17th International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
9-12 May 2016, Budapest, Hungary

DYNAMIC-STATISTICAL ODOUR DISPERSION MODEL USING THE CALPUFF MODEL AND GEOSTATISTICAL ANALYSIS

Maria Skrętowicz[1] and Jerzy Zwoździak[2]

[1] Division of Automotive Engineering, , Faculty of Mechanical Engineering, Wroclaw University of Technology (WUT), Wrocław, Poland
[2] Institute of Meteorology and Water Management, National Research Institute, Warsaw, Poland

Abstract: Reliable researches of odours are very difficult to perform due to the characteristics of these pollutants. Except that the sensing odours is a subjective for each person, with odours researches are also many technical and chemical problems. The odours appearance in the area is incidental and depends mainly on weather conditions. So it is important to use models which are 'sensitive' to temporary change meteorological parameters. In addition, it should be recognized that odours occurring in atmospheric air are usually a mixture of chemical gases. These substances can often interact: one substance can enhance, change or neutralize the smell of another substance, and hence the whole mixtures of odorants. That is the reason why chemical analysis of odorants make no sense. For these reasons, in order to achieve reliable results of researches of odours, there is often necessary to use more than one research tool.

In the paper dynamic-statistical odour dispersion model, consist of CALPUFF model and geostatistical analysis was be presented. Using of these two mathematical tools allowed for reliably evaluate odour impact of the analysed object causing the odour nuisance. Emission used in the CALPUFF model was calculated on the basis of measured odour concentration by dynamic olfactometry method. Data for geostatistical analysis have been obtained in field inspections in the plume according to VDI guidelines. The results of the field inspections was odour intensity. Odour intensity values have been converted into odour concentrations values with using Weber-Fechner law. As a result of the model and geostatistical analysis obtained a raster presented a distribution of odour's concentrations in the study area. Connections that two rasters in GIS software allowed for verification both of used tools and getting verified and reliable results of odour nuisance researches.

Key words: *mathematic modelling, method uncertainty, odour nuisance, air pollution, odours*

INTRODUCTION

Mathematical air pollution dispersion modelling is one of basic tools used for air quality evaluation in the vicinity of air pollution sources. Almost all of air pollutants could be modelled with using single dispersion model. However, there are types of air pollutants for which using single model gives not enough reliable results. Such pollutants are odours, which, due to their specific nature, are pollutants causing a lot of controversy. In many European countries and throughout the world relevant legislation has been established obligating abatement emission of odours for odour emission sources. These are such countries as Germany, Netherlands, United Kingdom, Denmark, the United States or Australia. In Poland in recent years there were also attempts to impose a duty on facilities owners to limit odour emission, by introducing into Polish law the relevant legislation acts.

For odour dispersion modelling purposes models with very advanced description of the meteorological processes in the atmosphere should be used. Previous studies show that wind velocity, wind direction, temperature and humidity are meteorological parameters that have the greatest impact on odours dispersion. While the temperature and humidity influence mainly the long-term odour immission concentrations (seasonal changes), wind velocity affect the instantaneous change (Nagaraj & Sattler, 2005), (Sówka et al., 2013). According to the German VDI guideline (VDI 3788-1:2000) it is recommended to consider any mixture of odours as individual air pollutant, without analysing chemical composition of the mixture. Therefore, it is not justified to use chemical models in terms of odour dispersion modelling. Additionally, in Danish and German VDI guidelines it is suggested not to use only one tool in odour measurements (Olesen et all., 2005), (VDI 3788-1:2000). When selecting odour dispersion model it is crucial to choose a model with detailed description of meteorological processes in the atmosphere. The model used for odour dispersion calculations due to the incidental occurrence of odour should be able to calculate the instantaneous odour concentration, for example averaged to several or dozen minutes.

There is a lot of dispersion models extra dedicated for odour dispersion modelling, eg. AUSTAL2000G, NaSt3D or AODM (Austrian Odour dispersion Model), which is the reference odours dispersion model in Austria (Piringer et al., 2007). But also the other models which meet the requirements concerned the odours could be used. One of them is CALPUFF model. It could be used as a simple tool and also in connection with the other such as field inspections. Sironi et all. (2010) applied the CALPUFF model to determine the maximum odour immission concentrations from four animal waste facilities located in Italy. There is also a lot of researches in which two or more models were compared. Dourado et all. proposed a FPM-PRIME model as a useful tool in odour dispersion modelling based on a comparison of this model with AERMOD and CALPUFF (Dourado et all., 2014). Piringer et all. compared Gaussian Austrian Odour Dispersion Model AODM and the Lagrange particle diffusion model LASAT used for short-term peak odour concentrations (Piringer et all., 2015).

