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Identification of odour provenance in presence of multiple sources

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In the last years, odour emissions from waste/wastewater treatment plants or from other industrial activities have become a serious environmental concern, especially because these facilities are often placed near residential zones, causing the raising of complaints from the population.
This is the case of an important city in the north of Italy, where the town council, in order to respond to the requests of a committee of citizens complaining about the frequent presence of unpleasant odours in a peripheral quarter south from the city centre, decided to undertake a study in order to characterize the odour immissions and identify their main source among a waste sorting plant, a wastewater treatment facility, the breather pipe of an actived carbon odour abatement system installed nearby the sluice of the sewer trunk line 1M and a paper factory, which are located in that part of the city.
The odour impact in this area of the city has been a troublesome issue for more than 20 years and is thus very felt by the population; the committee of citizens itself decided to conduct an extensive "scientific" odour survey, using a questionnaire system that can be considered as a primordial field inspection.
In the study commissioned by the municipality of the city in order to evaluate the odour impact of the different plants at issue and determine the odour provenance, was instead decided to use five electronic noses.
The study was articulated in three separated phases. The first phase is the electronic nose training, which consists in the collection of gas samples belonging to the olfactory classes corresponding to the odour sources of the plants at issue, which are necessary in order to train the instruments to recognize the odours form the plants. These sources were identified with a detailed preliminary olfactometric analysis. The second phase is the monitoring, which had a duration of 11 days and consisted in the repeated analysis of the ambient air by the electronic noses. Two instruments were installed at two different receptors. The first receptor is a flat located at 400 m south-south-west from the wastewater treatment facility, 410 m south from the waste sorting plant, a few meters south-east from the sluice of the sewer trunk line 1M and 700 m south-east from the paper factory, while the second receptor is represented by a dwelling at 420 m west-

south-west from the wastewater treatment facility, 300 m south-south-west from the waste sorting plant, 200 m north-west from the sluice of the sewer trunk line 1M and 450 m south-east from the paper factory. The other three instruments were positioned at the three plants, in order to monitor the odours at the plant fence lines. The last phase is the data processing: the comparison of the data registered by the electronic noses during the monitoring with the training data enabled to classify the analyzed air and to evaluate the frequency of odour detections and the odour provenance.
In this specific case, the odours detected at the receptors by the electronic noses were attributed to the olfactory classes relevant to the wastewater treatment facility and the breather pipe of the actived carbon odour abatement system installed by the sluice of the sewer trunk line 1M, which therefore turned out to be, as far as concerns odour emissions, the most problematic sources among the ones being considered for the study.
For the two sources identified as the main cause of odour impact, the study was carried out with the application of a numerical dispersion model in order to evaluate the odour fall-out area breeded by the wastewater treatment plant and the breather pipe nearby the sluice of the sewer trunk line 1M and to verify the correspondence between the electronic nose odour detections and the result of the mathematical simulation of odour dispersion: the correspondence was perfect and allowed to individuate a larger zone which might be concerned with odour pollution as well as the two receptors.

1. Introduction

In the last years industrial odour emissions, especially the ones of waste and wastewater treatment plants, have become a serious environmental concern. The sensitiveness of population and control government units to the problem of olfactory pollution has increased: unpleasant odours are often cause of intense discomfort which affect the citizens quality of life. Thus, industries have started to pay attention to this environmental concern, which was before not even considered as a kind of pollution, and to the abatement of their own odour emissions.

In addition, the town-planning development of many cities has not often been very rational and it has permitted to build dwellings closer and closer to the industrial installations. At the present moment there are thus industrial plants, once isolated and far from residential areas, completely surrounded by dwellings and obviously the reduction of the distance between houses and industries is proportional to the raising of complaints due to odours from the population.

This is the case of residential quarter of an important city in the north of Italy. The presence of plants and houses at close range has caused a troublesome issue between industries, government units and population living in the quarter and complaining about the frequent presence of unpleasant odours. In 2004, a committee of citizens, tired of the situation, decided to undertake a inquiry in order to identify the frequency and the source of odour immissions perceived in the quarter, distributing detailed questionnaires to the many families.

