CHEMICAL ENGINEERING TRANSACTIONS Volume 23, 2010
Editor Renato Del Rosso
 ISBN 978-88-95608-14-3 ISSN 1974-9791
DOI: 10.3303/CET1023052

An innovative system for the continuous monitoring of environmental odours: results of laboratory and field tests

Laura Capelli[1]*, Selena Sironi[1], Licinia Dentoni[1], Renato Del Rosso[1], Paolo Centola[1], Fabrizio Dematté[2], Matteo Della Torre[2], Ibanez Riccò[2]
[1]Politecnico di Milano, Department of Chemistry, Materials and Chemical Engineering "Giulio Natta", Piazza Leonardo da Vinci 32, 20133 Milano
[2]Sacmi s.c.a.r.l., via Provinciale Selice 17/a, 40026 Imola
*corresponding author: laura.capelli@polimi.it

At the Olfactometric Laboratory of the Politecnico di Milano, in collaboration with Sacmi Group, Imola, an innovative electronic nose for the continuous monitoring of environmental odours is being developed. The aim of this work is to show the laboratory and field tests conducted in order to verify the effectiveness of the new integrated systems and to evaluate the capability of the electronic nose to recognize environmental odours. The laboratory tests proved the sensors to be sensitive towards pure substances and environmental mixtures as well as the system to be capable of discriminating between the different tested odours and odour concentrations. The on field monitoring confirmed the laboratory experiences, showing a good capability of the electronic nose of detecting and discriminating environmental odours, which was further confirmed by the existence of a correspondence between electronic nose responses and odour perceptions by the resident population. Moreover, the efficiency of the system for the humidity regulation in facing external humidity variations, thus making the instrument responses more stable and reproducible, was proved.

1. Introduction

In the last years there has been a progressive growth of the attention of the population and the administrations towards odour emissions from industrial sites. The development of dynamic olfactometry (EN 13725, 2003) has permitted to quantify odour concentration in terms of odour units per cubic metre (ou_E/m^3). Nevertheless, this method is not applicable to continuous monitoring (Bourgeois et al., 2003) and therefore the possibility to use a system based on electronic noses for the prolonged survey of odour emissions from industrial sites has been recently considered (Hodgins, 1995; Baby et al., 2000). At present, commercial instruments present some critical aspects, such as sensors sensitiveness to variations of the atmospheric conditions (Romain et al., 2008) and, as a consequence, measures and odour recognitions are influenced by such variations.
For this reason, at the Olfactometric Laboratory of the Politecnico di Milano (Italy), in collaboration with Sacmi Group, Imola, Italy, an innovative electronic nose for the

Please cite this article as: Capelli L., Sironi S., Dentoni L., Del Rosso R., Centola P., Dematte F., Della Torre M. and Ricco' I., (2010), An innovative system for the continuous monitoring of environmental odours: results of laboratory and field tests, Chemical Engineering Transactions, 23, 309-314
DOI: 10.3303/CET1023052

continuous monitoring of environmental odours is being developed. The new instrument presents some innovative aspects, such as the use of a reference different from air to and a system for humidity regulation. Furthermore, for an optimal working, the instrument needs neutral air (air that doesn't cause any sensors response), therefore, a system for the realization of neutral air has been integrated in the electronic nose.
The aim of this work is to show the laboratory and field tests conducted in order to verify the effectiveness of the new integrated systems and to evaluate the capability of the electronic nose to recognize environmental odours.

2. Materials and methods

2.1 The electronic nose

The instrument has two inlets for air: one of them is connected with the system for the neutral air realization; the other one is connected with an electronic valve that regulates the sample flow that is sent to the sensor chamber containing 6 MOS sensors, which are considered to be the most appropriate for continuous environmental monitoring (Nake et al., 2005).
Moreover, the electronic nose is equipped with a temperature and humidity sensor, an anemometer, and it has a user's interface and an internal memory for data recording. For the regulation of the sample humidity, the electronic nose regulates neutral air humidity to a certain value RHwk that the software calculates from the external humidity value (RHext).

2.2 Features computation

With the new electronic nose, only one feature is calculated from the response of each sensor, defined as E.U. (EOS Unit). All measures are normalized using an internal standard carried out using n-butanol and, as a consequence of this normalization, sensors response should increase linearly with the concentration of the analyzed sample.

