Odour impact determination of a MSW treatment plant: dispersion modelling and electronic nose

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One of the most important research topics at the Olfactometric Laboratory of the Politecnico di Milano is the study and the development of a system for the continuous monitoring of environmental odours. The experimental methods adopted are laboratory tests, with samples of known quality and odour concentration, and field tests, represented by experimental monitorings of limited duration. This study describes one of these experimental monitorings, conducted at a plant for the mechanical and biological treatment of MSW, in order to determine its odour impact on the territory. The monitoring results were evaluated and validated by comparison with the results obtained by application of a mathematical model for the simulation of odour dispersion. The results of this comparison are interesting: the results are substantially agreeing, differences are due to the fact that the model does not consider temporary or accidental emission sources.

1. Introduction

In the last 30 years, problems associated with odour emissions from industrial plants have become a serious environmental concern, which brought to the development of specific techniques for odour measurement and control. Nonetheless, techniques such as dynamic olfactometry (EN 13725, 2003) and odour dispersion modelling are not always sufficient in order to meet the citizens' requirement of continuously analyzing the air, directly where the presence of odour nuisance is lamented. It's for this reason that one of the main research topics at the Olfactometric Laboratory of the Politecnico di Milano since 2003 is the study and the development of a system for the odour impact determination at specific receptors. This system should be capable of continuously analyzing the ambient air and, in real time, it should be able to qualitatively recognize the analyzed air by attributing it to a specific olfactory class, and to contemporaneously quantify odour by estimating the odour concentration of the analyzed air.

The development of this system is based on the use of an already existing technology, i.e. the electronic nose (Gardner and Bartlett, 1994, p. 211). Even though electronic noses are studied since several years (the first prototype of electronic nose was described by Persaud and Dodd in 1982), the studies published until now 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. This means that the instrument should be suitable for external use, i.e. with varying environmental conditions (T, RH), and for the use at receptors, i.e. with highly diluted odours. The work required for the development of a similar system is composed of two interconnected fundamental activities, 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 characteristics 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 patterns for the further comparison and recognition of unknown patterns. The procedures that must be defined concern therefore the creation of the training data set and the methods for relating it to the match data set, i.e. the methods for the extraction of significant features from the sensor responses and the pattern recognition techniques (Sironi et al., 2007a)
The experimental methods adopted for the instrument design and for the definition of the training and of the data processing procedures are:

- Laboratory tests with air samples of known odour quality and odour concentration;
- Field tests, represented by continuous monitorings of limited duration (Sironi et al., 2007b, p. 389).

This paper describes one of these experimental monitorings. In this specific case the continuous monitoring was conducted at a plant for the mechanical and biological treatment of MSW, in order to determine its odour impact on the neighbouring areas. This paper does not concentrate on the instrument design nor on the training procedures and on the principles that are followed for the data processing, but it focuses especially on the discussion of the results reliability and the validation by comparison of electronic nose responses with the results obtained by application of a mathematical model for the simulation of dispersion of the plant emissions.

2. Experimental

2.1 Electronic nose description

The instruments used for this study (EOS^{835} 25 and EOS^{835} 28) 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, p. 73). 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. Both instruments 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 Senso-instrumental monitoring

The first and most delicate phase of a monitoring with electronic nose is the instrument training. During this phase, it is necessary to create a complete database that the instrument uses as a reference for the subsequent pattern recognition. Practically, the training consists in the analysis of different gas samples of known olfactory quality at different odour concentration values, in order to teach the instrument to recognize odours from the qualitative and quantitative point of view. In this case, the training involved the execution of three campaigns for the collection of gas samples and their subsequent analysis by dynamic olfactometry (EN 13725, 2003) and by the electronic nose.

The monitoring period started during the morning of Thursday, 6th July 2006, and ended Thursday, 20th July 2006. During the first monitoring week, the electronic nose EOS^{835} 25 was installed inside a house at about 1 km north from the plant at issue. During the following monitoring week, the instrument was moved to a second receptor, represented by a house located at about 300 m north from the monitored plant. During the whole monitoring period the electronic nose EOS^{835} 28 was installed inside a room located at the northern boundary of the plant for the mechanical and biological treatment of MSW at issue. The Teflon^{TM} inlet tube for the gas suction was let outside the instrument installation room, in order to analyze the external ambient air. The tube for the reference air feed was internal to the electronic nose installation room. The reference air sucked by the instrument was filtered through active carbon and silica gel in order to have it odour and humidity free. The instruments analyzed the air every 15 min. For each of these time intervals, the electronic nose sucked the external air for three consecutive minutes, and a recovery time of 12 min was left between each measurement.