In 2007, in order to respond to the requests of the committee, the town council decided to undertake a in-depth odour study in the quarter with the purpose of characterizing the odour immissions and identifying their main source. The ambient air was monitored with five electronic noses. The work commissioned by the municipality was an articulated and complete study: starting from a deep knowledge of the local situation, the main odour sources in the quarter were identified and subsequently undergone a preliminary olfactometric analysis. The nucleus of the study was the electronic nose monitoring which had a duration of 11 days and enabled to evaluate the odour provenance. Finally, the study was carried out with the application of a numerical dispersion model in order to evaluate the odour fall-out area.

2. The industries involved in the study and the preliminary olfactometric analysis

The first step of this study was the identification of some potential sources of odour emissions in the quarter. The plants historically believed, both by population and institutions, possible responsible for the emission of unpleasant odours in the quarter were four:

1. *a wastewater treatment facility;*
2. *a waste sorting plant;*
3. *a paper factory;*
4. *the sewerage system of the quarter*.

Once these industrial and civil activities were identified, the study was carried on with a detailed plants inspection and olfactometric analysis, in order to define the odour sorces which might have been the cause for odour immissions in the surrounding. The preliminary olfactometric analysis was necessary for a correct air monitoring with electronic noses.

The olfactometric analysis was conducted on 2 different days (14^{th} and 16^{th} of May): in total 24 samples were collected.

At the wastewater treatment plant some odour sources were identified and 8 samples were collected:

- before and after the environmental abatement systems (biofilters and scrubbers);
- on oxidation and sedimentation tanks;
- on wastewater entry channel.

At the waste sorting plant 6 samples were collected:

- on waste and ligneous-cellulosic material heaps;
- on physical-chemical treatment and wastewater tanks.

At the paper factory 7 samples were collected, 6 of them at the wastewater treatment plant which treats the paper process wastewater and was itself located in the installation:

- at the chimneys discharging the fumes of the different phases of paper production;
- in the sewage sludge room and in the exhaust sludge manhole;
- on the equalization tank and on the wastewater entry channel.

The quarter sewage system was also monitored during the olfactometric analysis. 3 samples were collected there, 2 at street manholes and 1 at the breather pipe of an actived carbon odour abatement system installed nearby the sluice of the sewer trunk line 1M.

3. The electronic nose training phase

The electronic nose monitoring, whose purpose was to verify the presence at receptors of odours coming from the plants at issue, was articulated in 3 different phases:

- Training: it consisted in the collection of gas samples belonging to the olfactory classes relevant to odour sources of the plants and was necessary in order to train the instruments to recognize the odours from the plants.
- Monitoring: it consisted in the repeated analysis of ambient air and was performed with 5 electronic noses. 3 instruments were positioned at the fence line of the plants and 2 instruments were installed at receptors in the residential areas. They were able to detect the presence of odours relevant to the olfactory classes they were trained with, and thus their sources.
- Data processing: the comparison of the data registered by the electronic noses during the monitoring with the training data enabled to classify the analyzed air and to evaluate the odour provenance and the frequency of odour detections.

The nose training represented the first fundamental phase of the study with electronic nose; in this phase the instrument was given the necessary database for the next odour recognition.

The training consisted in subjecting samples of known olfactory quality at different values of odour concentration to the electronic nose and in instructing the processing software. Doing so, the electronic noses were able to:

- recognize the analysed air from a quality point of view, assigning it to a specific olfactory class;
- quantify the odour, estimating the odour concentration in odour units per cubic meter (ouE/m3).

Thus, at the plants at issue some samples were collected and next subjected to sensorial (dynamic olfactometry) and senso-instrumental analyses (electronic nose). The identification of the odour sources of each plant was realized on the base of the results of the preliminary olfactometric analysis conducted on 14th and 16th of May.

Finally, some ambient air samples were collected close to the receptors where the monitoring was carried on, when no odour was perceived, in order to create the olfactory class "neutral air" to be used as the reference olfactory class for the noses.