2.3 Laboratory tests

2.3.1. Evaluation of sensor sensitiveness

For the evaluation of sensor sensitiveness pure substances and environmental odour samples from different industrial sources were used. The n-butanol sample was drawn directly from a cylinder with a concentration of 45 ppm, the other odour samples were collected at the source in Nalophan bags (Beghi and Guillot, 2008) using a depression pump (Sironi et al., 2007). All samples were analyzed at different concentrations, from 10 to 100% (with 10% concentration steps) of the original concentration.

2.3.2. Verification of the system for the neutral air realization

For the verification of the efficiency of the system for the neutral air realization the same samples used for the sensors sensitiveness evaluation were used. For this purpose, the sensor responses to gas flow with and without the tested system were compared. t

2.3.3. Monitoring simulation in laboratory

In order to recognize the measures made during the monitoring period, the electronic nose needs a training data set, used as reference, composed of measures of sample with known quality and odour concentration (Sironi et al., 2007).

The training was carried out using three different odour samples (landfill gas, fresh waste and n-butanol) analyzed at different concentrations from 10 to 100% (with 10% concentration steps). Furthermore, non odorous ambient air samples were analyzed in order to create the "neutral air" class, to be used as a reference (Capelli et al., 2008).
For the monitoring simulation, the same training samples were used, diluted at concentrations of 10, 50 and 100% of the original samples. The simulations took two hours and half and during this period the electronic nose executed a measure every second, while the E.U. were calculated and the recognition was performed every 10 seconds.

2.4 Monitoring on field

The electronic nose was placed at a receptor near an aluminium foundry, in order to detect and identify the odours coming from the foundry.
The experimentation was carried out as explained below:

- Training: air samples from the main odour sources were collected, in order to create the "training set", considering the olfactory classes corresponding to the foundry main odour sources (Sironi et al., 2007).
- Monitoring: the electronic nose analyzed the ambient air, in order to recognize its quality ("match set").
- Data elaboration: elaboration of all the sensor responses and comparison between data recorded during the training and during monitoring, in order to classify analyzed air in terms of quality, establishing the proper olfactory class.

3. Results and discussion

3.1 Sensors sensitiveness towards pure compunds and environmental mixtures

Sensors responses are represented in plots, which in abscissa report the analyzed concentrations values and the corresponding E.U. values in ordinate. As an example, Figure 1 shows the sensor responses to the samples of n-butanol and compost odour.
All sensors give linear response to the analyzed samples, consistently with the E.U. definition.

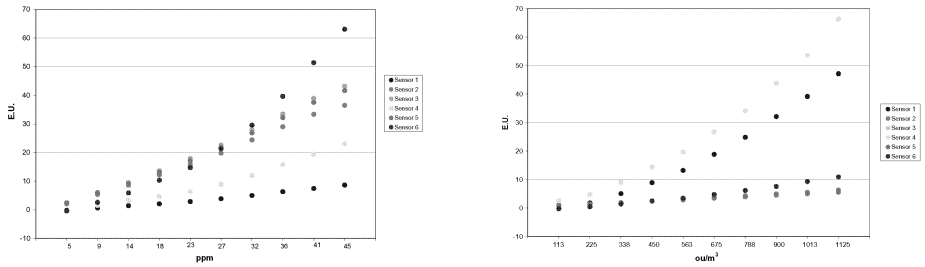

Figure 1. Sensors responses to n-butanol sample (left) and to compost sample (right)

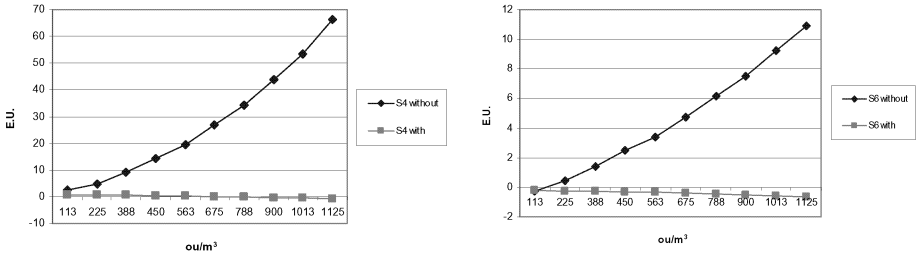

Figure 2. Comparison of sensors responses to compost sample with different configurations

As far as environmental samples are concerned, it can be noticed that some sensors are more sensitive to specific odours than other sensors, and this behaviour is predictive of a good odour distinction capability.

