

## Continuous Evaluation of Odour Concentration at a Plant Emission by Electronic Nose

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The development of an electronic nose for the continuous monitoring of odour emissions from an industrial plant would represent an important advantage in the field of environmental odour emissions control. For instance, it would allow to characterize odour emissions over time and use these data as real time input (data) for dispersion modelling purposes.

This study presents the first results of our research for the development of an electronic nose designed specifically for emission monitoring. The electronic nose EOS 507 was developed in collaboration with Sacmi s.c. and Progress S.r.l.

The emission chosen to test the electronic nose performances was a chimney for the emissions of the fumes produced by a plant for the disposal and treatment of hospital waste. A preliminary study was conducted in order to evaluate the instrument capability to quantify the odour concentration of pure compounds as well as of mixtures emitted by the monitored plant. An accurate instrument training was carried out in order to account for both the different operation phases of the plant and the variability of the conferred waste. The monitoring in the field involved the periodical collection of samples at the monitored emissions and their analysis by dynamic olfactometry, in order to verify the correctness of the electronic nose estimations.

The first results obtained seem to highlight that the electronic nose, if opportunely trained, is capable of estimating the odour concentration of the emission at a satisfying level of accuracy.

### 1. Introduction

The presence of odour in ambient air is nowadays recognized as an environmental stressor that negatively affects the quality of life (Blanes-Vidal et al., 2012). In order to evaluate odour exposure at receptors, several methods can be applied (Capelli et al., 2013). Different regulations provide to use dispersion modelling to simulate how odour disperses into the atmosphere, and consequently to calculate hourly ground odour concentration values in the simulation space-time domain (Cusano et al., 2010). Given that a detailed characterisation of emissions over time would require frequently repeated olfactometric tests, thus resulting in a very expensive (in terms of money and time) approach, emission data employed as model inputs are usually represented by averaged odour emission rate values. This approach may provide a good description of the average odour impact, but doesn't take account of fluctuations that are typical of some emission typologies (Isaac-Ho Tin Noe et al., 2010). This study discusses the possibility of installing an electronic nose directly at an emission, in order to measure odour concentration continuously and therefore to obtain data that could be possibly used as real-time inputs for dispersion models. This application requires the development of a specific instrument, as well as a specific training. An EOS 507 electronic nose, developed in collaboration with Sacmi s.c. and Progress S.r.l., was used to evaluate the

possibility to monitor the odour concentration at the emission of a plant for hospital waste treatment. Actually, the electronic nose was set up on the exhaust gas line - going to stack - of the sterilization process operating at 120°C.

Laboratory tests were conducted to evaluate the electronic nose capability of quantifying odour concentration: "artificial" samples created starting from pure compounds and mixtures of compounds, usually detected in the emission of the plant, were tested at different concentrations, as well as real samples collected directly from the odour source of the plant.

## **2. Materials and Methods**

### **2.1 The EOS 507 electronic nose**

The electronic nose used for this work is an EOS 507 (Dentoni et al., 2012).

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, which contains 6 MOS sensors, specifically selected for this application.

Moreover, the electronic nose is equipped with a temperature and humidity sensor. For the regulation of the sample humidity, the electronic nose regulates neutral air humidity to a certain value  $RH_{wk}$  that the software calculates from the external humidity value ( $RH_{ext}$ ).

With the EOS 507, 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 consisting of n-butanol at a known and constant concentration and, as a consequence of this normalization, sensors responses in terms of E.U. should increase linearly with the concentration of the analysed sample. The classification and quantification algorithm is a modified KNN-algorithm.

The electronic nose is trained with artificial and real samples collected on the source to be monitored, diluted as to obtain samples at different concentrations. For sample recognition, the system compares the distance, in the 6-dimensional response space (6 sensors giving each 1 E.U. value), of the point relevant to the unknown measure to be classified and the broken lines between two neighbouring points belonging to the same olfactory class. The unknown measure is then classified as belonging to the olfactory class for which the minimum distance is measured. The odour concentration of the analysed sample is then calculated based on the odour concentrations of the points at the extremities of the segment, by evaluating the relative distance between the two points at known concentration and the position of the projection of the point representing the unknown measure.