The training of the electronic noses for odour quantification consisted in the analyses of samples at different values of odour concentration for each olfactory class. These analyses were necessary in order to give the instrument a database which was later used to define the odour concentration of the unknown analysed air through interpolation of the data previously stocked.

4. The electronic nose monitoring phase

The monitoring period with the 5 electronic noses in the quarter at issue started on Monday 11th of June and ended on Thursday 21st of June 2007.

During the whole monitoring period the electronic noses were installed as showed in Figure 5: the instruments EOS 25 and EOS 28 were installed at receptors, EOS 19 was installed in the office building of the paper factory, EOS 20 was installed in the guardhouse of the waste sorting plant and EOS 35 was installed in the laboratory and office building of the wastewater treatment plant.

The electronic noses installed at the receptors were used to verify the presence of odour impact in the quarter, the three instrument installed at the plants had instead the purpose of comparing the results of each instrument installed in the plants with those detected by the electronic noses installed at the receptors. The main reason for this comparison was the exclusion of the so called “false positives” that could be detected at the receptors, that is, the detection of odours similar to the olfactory classes used for the nose training, but not belonging to the plants at issue.

The electronic noses intook the ambient air out the buildings where they were installed through a Teflon^{TM} small pipe directly connected with the instruments. The reference air intaken by electronic noses was previously filtered with actived carbon and silica gel, in order to make it odourless and dehumidified. This device made the base line of the sensors responses independent from humidity or from the presence of odours in the outside air.

During the whole monitoring period, the 5 electronic noses analyzed the air every 15 minutes. During each of these intervals the instruments had intaken the air to be analyzed for 3 minutes while, for the following 12 minutes, the instruments had intaken reference air in the sensors chamber, in order to clean the sensors and to restore the response base line.

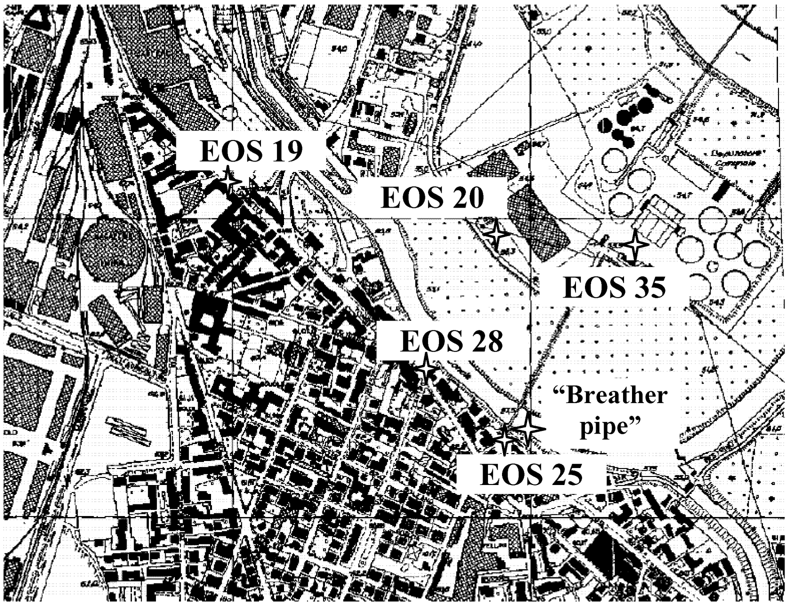

Figure 1: position of the 5 electronic noses and of the odour abatement system “Breather pipe”

5. The data processing phase

The data processing primarily consisted in the extraction of some meaningful characteristics of the sensors response curves (features) in order to obtain numerical data for the following processing.

The features and algorithms chosen and the principles adopted for the creation of an appropriate training set were based upon specific recognition tests which were carried on dividing in two the data collected during the training phase: one was then used as training set, the other as match set. It was thus possible to select the feature combinations that allowed to maximize the classification ability and to minimize the error in the estimation of odour concentration.

