in order to evaluate the instrument accuracy in odour quantification. Table 1 shows the results of this test, i.e. the odour concentration values attributed by the instrument to the measures that form that test match set. The extrapolation of statistical data from the test results, e.g. mean, maximum and minimum error, and correlation index between true and estimated values, allows to gain some information about the estimation accuracy (Table 2). The calculated correlation index is equal to 0.99923, indicating a very good correlation between estimated and true and estimated values.

Table 1.
Results of the odour concentration estimation test.

N.	Match Value	True Value	Error
1	19.46	22	-2.54
2	35.25	34	1.25
3	32.31	34	-1.69
4	43.41	44	-0.59
5	109.48	110	-0.52

Table 2.
Statistical parameters relevant to the odour concentration estimation test.

Mean absolute error	1.3173
Max error	2.5398
Min error	0.51962
Correlation index	0.99923

4 CONCLUSIONS

Our current work consists in the execution of a large number of tests with the aim of studying the optimal combination of sensors for the development of an electronic nose for the continuous monitoring of odours at a biofilter outlet. The most important characteristics for such a system are high sensitivity and accuracy.

The studies we already conducted allowed to exclude some sensors, with too low sensitivity or stability, considering that sensors to be applied for real-time odour concentration measurements should be very sensitive even to very small odour concentration variations (<10 ou_E/m^3), whereas for the development of an instrument to be used just as an alarm for the exceeding of a given odour concentration threshold it might be sufficient to use sensors with a lower sensitivity to odour concentration variations (40-50 ou_E/m^3).

Our future work will consists in the realization of the described system for the continuous monitoring of odours at a biofilter outlet and, after an accurate training phase, in its application on field. This will allow to overcome the difficulties associated with the intrinsic discontinuity of the olfactometric analyses. Nonetheless, because of the reliability of dynamic olfactometry, this technique will still be needed for the instrument validation, by the execution of periodical contemporaneous analyses by dynamic olfactometry and electronic nose, in order to evaluate the instrument accuracy in the odour concentration estimation.

References

Bockreis, A. and Steinberg, I. (2005) Measurement of odour with focus on sampling techniques. *Waste Manage.* 25: 859-863.

Darlington, A.B., Dat, J.F. and Dixon, M.A. (2001) The biofiltration of indoor air: air flux and temperature influences the removal of toluene, ethylbenzene and xylene. *Environ. Sci Technol.* 35: 240-246.

Delhomenie, M.C., Bibeau, L. and Heitz, M. (2002) A study of the impact of particle size and adsorption phenomena in a compost based biological filter. *Chem. Eng. Sci.* 57: 4999-5010.

Devinny, J.S., Deshusses, M.A. and Webster, T.S. (1999) Biofiltration for air pollution control, Lewis Publisher Ed.

EN 13725 (2003) Air quality - Determination of odour concentration by dynamic olfactometry, Comité Européen de Normalisation, Brussels, Belgium.

Falasconi, M., Pardo, M., Sberveglieri, G., Riccò, I. and Bresciani, A. (2005) The novel EOS^{835} electronic nose and data analysis for evaluating coffee ripening. *Sens. Actuators B Chem.* 110: 73-80.

Krailas, S. and Pham, Q.T. (2002) Microkinetic determination and water movement in a downward flow biofilter for methanol removal. *Biochem. Eng J.* 10: 103-113.

Krailis, S., Pharm, Q.T., Amal, R., Jang, J, K. and Heitz M. (2000) Effects of inlet mass loading, water and total bacterial count on methanol elimination using upward flow biofilter. *J. Chem. Technol. Biotechnol.* 75: 299-305.

Leson, G. and Winer, A.M. (1991) Biofiltration: an innovative air pollution control technology for VOC emissions. *J. Air Waste Manage Assoc.* 41: 1045-1054.

Morales, M., Hernández, S., Cornabe, T., Revah, S. and Auria, R. (2003) Effect of drying on biofilter performance modelling and experimental approach. *Environ. Sci. Technol.* 37: 985-992.

Mac Nevin, D. and Barford, J. (2001) Inter-relationship between adsorbtion and pH in peat biofilters in the context of a cation-exchange mechanism. *Water Res.* 35: 736-744.

Persaud, K. and Dodd, G.H. (1982) Analysis of discrimination mechanisms in the mammalian olfactory system using a model nose. *Nature* 299: 352-355.

Quiniam, C., Strevett, K. and Ketcham, M. (1999) VOC elimination in a compost biofilter using a previously acclimated bacterial inoculum. *J. Air Waste Manage Assoc.* 49: 544-553.

Sironi, S., Capelli, L., Céntola, P. and Del Rosso, R. (2007) Development of a system for the continuous monitoring of odours from a composting plant: Focus on training, data processing and results validation methods. *Sens Actuators B Chem.* 124: 336-346.

Tawil, A.A. (2001) Bioxidation of n-propanol and acetone in biofilters and bioscrubbers, PhD Thesis University College Dublin.

Yang, Y. and Allen, E.R. (1994) Biofiltration control of hydrogen sulphide design and operational parameters, *J. Air Waste Manage Assoc.* 44: 863-868.

Van Lith, C., Leson, G. and Michelsen, R. (1997) Evaluating design options for biofilters. *J. Air Waste Manage Assoc.* 47: 37-48.