3.2 Realization of the neutral air

Test results obtained are represented in plots, which, for each sensor, in abscissa report the analyzed concentration values and in ordinate both the responses with and without the use of the neutral air realization system. As an example, Figure 2 shows the results obtained for two sensors (S4 and S6), using the compost sample.

From the obtained results, it can be noticed that the E.U. recorded when using the system for the realization of neutral air (S4 “with”, S6 ”with”) are near to 0, thus indicating a good efficiency of the system under study.

3.3 Laboratory monitoring simulation

In order to graphically evaluate the discrimination of the olfactory classes considered for training, Principal Component Analysis was performed, which showed a good capability of discriminating the points belonging to the different olfactory classes and of distinguishing different odour concentrations (Figure 3).

The number and the percentage of correct recognitions that the system performed during the monitoring are summarized in Table 1. From these results it can be stated that the electronic nose executes recognitions with a good accuracy.

3.4 On field monitoring

In order to evaluate the sensors capability of discriminating the considered olfactory classes and consequently recognizing odours, it is useful to perform Principal Component Analysis (PCA) of the training data set. The PCA showed a good discrimination of the different olfactory classes.

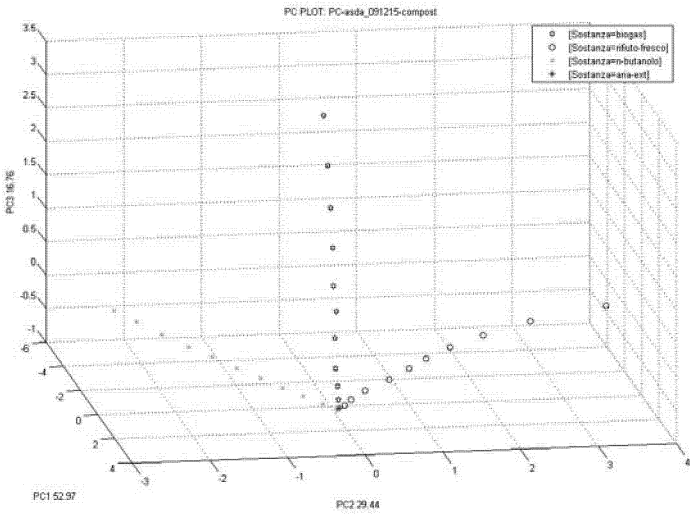

Figure 3. Principal Component Analysis applied to training data of the laboratory monitoring simulation

Table 1. Number and percentage of exact recognitions in the laboratory monitoring simulation

	Correct	Wrong	Uncertain	Total
n. of recognitions	571	21	15	607
%	94%	3,5%	2,5%	100%

The monitoring results are represented by large tables in which, to every measure of the executed during the monitoring period, the olfactory class ascribed by the electronic nose to the analyzed air is associated. After the elaboration of the monitoring data, it is possible to notice that in some periods the electronic nose detected the presence of odours from the foundry in the analyzed air, because in these periods the analyzed air was classified as different from "neutral air". Moreover, there is a good correspondence between odour detections by the electronic nose and the records of odour perceptions by the population.

4. Conclusions

The tests for the evaluation the sensors sensitiveness and the efficiency of the system for the realization of neutral air show that:

- In general, sensors are sensitive to the tested sample, as the recorded E.U. are different from 0 and increase whit the analyzed sample odour concentration. According with E.U. definition, E.U. have a linear growth with odour concentration.
- The system for the neutral air realization is effective. It is worth to highlight that the tested sample were more concentrated (in terms of odour concentration) than the typical environmental air of an industrial site.

Concerning the monitoring simulation that was performed in laboratory, some considerations about the electronic nose capability to recognize environmental odours can be done:

- Analyzing the training data set, it can be noticed that the system has a good capability of discriminating between the different tested odours and the different odour concentrations.
- The capability of recognizing different environmental odours was demonstrated by the monitoring simulation realized using neutral air, and odour samples of landfill gas, fresh waste and n-butanol at different concentrations.

Finally, about the on field monitoring and the verification of the efficacy of the systems that were introduced in order to make the electronic nose stable towards atmospheric conditions changes, it can be noticed that:

- The on field monitoring confirmed the laboratory experiences, showing a good capability of the electronic nose of detecting and discriminating environmental odours, which was further confirmed by the existence of a correspondence between electronic nose responses and odour perceptions by the resident population.
- Moreover, the tests on field allowed to prove the efficiency of the system for the humidity regulation in facing external humidity variations, thus making the instrument responses more stable and reproducible.

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