The precision of the qualitative classification increases with the reduction of the number of the olfactory classes (Falasconi et al., 2005). This is why the described olfactory classes initially identified in the training phase were grouped in the following macro-classes on the base of their odour similarity.

Table 1: olfactory macro-classes used for the qualitative classification

	OLFACTORY MACROCLASSES	OLFACTORY CLASSES INCLUDED
WASTEWATER TREATMENT FACILITY	**Wastewater treatment (wasteater treatment facility)**	"wastewater entry channel" and "oxidation"
	Sludge treatment (wasteater treatment facility)	"sludge pressing room" and "sludge storage room"
	Biofilter	"biofilter"
WASTE SORTING PLANT	**Dry waste**	"dry waste heap" and "dry waste heap with deodorizer"
	Green	"ligneous-cellulosic material heap"
	Organic waste	"organic waste tank"
	Wastewater treatment (waste sorting plant)	"physical chemical treatment tank"
	Sludge treatment (wasteater treatment facility)	"sludge tank" and "purging machicolations tank"
PAPER FACTORY	**Coating machines chimney**	"coating machines chimney"
	Printing machines chimney	"printing machines chimney"
	Wastewater treatment (paper factory)	"cone" and "equalization"
	Sludge treatment (paper factory)	"sludge room" and "sludge manhole"
SEWAGE SYSTEM	**Breather pipe**	"actived carbon odour abatement system"
	Manholes	"manholes"

6. Olfactory impact determination

6.1 Receptor 1

The electronic nose EOS 25, which was installed at receptor 1, had sometimes detected odours relevant to the plants at issue. The results of the qualitative classification of the air analyzed enabled to define the number of measures attributed by the electronic nose EOS 25 to each of the olfactory classes considered and to calculate the percentage of these measures out of the total number of measures. These results are represented in Figure 2.

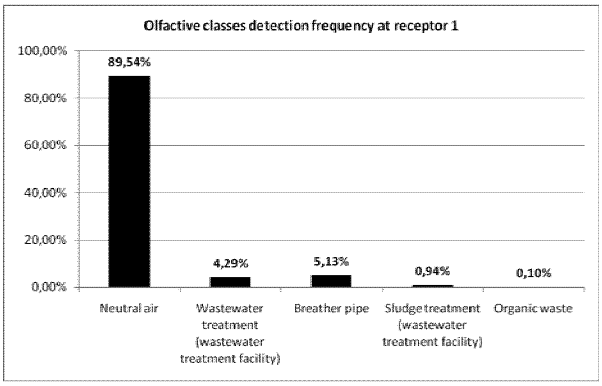

Figure 2: olfactory classes detection frequency at receptor 1.

During the 11 days of monitoring the electronic nose EOS 25 installed at receptor 1 (which was located 400 m south south-west from the wastewater treatment facility, 410 m south from the waste sorting plant and 700 m south-east from the paper factory and a few meters away from the breather pipe of the actived carbon odour abatement system installed nearby the sluice of the sewer trunk line 1M) detected in the ambient air odours belonging to the plants at issue for the 10,46% of the total time of the monitoring. The odours detected were ascribable primarily to the waste water treatment plant and to the breather pipe of the actived carbon system, with a percentage of 10,36% odour detections; 5,13% of measure corresponded to the odour abatement system, 5,23% to the processes (wastewater and sludge treatment) of the wastewater treatment facility. The percentage of 10,46% is slightly above the 10% limit which is fixed by the german standard “GIRL Geruchsimmisions-Richtlinie” (13th May 1998) on odour immission for residential areas.

The values of odour concentration detected by the electronic nose EOS 25 vary from 11 and 149 ou_E/m^3. Even if a concentration peak was detected in the morning of 13th June 2007, these values are often detected in urban ambient air.

6.2 Receptor 2

The electronic nose EOS 28, which was installed at receptor 2, as the EOS 25, had also sometimes detected odours belonging to the plants at issue.

The results of the qualitative classification of the air analyzed enabled to determine the number of measures ascribed by the electronic nose EOS 28 to each of the olfactory classes considered and to calculate the percentage of these measures out of the total number of measures. These results are represented in Figure 3.