2.3 Impact study by dispersion simulation

The model used for the simulation of the emission dispersion is the CALPUFF model. This model is realized by Earth Tech Inc. for the California Air Resources Board (CARB) and the U.S. Environmental Protection Agency (US EPA). CALPUFF is a non-stationary puff atmospheric dispersion model. It is suitable for the estimation of emission from single or multiple industrial sources. It allows to calculate dry and wet deposition, building downwash, dispersion from point, area and volume sources, the gradual plume raising in function of the distance from the source, the influence of the soil orography on dispersion, and the dispersion in case of weak or absent wind. The dispersion coefficients are obtained from the turbulence parameters (u_*, w_*, L_{MO}), instead of being calculated from the Pasquill-Gifford-Turner stability classes. This means that the turbulence is described by continuous functions, not by discrete ones. During the periods in which the boundary layer has a convective structure, the concentration distribution inside each puff is gaussian on the horizontal planes, but asymmetric on the vertical planes, i.e. it takes account of the probability distribution function of the vertical speeds. In other words, the model simulates the effects on dispersion due to ascending and descending air movements that are typical of the day hottest hours and due to big scale vortex.

The emission data used as input for the dispersion model are the results of the measurements of the emissions of odour, ammonia (NH_3) and hydrogen sulphide (H_2S)

on the plant principal odour sources, i.e. the biofilters and the open air stored heaps of bio-stabilized material resulting from the aerobic biological degradation of the MSW.

3. Results and discussion

3.1 Results of the senso-instrumental monitoring

The monitoring results are represented by large tables that report the olfactory class and the odour concentration value attributed to the analyzed air for each measurement carried out during the monitoring period.

The odour impact caused by the plant at issue at each monitoring position can be evaluated by the number of measures that each electronic nose attributed to the single olfactory classes being considered and their relative frequency with respect to the total number of measures that were carried out during the monitoring period.

Table 1 resumes the results of the senso-instrumental monitoring.

It is possible to observe that at both receptors, the total percentage of time in which the olfactory class attributed by the instrument to the analyzed air coincides with one of the olfactory classes corresponding to the plant odour sources is lower than 10% and 15%, which represent the limits fixed by the German guideline “GIRL Geruchsimmisions-Richtlinie” (LAI, 1998) about odour immissions respectively for residential areas and for industrial or agricultural areas.

It is interesting to observe that, almost every time that the olfactory class of the analyzed air was classified differently from “neutral air”, it was recognized as belonging to the olfactory class corresponding to the odour emissions originated from the open air stored heaps of bio-stabilized material. The area dedicated to the storage of these heaps can therefore reasonably be considered as the principal odour source of the monitored plant.

3.2 Results of the impact study by dispersion simulation

Among the results obtained from the impact study by simulation, this work only considers the ones that can be compared with the results of the senso-instrumental odour monitoring: the concentrations of NH_3 and H_2S (in $\mu g/m^3$) and the odour concentration values (in ou_E/m^3) calculated by the dispersion model at the second receptor, i.e. the house located at 300 m North from the plant at issue, in the same period in which the electronic nose was installed there, i.e. from the 13th July to the 20th July.

Table 1 Relative detection frequency of the olfactory classes corresponding to the plant odour sources for each monitoring position

Olfactory class	Instrument (electronic nose)		
	EOS^{835} 28 Plant: northern boundary	**EOS^{835} 25 Receptor 1: 1 km north from plant**	**EOS^{835} 25 Receptor 2: 300 m north from plant**
Bio-stabilized material	28.3%	7.5%	3.8%
MSW receiving	0.1%	_	_
Biofilter output	_	_	_
Total	**28.4%**	**7.5%**	**3.8%**

From the hourly set of peak concentration values extracted from the totality of the results, it was possible to calculate some significant synthetic parameters, which are reported in Table 2. Considering that the odour detection threshold corresponds, by definition, to 1 ou_E/m^3, and that the odour thresholds relevant to NH_3 and H_2S correspond to an experimentally determined analytical concentration of respectively 23 $\mu g/m^3$ and 0.47 $\mu g/m^3$, it is possible to conclude that the odour impact simulated by the model caused by the plant at issue at the second receptor is absolutely negligible.