### **2.2 Considered emission**

The emission considered in this study is a chimney of a hospital waste treatment plant. More in detail, the chimney emits the air sucked from the grinder where the medical waste is first treated, as well as all the vents coming from the sterilization process. The plant operates with cycles and each cycle can be considered as composed by different phases. After collection, the medical waste is grinded and sent to a batch sterilizer. When the waste loading in the sterilizer is completed, the air inside the sterilizer is sucked by means of a pump and emitted through the chimney. After that, the sterilization process starts with the injection of steam. After 15-20 minutes, the sterilizer is vented, and this vent is emitted through the chimney, as well. The emission from the chimney is therefore variable. Based on the above described process, three different emissions typologies can be identified: the air sucked from the grinder, the vent of the air sucked from the sterilization system before the steam injection and the vent after the sterilization process. Gaseous samples were collected at the emission during these three different phases, and then tested by dynamic olfactometry in order to evaluate their odour concentration. Moreover, chemical analyses were carried out in order to determine the chemical composition of the emission.

### **2.3 Tests with pure compounds**

Pure compounds to be used for laboratory tests were chosen among compounds detected in the emission. More in detail, starting from chemical analysis results, and considering the odour threshold of each compound, the theoretical odour concentration related to each single compound in the emission was estimated (Table 1). Laboratory tests were conducted using those chemical compounds having the major theoretical odour concentration in the emission: ethanol and ammonia.

Table 1. Chemical compounds at the emission with odour threshold

Compound	Amount of pollutant [mg/Nm <sup>3</sup> ]	OT [ppm/ou <sub>E</sub> /m <sup>3</sup> ]	Calculated Odour Concentration
n-pentane	1.20	135.47	0.01
2-propanol	10.00	18.10	0.83
Cyclohexane	1.20	50.08	0.02
Ethanol	31.00	0.04	437.14
Acetone	0.56	0.39	0.56
Hexane	2.10	26.40	0.02
Chloridric acid	0.73	4.36	0.10
Acetaldehyde	0.68	0.01	70.40
Formaldehyde	0.49	0.75	0.49
Butyraldehyde	0.02	0.00	1.23
Benzaldehyde	0.06	0.05	0.27
Ammonia	1.31	0.01	172.61

Gaseous samples of each pure compound were analysed with the electronic nose at different concentrations in order to train the electronic nose to estimate odour concentration. After the training phase, gaseous samples were analysed with the EOS 507, which estimated their odour concentration. Tests were performed using gaseous samples containing ammonia and ethanol separately, as well as mixtures of the two compounds. The odour concentration of analysed samples was in the range between 20 and 500 ou<sub>E</sub>/m<sup>3</sup>.

#### 2.4 Tests with real samples

Different samples were collected at the emission during the 3 different phases of the process. All samples were analysed by dynamic olfactometry to determine their odour concentration. The electronic nose was trained with all real samples at different odour concentrations, between 10 and 100% of the measured odour concentration. The capability of the electronic nose to estimate the odour concentration of real samples was tested. For this purpose, different samples having different odour concentrations were obtained from collected real samples. Those samples were then analysed with EOS 507 and the estimated odour concentration registered.

During the quantification process the following procedure was used:

- First for each odour typology, only the corresponding training dataset was considered (e.g. ethanol testing used Ethanol training only)
- Then, all the training datasets were involved for odour quantification (e.g. ethanol testing used training for each substance).
- Finally, the estimated and real odour concentrations were compared, to evaluate the performance of the instrument according to the data sets provided (i.e. only one dataset vs. all).

#### 2.5 Tests at the chimney

The electronic nose was installed at the chimney of a hospital waste treatment plant. A complete of the train 3 different phases of the waste treatment was used.

In order to compare the ability of the electronic nose of estimating the odour concentration of the emission at a satisfying level of accuracy, different sample were collected at the emission during the 3 different phases of the process. All samples were analysed by dynamic olfactometry to determine their odour concentration. The estimated and real odour concentrations were compared to evaluate the performances of the instrument when it work on site.

The quantification was performed using a complete training.

### 3. Results and discussion

#### 3.1 Tests with pure compounds – results

Electronic nose responses to different odour concentrations of the different considered pure compounds were evaluated in order to verify the linearity between electronic nose responses (E.U.) and odour concentration. As an example, the electronic nose responses to different odour concentrations of a gaseous sample containing ethanol are reported in Figure 1.