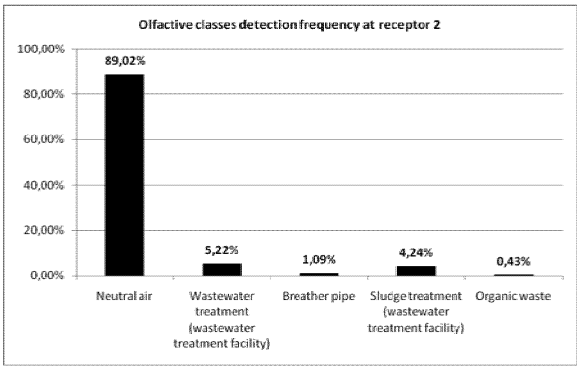

Figure 3: olfactory classes detection frequency at receptor 2.

During the 11 days of monitoring the electronic nose EOS 28 installed at receptor 2 (which was located 420 m south south-west from the wastewater treatment facility, 300 m south from the waste sorting plant and 450 m south-east from the paper factory and 250 m north-west from the breather pipe of the actived carbon odour abatement system installed nearby the sluice of the sewer trunk line 1M) detected in the ambient air odours belonging to the plants at issue for the 10,97% of the total time of the monitoring. The odours detected were ascribable primarily to the waste water treatment plant and to the breather pipe of the actived carbon, with a percentage of 10,54% odour detections; 1,09% of measure corresponded to the odour abatement system, 9,46% to the processes (wastewater and sludge treatment) of the wastewater treatment facility. The percentage of 10,97% is slightly above the 10% limit which is fixed by the german standard "GIRL Geruchsimmisions-Richtlinie" (13th May 1998) on odour immission for residential areas.

The values of odour concentration detected by the electronic nose EOS 28 vary from 12 and 85 ou_E/m^3. These values are often detected in urban ambient air.

6.3 Consideration

It's important to note that the instruments were trained to recognize only the characteristic odours of the monitored plants: the wastewater treatment facility, the waste sorting plant, the paper factory and the sewage system, that is, plants historically believed, both by population and institutions, possible responsible for the emission of unpleasant odours in the quarter. It's thus apparent that it's not possible to exclude that, during the monitoring period, other odours belonging to sources which were not the plants at issue could had been detected by the population. If so, the instruments weren't able to detect these odours because they had not been trained with them. These odours were classified as belonging to the class "neutral air".

7. Dispersion model

After the conclusion of the air monitoring with electronic noses, it was decided to apply an odour dispersion model on the emission sources which had turned out to be the main cause of the olfactory impact in the quarter: the wastewater treatment plant and the breather pipe of the actived carbon odour abatement system installed nearby the sluice of the sewer trunk line 1M.

The study had a dual purpose:

- To bound the odour fall-out area breeded by the wastewater treatment plant and the actived carbon filter breather pipe;
- To verify the correspondence between the electronic noses odour detection and the result of the mathematical simulation of odour dispersion.

In order to identify the odour fall-out area, an atmospherical dispersion model (CALPUFF) was used. Once the motion domain (wind) which transports the odour was calculated, the model solves the odour transport semplified equation. The motion domain was calculated with a meteorological preprocessor (CALMET) which uses meteorological (anemometric, barometric, pluviometric) and cartographic data (altimetric and of soil use) which are available for the area at issue.

The results of the dispersion model application are shown on a odour fall-out area map (Figure 13) which allowed to identify the zone where the odour concentration caused by the odour sources was high enough to be perceived by the population. The isoconcentration curves are superposed on a local cartography map (scale 1:10.000).

The UK EPA standard "IPPC-H4. Integrated Pollution Prevention and Control – Draft. Horizontal Guidance for Odour. Part 1 – Regulation and Permitting" (Environmental Agency, Bristol, 2002) was taken as the legislative reference document to process and evaluate the model results; it defines the 3 ou_E/m^3 odour concentration calculated as the 98° percentile (concentration value that is not exceeded for more than the 2% of the simulation time) as the limit that can't be exceeded.