Eusebio et all. in Italy investigated an odour impact from composting sludge heaps on the nearby area using field inspections and mathematical dispersion modelling (CALPUFF model) (Eusebio et all., 2013). But nobody have done physically connection of two different tools as a one, compact model yet. In this paper the model developed by physically connection of two different, but consistent tools: CALPUFF model and geostatistical analysis based on field inspections are presented.

MATERIAL AND METHODS

In the study a distillery situated in the south-west of Poland was analysed. A plant is located in small town, abutting with a city with population above 500 thousand, in the industrial-service area. The nearest residential buildings are located about 1500 meters south from the plant and these are low buildings. The distillery produces ethanol and gluten for food industrial purposes. Three characteristic smells emitted by distillery were identified: smell of ‘a baked bread’ (from the gluten drying process), smell of ‘a cooked pasta’ (from the feeding stuff drying process) and smell of ‘an alcohol’ (from fermentation process).

The model was built based on two tools: odour dispersion calculations using a mathematical model CALPUFF and geostatistical analysis (ordinary kriging) carried out suing spatial data obtained during field measurement of odour intensity in the plume (VDI 3940-2:2006). So, the model is based on two spatial meshes: fixed mesh for deterministic model and variable in space and time measurement mesh prepared as a result of geostatistical calculations. Both of the meshes after imposition on each other provide a coherent tool, which aim is to improve the reliability and accuracy of odour research. Model diagram shown in Figure 1.

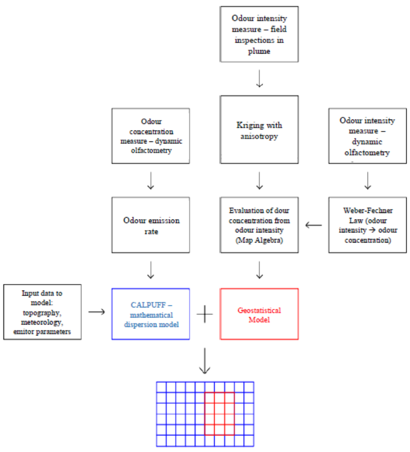

Figure 1. The model conception scheme

Odour emission values used as input data for CALPUFF model are obtained by laboratory odour concentration analysis using dynamic olfactometry (according to EN 13725:2003). Kriging geostatistical analysis method is carried out based on the results field odour intensity measurements in plume (according to VDI 3940-2:2006). Through statistical analysis odour intensity spatial distribution is obtained from discrete (point) data. What is important, the term of odour dispersion calculations using CALPUFF model was the same as term of field inspections. It means that the date inserted into the CALPUFF model (and the date of meteorological data) corresponded to date of field inspections execution. Totally, 9 measurement series have been receiving for 2 years (2011/2012).

Data obtained in olfactometry measurements was odour concentrations in European odour units per cubic meter (ou_E/m^3). Data collected in field measurements was odour intensity on a scale from 0 to 6, where 0 means no odour and 6 0 extremely strong odour. To calculate odour intensity from field inspections to odour concentration with using Weber-Fechner law it was necessary to conducted additional measurements of odour intensity using dynamic olfactometry (according to VDI 3882-1:1992).

Samples to olfactometry were collected from emitters which emit characteristic for the distillery smells: E-14, E-22, E-24, hall ventilation, fermenters and CO2 scrubber. Analysed emitters covered all of the processes conducted in the plant. In addition, for field inspections, characteristic smells have been marked by letters symbols. In table 1 all of information refer to emitters and emitted odours were compared.

Table 1. Comparison of emitters and odours emitted from the distillery

Process	**Smell description**	**Emitters**	**Odour symbol in field inspections**
gluten drying	a baked bread	E-22, E-24	L
feeding stuff drying	a cooked pasta	E-14, hall ventilation	M
fermentation	an alcohol	fermenters, CO_2 scrubber	N

