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# Monitoring of Odour Nuisance from Landfill Using Electronic Nose

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The paper presents the results of investigation on classification of atmospheric air samples collected in a vicinity of municipal landfill with respect to their odour nuisance. The research was conducted using a prototype of electronic nose instrument and a commercial electronic nose of Fast/Flash GC type – HERACLES II. The prototype was equipped with a set of six semiconductor sensors by FIGARO Co.. Classification of the air samples with respect to the place of collection relative to the landfill was performed using linear discriminant function supported with cross-validation method. More than 70 % of the samples were correctly classified employing the analysis with HERACLES II. The prototype of electronic nose provided correct classification of 40 % of the samples.

## 1. Introduction

Annual reports on air quality prepared by the Province Inspectorate for Environmental Protection in Gdańsk alarm that concentration of the air pollutants such as $O_3$, benzo/a/pyrene, PM10 and PM2,5 exceed the admissible levels (Gębicki and Szymańska 2011, Gębicki and Szymańska 2012). Hence, respective administrative bodies follow the Directive 2008/50/WE of the European Parliament and of the Council of 21$^{st}$ May 2008 and undertake the corrective actions aimed at reduction of atmospheric air pollutants down to the levels lower than the admissible ones. Another type of pollution in the Tri-city region (Gdańsk, Sopot, Gdynia) exceeding the admissible level is odour, which is not monitored. Works on the legal regulations concerning odour nuisance, which have been carried out for more than 20 years, did not yield expected document defining admissible levels and frequency of their exceeding. Odour nuisance in vicinity of air pollution sources is the major cause of social complaints on the quality of environment. It is connected mainly with health hazard and odour discomfort. A valuable source of information on the properties of particular odour can be volatile compounds analysis performed via classical organoleptic method utilizing human sense of smell or via instrumental techniques – chromatographic and electronic nose ones (Rock et al. 2008, Wilson and Baietto 2009, Sówka 2010, Dymerski et al. 2011, Szczurek et al. 2011). The instrumental analysis of gas samples takes advantage of two main approaches. The first one consists in identification of volatile odour compounds using gas chromatography (GC) (Harynuk and Górecki 2004, Pineiro et al. 2004), the second one is based on comprehensive analysis of gas mixture without separation into particular components using electronic nose (Maekawa et al. 2001, Bai and Shi 2007, Gębicki et al. 2014). The e-nose instruments are cheap in service, fast in operation, so they constitute an alternative to relatively expensive methods of gas samples evaluation with gas chromatography.

The main cause of odour nuisance in the Tri-city region is emission of volatile compounds characterized by unpleasant odour from petroleum plants, phosphorous fertilizers plants, landfills and sewage treatment plants. Thus, there is a need of creation of regional monitoring web, which would provide reliable information on odour nuisance. Currently there are some preliminary actions undertaken within the framework of a scientific project (Grant No. PBSII/B9/24/2013) aimed at building a monitoring web

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dedicated to odour fractions originating from petroleum-domestic sources in the Tri-city agglomeration. The only legal act in Poland, which concerns the method of odour nuisance measurement is the standard PN-EN 13725:2007 ‘Air Quality. Determination of odour concentration by dynamic olfactometry’. Accuracy of odour nuisance measurement calls for accredited laboratory fulfilling certain standards as far as the personnel and the laboratory room are concerned. In many cases there are short-lasting episodes of excessive odour nuisance over particular region, which creates some problems with its recording (arrival of the personnel on site, sampling, transport to the laboratory, measurement in the laboratory). In this case an alternative could be the electronic nose instrument as an element of an early warning system against sudden odour risk, capable of recording nuisance during the short-lasting odour outbreaks. The paper presents the preliminary results of investigation on air quality with respect to odour nuisance using the prototype of electronic nose equipped with semiconductor sensors by FIGARO Co. and the commercially available HERACLES II electronic nose of Fast/Flash GC type by Alpha MOS Co.. The aim of the investigation was monitoring and recording of odour nuisance originating from the landfill located in the Tri-city region as well as comparison of detection abilities of both types of electronic nose devices and potential application of the electronic nose prototype in odour nuisance investigation.

## 2. Experimental

### 2.1 Atmospheric air samples

Investigation of air quality with respect to odour nuisance was performed with the air samples collected within 2-kilometre distance around the landfill along six directions (N-0$^0$, NE-60$^0$, SE-120$^0$, S-180$^0$, SW-240$^0$, NW-300$^0$, figure 1).

