H15-101

# ESTIMATING ODOUR IMPACT RANGE OF SELECTED WASTEWATER TREATMENT PLANT FOR WINTER AND SUMMER SEASONS IN POLISH CONDITIONS USING CALPUFF MODEL

*Izabela Sówka, Maria Skrętowicz, Piotr Sobczyński, Jerzy Zwoździak*

Environmental Protection Engineering Institute , Ecologistic Group, Wroclaw University of Technology (WUT), Plac Grunwaldzki 9, 50-377 Wroclaw (Poland)

Odour emission from Wastewater Treatment Plants (WWTP) is a common cause of odour nuisance to neighboring areas. Odour impact assessment can be realized by conducting field inspections or mathematical modeling. Odour impact range of selected wastewater treatment plant was determined using both methods, but this paper focuses on the results of calculations made using CALPUFF dispersion model.

The analyzed object was mechanical biological wastewater treatment plant with intensified nutrients removal and full sludge treatment, designed for 1200000 population equivalent. Collection of the samples was carried out in accordance with the methodology described in VDI 3880 and PN-EN 13725 during the rainless weather. Odour concentration measurement was made using the method of dynamic olfactometry, in accordance with the procedures described in -EN: 13725 "Air Quality. Determination of odour concentration by dynamic olfactometry". For selected emission sources (with the highest odour emissions) model calculations were conducted using CALPUFF dispersion model for the grid size 3 x 5 km. Grid includes neighboring residential areas, which are exceptionally exposed to odours. This study presents results of modeling in local scale, for different meteorological scenarios, respectively for winter and summer seasons. Presented results show if analyzed wastewater treatment plant could be a cause of negative odour impact to nearby residential areas and which meteorological conditions determine the worst case scenarios in terms of odour dispersion in selected area.

**Key words:** *odours, wastewater treatment plant, impact assessment, CALPUFF model*

## INTRODUCTION

Odour emission from Wastewater Treatment Plant (WWTP) is a common cause of odour nuisance to neighboring areas. Rapid development of large urban centers makes suburbs, which weren't considered as potential residential areas in the past, more attractive for people working in cities. Therefore, new estates are often built in the vicinity of a Wastewater Treatment Plants which makes them exposed to negative impact of odours which originate from the units of a WWTP.

In this study are presented results of dispersion modeling using CALPUFF/CALMET model (Scire, J.S., D.G Strimaitis, and R.J Yamartino, 2000). Study was applied to mechanical biological wastewater treatment plant designed for 1200000 population equivalent. Dispersion modeling allowed to asses odour impact range of analyzed municipal wastewater treatment plant and estimate plume shape under different weather conditions.

## MATERIALS AND METHODS

### Site description

The study was conducted on an area of western Poland, comprising two big villages (about 15 000 inhabitants), which are located just a few kilometers from a city of over 500 000 inhabitants. Analyzed site consists of industrial, residential as well as agricultural areas. WWTP and industrial facilities are located in Warta river valley. The study focuses on estimating odour impact of WWTP to residential areas which are situated in eastern and northeastern part of the site. Topography of the site is quite complex. Only small part of residential areas are located in the river valley, most of them lies on the hills in the eastern part of the site.

### Technological system of the selected WWTP

The analyzed object is mechanical biological wastewater treatment plant with intensified nutrients removal and full sludge treatment, designed for 1200000 population equivalent. Raw wastewater enters screening house where coarse parts are separated. Afterwards sewage is led to aerated grit chambers and through pumping station goes to radial primary clarifiers. After preliminary and primary treatment effluent is subjected to biological treatment, where in anaerobic, aerobic and anoxic tanks, organic compounds, as well as nutrients are being reduced. Wastewater flows from bioreactors to secondary clarifiers. Part of sedimented sludge is recirculated to anoxic tanks, excess sludge is transferred to sludge treatment facilities. Primary sludge thickened in gravity thickeners and waste activated sludge thickened in gravity-belt thickeners is subjected to mesophylic anaerobic digestion in separated anaerobic digesters. Fermentation gas is used as a fuel in generator. Digested sludge is dewatered in belt-filter presses and dried in thermal drying plant. Dried sludge is sold to external companies for combustion purposes.