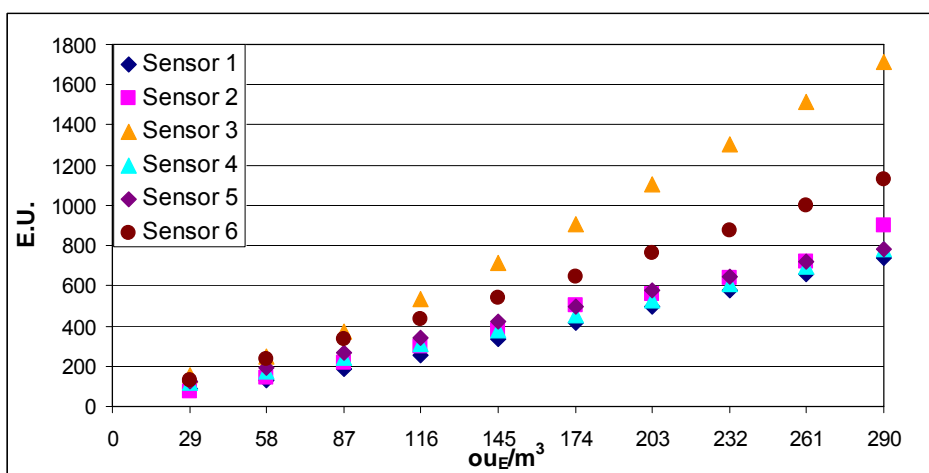


Figure 1. E.U. registered for different odour concentrations of the ethanol sample

Some of the results of the odour concentration estimation performed by the electronic nose using the pure compounds are reported in Table 2.

Table 2. Real and estimated odour concentrations relevant to the tests with pure compounds

Tested Compound	Real concentration [ouE/m <sup>3</sup> ]	Estimated concentration [ouE/m <sup>3</sup> ]	Error [%]
Ethanol	145	150	3
Ethanol	145	149	3
Ethanol	290	255	12
Ethanol	290	255	12
Ethanol	290	283	2
Ethanol	290	275	5
Ethanol	580	593	2
Ammonia	82	99	21
Ammonia	164	141	14
Ammonia	246	208	15
Ammonia	328	301	8
Ammonia	411	417	1
Ammonia + Ethanol	62	70	13
Ammonia + Ethanol	125	118	6
Ammonia + Ethanol	187	194	4
Ammonia + Ethanol	249	260	4
Ammonia + Ethanol	312	306	2
Ammonia + Ethanol	124	120	3
Ammonia + Ethanol	187	193	3
Ammonia + Ethanol	312	314	1

In the table, the real and the estimated odour concentrations are listed; the error (per cent) of the concentration estimation is reported, as well.

Odour concentrations estimated by the electronic nose are comparable with the real concentration evaluated by means of dynamic olfactometry, or obtained by diluting gaseous samples having a known odour concentration. The per cent error is comprised between 1 and 20 %, and the error decreases when the odour concentration increases.

### 3.2 Tests with real samples – results

Table 3 reports the results obtained with the real samples. More in detail, column 2 of Table 3 reports the real odour concentration detected by means of olfactometric analysis, column 3 reports the odour concentration estimated using only the training data set of the same emission phase (single training dataset) and column 5 the odour concentration estimated using the complete training dataset.

The electronic nose is able to estimate the odour concentration of real samples with an error between 2 and 37%. The quantification system guarantees the same performances both using the single training and the complete training. In general, it can be observed that the odour concentrations estimated by the electronic nose are almost always lower than the odour concentration measured by dynamic olfactometry. This may be due to the losses through the sampling bags that may occur during the time interval between the two analyses (Hansen et al., 2011). These leakages could concur in a non-negligible way to the error of the concentration measurements for an undefined percentage.

*Table 3. Real and estimated odour concentrations relevant to the tests with real samples*

Emission typology	Real concentration [ou <sub>E</sub> /m <sup>3</sup> ]	Estimated concentration (single training) [ou <sub>E</sub> /m <sup>3</sup> ]	Error [%]	Estimated concentration (complete training) [ou <sub>E</sub> /m <sup>3</sup> ]	Error [%]
Grinding	900	600	33	599	33
Grinding	1200	843	30	839	30
Grinding	1500	1088	27	1081	28
Pre-sterilization	80	58	28	58	28
Pre-sterilization	160	101	37	101	37
Pre-sterilization	240	154	36	153	36
Pre-sterilization	320	268	16	271	15
Pre-sterilization	400	321	20	321	20
Post-sterilization	620	619	0	650	5
Post-sterilization	1240	995	20	947	24
Post-sterilization	1860	1823	2	1700	9
Post-sterilization	2480	2716	10	2656	7
Post-sterilization	3100	3921	26	3049	2

### 3.3 Tests at the chimney – results

Table 2 reports the results obtained at the chimney by the electronic nose and the dynamic olfactometry of the real samples. More in detail, the real odour concentration measured by dynamic olfactometry, the odour concentration estimated using the complete training dataset and the percentage error are reported.