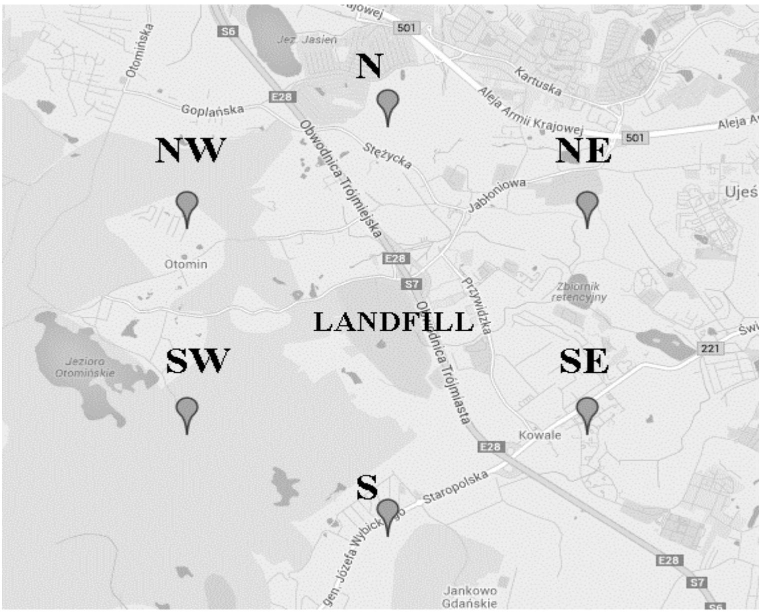


*Figure 1: Map of the landfill with the points of atmospheric air sampling.*

The samples were collected from 28$^{th}$ January to 2$^{nd}$ February 2014 and from 18$^{th}$ March to 23$^{rd}$ March 2014. Each day 6 samples were collected along the aforementioned directions and within the aforementioned distance from the landfill. Selection of the sampling periods was connected with the complaints (on odour nuisance) of the inhabitants of the housing estates neighbouring with the landfill. Average air temperature during the first sampling period was from -5 ºC to -12 ºC, average relative humidity was 74.4 % and pressure was equal 1004.6 hPa. During the second sampling period average air temperature was from 7 ºC to 14 ºC. Average relative humidity was 68.2 % and average pressure was equal 1000.2 hPa. The samples were collected into Tedlar bags (SKC Inc., USA) of 5 dm$^3$ volume using a device called lung sampler (figure 2). The total of 72 atmospheric air samples collected around the landfill were analysed.

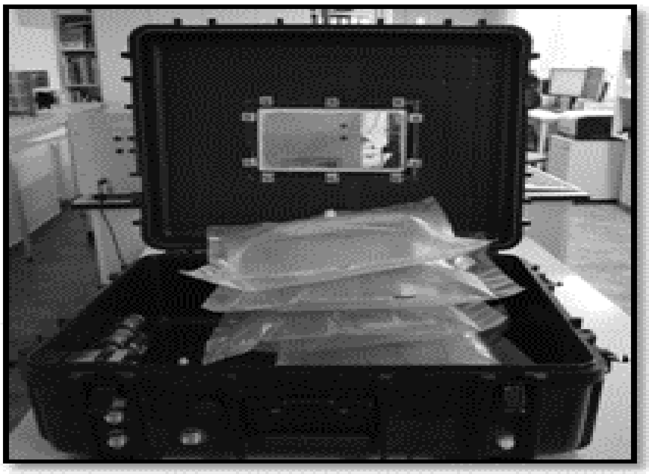

*Figure 2: Lung sampler with Tedlar bags.*

**2.2 Measurement set-up**

In case of the investigations conducted using the prototype of electronic nose the measurement set-up consisted of a Tedlar bag, Tecfluid 2150 series flow meter, a prototype of electronic nose, a suction pump and a PC class computer. Volumetric flow rate of air sucked from the Tedlar bag was 0.5 $dm^3$/h. In case of the investigations conducted using HERACLES II air for analysis was sampled directly from the Tedlar bag using 5 $cm^3$ syringe. Then the air was supplied to a proportioner. The proportioner was followed by a sorption trap of Tenax. The analytes were released from the trap after it had been heated to 270°C and the stream simultaneously directed to two independent chromatographic-detection systems characterized by different polarity of stationary phase and equipped with two detectors of FID type. Figure 3a presents the general scheme of the electronic nose prototype, whereas figure 3b illustrates the general scheme of HERACLES II electronic nose.