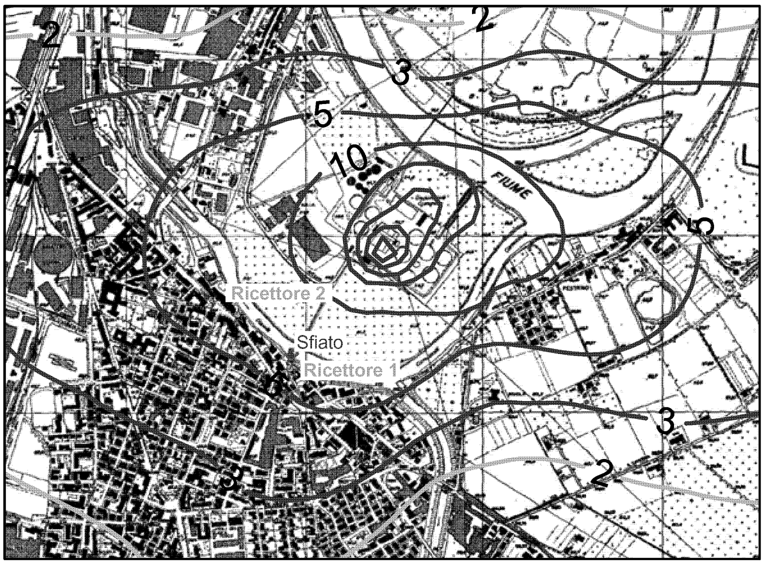

Figure 4: odour isoconcentration curves and position of the receptors where the electronic noses were installed.

The map shows that the wastewater treatment plant and the breather pipe of the actived carbon system were responsible of an odour fall-out on almost all the residential quarter.

Both the receptors where the electronic noses EOS 25 and EOS 28 were installed are in the area delimited by the 5 ou_E/m^3 isoconcentration curve, above the reference 3 ou_E/m^3. 5 ou_E/m^3 corresponds to, according to the English standard IPPC-H4 (Appendix 1), a weak odour, while 10 ou_E/m^3 corresponds to a distinct odour.

8. Conclusions

The results of the electronic nose monitoring and the model dispersion application were evaluated on the base of the following standards:

- ambient air sensors monitoring: german standard "GIRL Geruchsimmissions-Richtlinie" on odour immissions;
- odour dispersion model: UK standard "IPPC-H4".

The choice to evaluate the results comparing them with these standards is due to the fact that at the moment they are the most restrictive standards for the two different applications. They are thus the most suitable standards for the evaluation of a plant olfactory impact on the surrounding areas.

The combined evaluation of the results of the two studies carried on the quarter allowed to compensate for the two techniques' respective limitations:

- the electronic nose monitoring enabled to have real data, which were directly measured and not the outcome of a mere simulation, but the monitoring period is limited (11 days for this specific case) and it can't at the moment last more than 30 days. Furthermore, the detections regarded specific points on the territory, that is the sensitive receptors chosen on the base of the study of local meteorology and mutual position of receptors and possible odour sources (plants);
- the application of a dispersion model allowed instead to realize a long period study on a extended territory but its results were the outcome of a mathematical simulation and not of a direct measure of odour concentration at receptors.

Thus, the comparison between the sensor monitoring detections and the dispersion model isoconcentration curves allowed to identify a larger zone which could be concerned with odour pollution as well as the two receptors. The dispersion model showed also that the olfactory impact detected by the sensors during the monitoring period is probably present not only in the period 11-21 June but, with the characteristics showed by the model, throughout the whole year.

The comparison between electronic nose monitoring and dispersion model results also verified the good choice of the position of the receptors for the air sensor monitoring (Figure 13); the receptors are thus exactly in the critic area individuated with the dispersion model.

To conclude, the sensors and the mathematical modelling showed that the most problematic sources of olfactory impact in the quarter, among the ones being considered for this study, turned out to be the wastewater treatment facility and the breather pipe of the actived carbon odour abatement system installed nearby the sluice of the sewer trunk line 1M.

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