THE MODEL BUILD AND THE RESULTS

According to the German VDI guideline (VDI 3788-1:2000) any mixture of odours were treated as individual air pollutant. It means that each of smell emitted from the distillery (‘L’, ‘M’ and ‘N’) were three different pollutants. As a results of calculations of odour dispersion using CALPUFF model were spatial distributions of odour concentration as a raster in the Geographic Information System (GIS) software ArcGIS 10.1 ESRI. Odour intensity (immission) obtained from field inspections were as discreet data (points). These discreet data of odour intensity were used in geostatistical analysis conducted using ordinary kriging. As a results of the estimation were spatial distributions of odour intensity also in GIS software as a raster. Values of odour intensity were converted in ArcGIS (using Map Algebra tool) to odour concentrations using Weber-Fechner law:

$$I = k_1 \cdot \log C + k_2 \tag{1}$$

where: I – odour intensity
C – odour concentration (in ou_E/m^3)
k1, k2 – constance

As it was said, the mesh for all calculations using CALPUFF model was fixed, while the mesh for kriging was variable (always smaller than for model) and depended on the area of each of field inspection series. Example of results of odour dispersion modelling and the corresponding geostatistical analysis in Figure 2 were presented.

a) b)

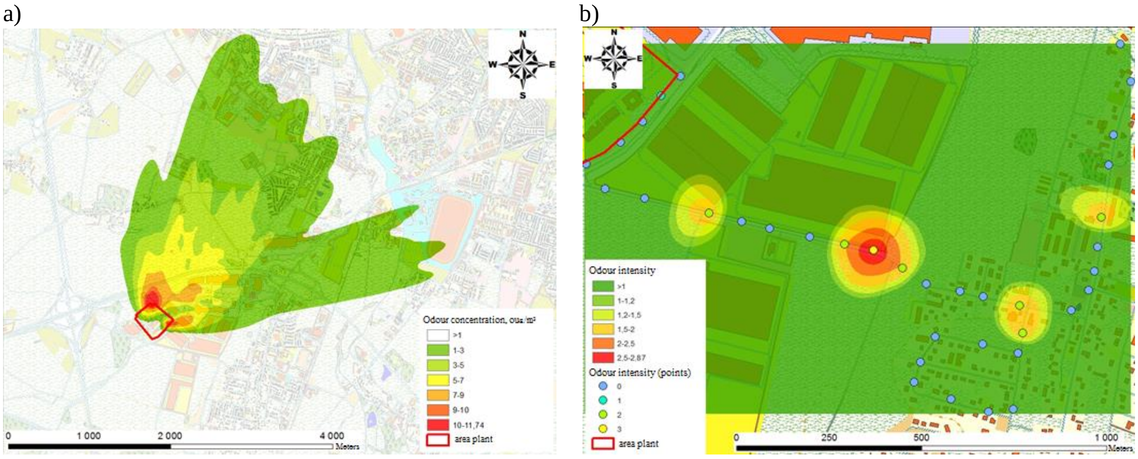

Figure 2. Results of calculations for series 6 (25.06.2012): a) spatial distribution of ‘M’ odour concentration calculated with CALPUFF model; b) spatial distribution of ‘M’ odour intensity estimated with ordinary kriging

Model was developed by physical connection in GIS software using Arc Toolbox application in ArcGIS 10.1 ESRI. Connection of the two rasters (from CALPUFF and from kriging) was done using raster mosaic process (with Mosaic To New Raster tool). Every new raster was created in PUWG 1992 coordinate system (applicable in Poland) and with resolution 10 meters. The new rasters were created in such a way that in the places, where surface of two rasters overlapped, the values of odour concentration to new raster were taken from raster made of kriging. It allowed the evaluation the modelling results.

In Figures 3a and 3b two examples of created models for two different measurement series are presented. Built models allow to identify differences between results of simulations made in CALPUFF model and estimation of odour concentrations measured as odour intensity in the field. In the Figures the occurrence of odour ‘L’ in series 3 (Figure 4) and ‘M’ in series 6 (Figure 5) measured in the field inspections in some places overlap with occurrence of odours calculated using CALPUFF model. However, we have got an information, that in places not covered by the CALPUFF model, the odours also were perceptible. It means that CALPUFF model in both examples underestimated range of the odours impact. But, on the other side, the model complements the range of the odours in other areas, where at the same time field measurements were not possible to do, because of time and human restrictions. CALPUFF model extends the range of occurrence of odour plume.

a) b)