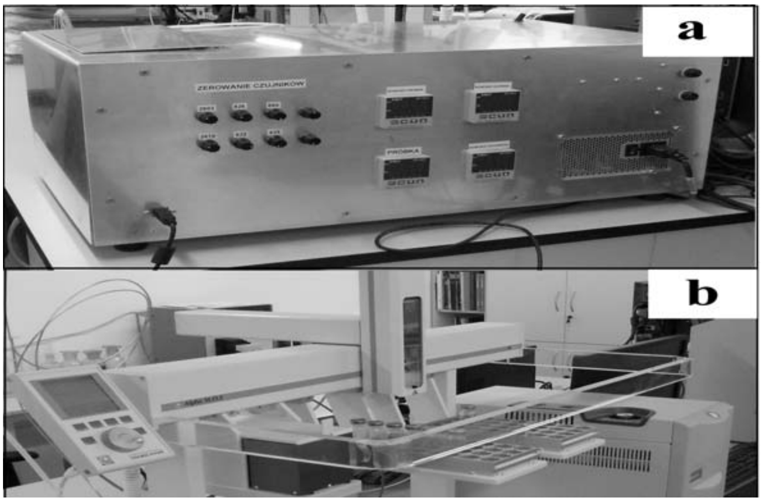


*Figure 3: Prototype of electronic nose -(a), HERACLES II electronic nose of Fast/Flash GC type -(b).*

**2.3 Apparatus–prototype of electronic nose**

The prototype consisted of a set of six commercial semiconductor sensors by FIGARO Co. (TGS 880, TGS 825, TGS 826, TGS 822, TGS 2610, TGS 2602). All internal elements of the prototype were thermostated in order to provide stable measurement conditions. Dedicated miniaturized electronic circuit conditioned the output signal from the sensor set of the prototype. Its task was to convert changes of sensor resistance into voltage signal measurable by analogue-to-digital converter (ADC). This step yielded a voltage signal, the changes of which within full measurement range of the converter corresponded to complete range of changes of the sensor resistance. The voltage obtained was converted into digital from in the range from 0 to 14 bits. Accurate description of the prototype electronic nose can be found in the works: (Dymerski et al. 2013a, Dymerski et al. 2013b).

### 2.4 Measurement methodology

In case of the electronic nose prototype time of sensor signal acquisition since air suction from Tedlar bags onset was 2 minutes. In the case of HERACLES II device the result of analysis – area of chromatographic peaks – was treated as an input for data analysis methods (situation analogous to the prototype of electronic nose equipped with a set of semiconductor sensors). Classification of the atmospheric air samples with respect to their odour nuisance was performed using linear discriminant analysis (LDA) employing free R software being a part of Free Software Foundation (Free Software Foundation, Boston, MA, USA).

## 3. Results and discussion

Table 1 presents a matrix with the results of LDA classification of all atmospheric air samples collected in a vicinity of the landfill and subjected to analysis with the electronic nose prototype. 51.4 % of the samples were classified correctly. The biggest number of correctly classified samples was 10 and they originated from NW and SW directions. In the remaining cases (directions) the following were correctly classified: 6 samples from N direction, 5 samples from S direction, 4 samples from SE direction and 2 samples from NE direction.

*Table 1: Classification of atmospheric air samples using LDA collected from different directions around the landfill. Electronic nose prototype.*

| | N | NE | NW | S | SE | SW |
|---|---|---|---|---|---|---|
| N | 6 | 0 | 5 | 0 | 0 | 1 |
| NE | 1 | 2 | 2 | 2 | 1 | 4 |
| NW | 1 | 0 | 10 | 1 | 0 | 0 |
| S | 0 | 2 | 1 | 5 | 2 | 2 |
| SE | 2 | 0 | 2 | 2 | 4 | 2 |
| SW | 0 | 0 | 2 | 0 | 0 | 10 |

The LDA classification using cross-validation method, thus complete classification with training and testing sets, provided 37.5 % of correct classifications. In the case of cross-validation the entire data set is treated as both training and testing set. Having n-vector set (n=45) with explanatory variables one vector is withdrawn and treated as the testing set. The remaining n-1 vectors are subjected to classification and then the withdrawn vector is verified for its compatibility with a particular class. Afterwards the vector is returned to the n- vector set and the procedure is repeated for every vector from the set. Table 2 presents a matrix with classification of the air samples using the LDA classifier and cross-validation method; the biggest number (9 samples) of correct classifications concerned the samples collected along SW direction.

*Table 2: Classification of atmospheric air samples using LDA supported with cross-validation collected from different directions around the landfill. Electronic nose prototype.*

| | N | NE | NW | S | SE | SW |
|---|---|---|---|---|---|---|
| N | 4 | 0 | 5 | 0 | 1 | 2 |
| NE | 1 | 2 | 2 | 2 | 1 | 4 |
| NW | 3 | 0 | 7 | 2 | 0 | 0 |
| S | 0 | 2 | 1 | 5 | 2 | 2 |
| SE | 2 | 1 | 2 | 5 | 0 | 2 |
| SW | 0 | 0 | 2 | 0 | 0 | 9 |

Figure 4 illustrates graphical picture of classification of the atmospheric air samples together with generated linear functions separating particular classes depending on selected explanatory variables (sensor response signal) characterized by the biggest variability.