3.3 Comparison between results of the two odour impact determination methods

For each hour of the monitoring period, the electronic nose responses were compared with the pollutant concentration values simulated at receptor 2. As an example, Table 3 reports the relevant data extracted from the results of the study. It is possible to observe that there is a qualitative correspondence between the results of the two methods. In general, the periods during which the electronic nose installed at receptor 2 detected the presence of odours from the plant at issue correspond to periods in which the concentration values simulated at the receptor by means of the adopted dispersion model are higher with respect to the rest of the monitoring period. Even though the results are substantially agreeing, it must be observed that they are quantitatively different because, based on the results of the odour dispersion modelling, the presence of odour at the considered receptor is underestimated. These differences may be due to the fact that the model does not consider temporary or accidental emission sources, such as the trucks transporting the MSW or the bio-stabilized material.

4. Conclusions

This study compares two different techniques that my be used in order to evaluate the odour impact of an industrial plant on the neighbouring areas.

The comparison of the results of the senso-instrumental monitoring conducted at a plant for the mechanical and biological treatment of MSW by means of innovative and specific electronic noses developed at the Olfactometric Laboratory of the Politecnico di Milano and the results obtained by application of a dispersion model for the simulation of the atmospheric dispersion of pollutants shows a good qualitative correspondence between the instrument responses and the simulated concentration values. From the quantitative point of view the two techniques produce different results: the model seems to underestimate the odour present at the considered receptor, due to the fact that it does not take account for temporary or accidental emission sources.

Table 2. Synthetic values extracted from the results of the dispersion modelling

Synthetic parameter	Odour concentration (ou_E/m^3)	NH_3 concentration ($\mu g/m^3$)	H_2S concentration ($\mu g/m^3$)
98° percentile	0.026175	0.243533	0.024747
Average	0.003003	0.027266	0.002734
Maximum	0.044174	0.411154	0.041850
Minimum	0.000000	0.000000	0.000000

Table 3. Comparison between electronic nose responses and concentration values simulated by dispersion modelling at receptor 2

Date	**Hour**	**Odour conc. (ou_E/m^3)**	**NH_3 conc. ($\mu g/m^3$)**	**H_2S conc. ($\mu g/m^3$)**	**Olfactory class recognized by EOS 25**
15/07/2006	10.00	0.000000000	0.000000000	0.000000000	Neutral air
15/07/2006	11.00	0.000000000	0.000000000	0.000000000	Neutral air
15/07/2006	12.00	0.000000000	0.000000000	0.000000000	Neutral air
15/07/2006	13.00	0.000136628	0.001271886	0.000129044	Neutral air
15/07/2006	14.00	0.000000000	0.000000000	0.000000000	Neutral air
15/07/2006	15.00	0.000000000	0.000000000	0.000000000	Bio-stabilized material
15/07/2006	16.00	0.010202430	0.095593530	0.009607316	Bio-stabilized material
15/07/2006	17.00	0.000167998	0.001577853	0.000159072	Bio-stabilized material
15/07/2006	18.00	0.014274890	0.132315600	0.013313150	Bio-stabilized material
15/07/2006	19.00	0.011994950	0.112650000	0.011331550	Bio-stabilized material
15/07/2006	20.00	0.000139104	0.001335324	0.000134466	Neutral air
15/07/2006	21.00	0.000012130	0.000114132	0.000011580	Neutral air
15/07/2006	22.00	0.000000000	0.000000000	0.000000000	Neutral air

5. References

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

Falasconi, M., M. Pardo, G. Sberveglieri, I. Riccò, A. Bresciani, 2005, The novel EOS[835] electronic nose and data analysis for evaluating coffee ripening, Sens. Actuators B Chem. 110, 73.

Gardner, J.W. and P.N. Bartlett, 1994, A Brief history of Electronic Noses, Sens. Actuators 18, 211.

LAI (Länderausschuss für Immissionsschutz), 1998. Geruchsimmissions - Richtlinie (GIRL - Odour Emissions Guidelines), Ministry of Environment, Environmental Planning, and Agriculture of the State Nordrhein-Westfalen, Germany.

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

Sironi, S., L. Capelli, P. Céntola, R. Del Rosso, 2007a, 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., in press.

Sironi, S., L. Capelli, P. Céntola, R. Del Rosso, M. Il Grande, 2007b, Continuous monitoring of odours from a composting plant using electronic noses, Waste Manage. 27, 389.