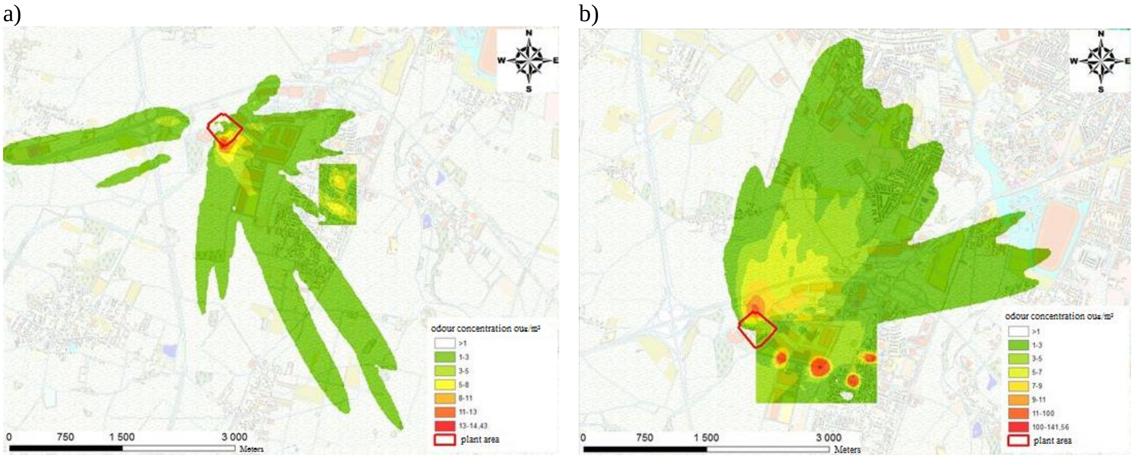

Figure 3. Dynamic-statistical odour dispersion model built a) for odour ‘L’ in series 3 (8.07.2011); b) for odour ‘M’ in series 6 (25.06.2012)

SUMMARY

The dynamic-statistical model was built by physically connection of two rasters as the results of the modelling simulates based on emission measures and geostatistical analysis based on field inspections. It is very good tool for assessment of odour nuisance because of its reliability. In this way both of the methods verify and complement each other. It creates the new, reliable tool to evaluate odour impact on the analysed area. The developed model can be used in researches of the odour impact evaluation for every object which emits odours: agricultural, municipal economy or industrial plant.

REFERENCES

Dourado H., Santos J.M., Reis N.C, Jr., Mavroidis I., 2014: Development of a fluctuating plume model for odour dispersion around buildings, *Atmospheric Environment*, **89**, 148-157

EN 13725:2003: Air quality. Determination of odour concentration by dynamic olfactometry

Eusebio L., Dentoni L., Capelli L., Sironi S., Rossi A.N., Bonati S., 2013: Odour impact assessment in the field: the plume method, 2013, *Environmental Engineering and Management Journal*, **12**, S11, Supplement, 193-196, http://omicron.ch.tuiasi.ro/EEMJ/

Nagaraj A., Sattler M.L., 2005: Correlating Emissions with Time and Temperature to Predict Worst-Case Emissions from Open Liquid Area Sources, *Journal of the Air & Waste Management Association*, **55** (8), 1077-1084

Olesen H.R., Løfstrøm P., Berkowicz R., Ketzel M., 2005: Regulatory odour model development: Survey of modelling tools and datasets with focus on building effects, National Environmental Research Institute, Technical Report No. 541, Denmark

Piringer M., Petz E., Groehn I., Schauberger G., 2007: „A sensitivity study of separation distances calculated with the Austrian Odour Dispersion Model (AODM)", *Atmospheric Environment*, **41**, 1725–1735

Piringer M., Knauder W., Petz E., Schauberger G., 2015: "A comparison of separation distances against odour annoyance calculated with two models", *Atmospheric Environment*, **116**, 22-35

Sironi S., Capelli L., Centola P., Del Rosso R., Pierucci S., 2010: „Odour impact assessment by means of dynamic olfactometry, dispersion modelling and social participation", *Atmospheric Environment*, **44**, 354-360

Sówka I., Skrętowicz M., Sobczyński P., Zwoździak J., 2013: Estimating odour impact range of selected wastewater treatment plant for winter and summer seasons in Polish conditions using CALPUFF model, HARMO'15 Proceedings, 15th Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes HARMO 15, Madrid, Spain

VDI guidelines – 3788 part 1, 2000: Environmental meteorology - Dispersion of odorants in the atmosphere – Fundamentals

VDI 3882 part 1,1992: Olfactometry; determination of odour intensity

VDI guidelines – 3940 part 2, 2006: Measurement of odour impact by field inspection - Measurement of the impact frequency of recognizable odours - Plume measurement