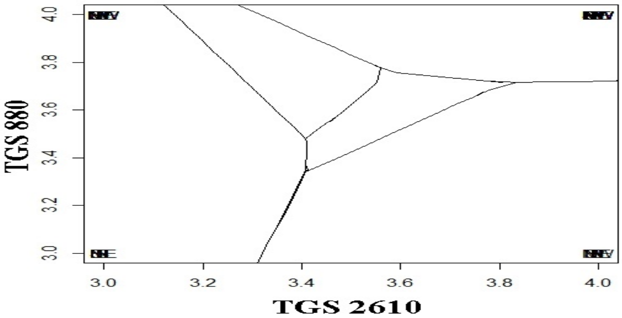


*Figure 4: Classification of atmospheric air samples using LDA as a function of selected descriptive variables (response signals of the sensors TGS 2610 and TGS 880). Electronic nose prototype.*

Table 3 shows a matrix with the results of LDA classification of the atmospheric air samples collected in a vicinity of the landfill and performed with HERACLES II device. This time 79.2 % of samples were correctly classified. Application of LDA classification together with cross-validation method yielded 69.4 % of correctly classified samples. The biggest number (9 samples) of correct classifications concerned the samples collected along NE, S, SW directions.

*Table 3: Classification of atmospheric air samples using LDA supported with cross-validation collected from different directions around the landfill. HERACLES II*

| | N | NE | NW | S | SE | SW |
|---|---|---|---|---|---|---|
| N | 8 | 0 | 2 | 0 | 0 | 2 |
| NE | 0 | 9 | 0 | 1 | 2 | 0 |
| NW | 2 | 0 | 8 | 0 | 0 | 2 |
| S | 1 | 1 | 0 | 9 | 0 | 1 |
| SE | 0 | 5 | 0 | 0 | 7 | 0 |
| SW | 0 | 0 | 2 | 1 | 0 | 9 |

Figure 5 depicts graphical picture of classification of the atmospheric air samples together with generated linear functions separating particular classes depending on selected explanatory variables (area of chromatographic peaks) characterized by the biggest variability of the response. Applied discriminant function highly satisfactorily divided the plane into six regions (classes) and correctly assigned the samples of atmospheric air into particular classes in case of HERACLES II application.

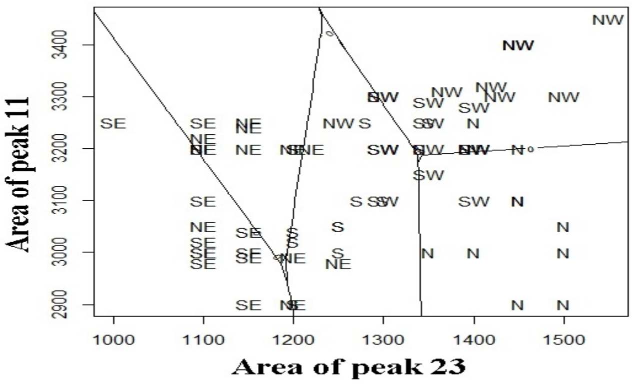


Figure 5: Classification of atmospheric air samples using LDA as a function of selected descriptive variables (area of peak 23 and area of peak 11) HERACLES II.

## 4. Conclusions

The aim of the investigation was to monitor and to record the episodes of odour nuisance from the Tri-city landfill and to compare the results obtained with both electronic nose devices . Moreover, the authors made an attempt to verify usefulness of the prototype in this type of analysis as well as its potential future application in odour nuisance investigation. Based on the classification of the atmospheric air samples collected in a vicinity of the landfill one can observe that the biggest number of correctly classified samples originated from NW direction. Indeed, during the time of investigation this direction was the most susceptible to odour nuisance as predominant wind direction during this period of time was NW. Moreover, most of the inhabitants' complaints concerned that particular region. An ability to discriminate the samples of atmospheric air collected in a vicinity of the landfill is a basis of training and preparation of a database necessary for correct interpretation of obtained results. LDA classification level using the method cross-validation of 70% appears to be satisfactory. The commercial e-nose instrument fits perfectly for that purpose. However, the results obtained with the prototype of electronic nose are not satisfactory. The reason could be relatively high limit of detection (at the level of 1-100 ppm v/v, detection limit applies to individual components of air pollution) of the applied sensors as well as poor selectivity. Application of preliminary enrichment of atmospheric air samples with their components using sorption methods and then their release in the sensor chamber may increase sensitivity and limit of detection of particular compounds influencing on odour nuisance. The works on the prototype with bigger number of sensors and suitable integrated circuit enabling lowering the limit of detection by one order of magnitude are in progress within the framework of the scientific project (Grant No. PBSII/B9/24/2013).

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