In general, it can be observed that the odour concentrations estimated by the electronic nose at the chimney are almost always lower than the odour concentration measured by means of dynamic olfactometry for the emission from “Pre-sterilization” and “Post-sterilization” operations. Conversely, the “grinding” phase presents odour concentrations estimated with the electronic nose at the chimney higher than those measured through dynamic olfactometry.

The electronic nose is able to estimate the odour concentration of real samples on site with an error between 10 and 64% with the only exception of one measure of the grinding phase where the error is equal to 86%.

This high value may be due to a combination of two effects:

1. the high response of the sensor to some pollutant present in the grinding emission,
2. the fact that the nose does not have time to fully regenerate the sensors between one measure and the following one.

On the contrary, during training a long cleaning time between two sessions was scheduled for the nose. Moreover, during the tests with the real samples the sensors were cleaned before every recognition run.

Since for a plant working continuously it's not possible to perform a full clean, probably one solution could be diluting the emission at the inlet of the nose in order to contain the sensor response avoiding excessive feedbacks.

Table 4. Real and estimated odour concentrations relevant to the tests estimated on site by the electronic nose and with real samples measured by dynamic olfactometry

Emission typology	Real concentration [ou <sub>E</sub> /m <sup>3</sup> ]	Estimated	Error [%]
		concentration (complete training) [ou <sub>E</sub> /m <sup>3</sup> ]	
Grinding	10000	25000	60
Grinding	10000	28000	64
Grinding	8200	59000	86
Pre-sterilization	23000	21760	6
Pre-sterilization	15000	13600	10
Post-sterilization	11000	9000	22
Post-sterilization	12000	9417	27

#### 4. Conclusion

Laboratory tests show that the EOS 507 is able to quantify the odour concentration of samples of pure compounds and of real samples.

The error obtained with pure compounds is comprised between 1 and 20%. The capability of the system to estimate the odour concentration turned out not to be influenced by the use of mixtures of different pure compounds in air instead of gaseous samples of pure compounds in air.

Tests performed with real samples demonstrate that the system is capable to estimate the odour concentration with the same accuracy using only a training dataset obtained with samples belonging to the same olfactory class as the sample to be quantified, as well as using a “complete” dataset, which contains data relevant to different olfactory classes. This of course is an important information, meaning that the use of one single “complete” dataset will be sufficient in order to quantify the odour concentration of the monitored emission during all the phases within a satisfying level. The error relevant to the odour concentration estimation of real samples is comprised between 2 and 37%.

Laboratory tests proved the electronic nose EOS 507 to be able to quantify odour concentration with a error below 40%.

Tests performed on site demonstrate that the system is capable to estimate the odour concentration. The error relevant to the odour concentration estimation of real samples is comprised between 10 and 64%.

Future studies will be carried out in order to verify the electronic nose performances directly in different applications. Moreover, the instrument will be tested with different samples, collected on other odour sources, in order to evaluate its performances with different emissions and different plants.

#### References

- Blanes-Vidal V., Nadimi E.S., Ellermann T., Andersen H.V., Loftrom P., 2012, Perceived annoyance from environmental odors and association with atmospheric ammonia levels in non-urban residential communities: a cross-sectional study, *Environ. Health* 11, 27-37.
- Capelli L., Sironi S., Del Rosso R., Guillot J.-M., 2013, Measuring odours in the environment vs. dispersion modelling: A review, *Atmos. Environ.* 79, 731-743.
- Cusano G., Licotti C., Sironi S., Capelli L., Rossi A.N., Il Grande M., 2010, Odour regulation in Italy: the regional guidelines on odour emissions in Lombardia, *Chem. Eng. Tans.* 23, 19-24.
- Dentoni L., Capelli L., Sironi S., Del Rosso R., Zanetti S., Della Torre M., 2012, Development of an electronic nose for environmental odour monitoring, *Sensors*, 12, 14363-14381.
- Hansen M. J., Adamsen A. P. S., Feilberg A., Jonassen K. E. N. 2011, Stability of Odorants from Pig Production in Sampling Bags for Olfactometry, *J. Environ. Qual.* 40, 1096-102.
- Isaac-Ho Tin Noe I., Siino F., Bara C., Urvoy Y., Haaser C., Tripathi A., Ait Hamou L., Mailliard T., 2010, Tool for predicting and monitoring the impact of wastewater treatment plants on odour, *Chem. Eng. Tans.* 23, 267-272.