**Sample collection and analyses**

Odour concentrations has been determined for the following objects of analyzed WWTP that can emit malodorous gases: screening hall, grit chambers, grids channels between primary settlers, sludge gravity thickeners, primary clarifiers, predenitrification, denitrification, dephosphatation and nitrification tanks, secondary clarifiers, digested sludge tanks, thermal drying plant, primary sludge buffer tank and sludge drying bed (Stuetz, R. and F. Frechen, 2001). At each point odour samples were collected to three bags. Collection was carried out in May and June 2011 in accordance with the methodology described in VDI 3880 and PN-EN 13725 during the rainless weather. Odour samples were collected using vacuum sampler to special purpose sampling bags made of PTFE, which do not absorb or emit odours. Other elements of the sampling kit are also made of odourless materials, which does not absorb odours. Following the recommendations, bags have been previously conditioned. Collection of the samples is based on lung function principle. Sampling on point sources was carried out using standard samplers (30 s collection time). Sampling on area sources was performed using special 1 m x 1 m cover for active sources (i.e. biofilters, aeration tanks) and wind tunnel manufactured by ECOMA for passive sources (i.e. liquid surfaces without outward flow, e.g. primary clarifiers, anaerobic and anoxic tanks). Wind tunnel used is made as stainless steel hood with two electric fans which induce constant air flow under the hood. Base area of the hood is 0,5 $m^2$. Activated carbon filter is installed in the inlet of the air to provide flow of relatively clean and odourless air.

Immediately after collection, samples were transported to the Olfactometric Laboratory to determine odour concentrations. Odour concentration measurement was made using the method of dynamic olfactometry, in accordance with the procedures described in PN-EN: 13725 "Air Quality. Determination of odour concentration by dynamic olfactometry”. Measuring device was ECOMA TO8 four panelists olfactometer with the necessary equipment. According to the standards measurements were conducted in muted and isolated room with stable temperature and lighting conditions. Measuring team was composed of four panel members and one operator. Panel members were selected in accordance with the guidelines specified in the standard using reference substance - n-butanol in nitrogen. The analysis is carried out by presenting the sample to the panel at increasing concentrations by means of a particular dilution until the panel members start perceiving an odour that is different from the reference air. Concentration of odours in sample is calculated as the geometric mean of the odour threshold values of each panelist. As defined by the EN 13725, the individual threshold estimate is defined by the two presentations in one dilution series, sorted on growing odour concentration, where a certain change in response from “false” to a consistently “true”. The individual threshold estimate is calculated as the geometric mean of the dilution factors of the two defined presentations.

**Odour emission rates from selected sources**

Taking into account results of olfactometric analyses and field inspections indicated, sources as primary clarifiers and thermal drying plant have been selected for further WWTP odour impact assessment. It was assumed that every source emits one specified mixture of odorants, which is considered as an individual type of odour.

For passive area sources (four primary clarifiers) evaluation of Odour Emission Rate (OER - $ou_E\ s^{-1}$) required calculation of Specific Odour Emission Rate (SOER - $ou_E\ m^{-2}\ s^{-1}$). SOER was obtained by multiplying the determined odour concentration values ($ou_E\ m^{-3}$) by airflow in the wind tunnel ($m^3\ s^{-1}$) and dividing by wind tunnel base area ($m^2$) (Capelli, L., S. Sironi and R. Del Rosso, 2013). Table 1 presents results of olfactometric analyses as well as calculated odour emissions for four primary clarifiers an thermal drying plant.

Odour Emission Rate for thermal drying plant biofilter (area active source) was obtained by multiplying the determined odour concentration value ($ou_E\ m^{-3}$) by the flowrate of the biofilter fan ($m^3\ s^{-1}$).

Table 1. Odour emissions from selected sources

| Emission source | Type of source | Odour concentration ($ou_E\ m^{-3}$) | SOER ($ou_E\ m^{-2}\ s^{-1}$) | OER ($ou_E\ s^{-1}$) |
|---|---|---|---|---|
| primary clarifiers | area-passive | 11130 | 835 | 7089618 |
| thermal drying plant | area-active | 19916 | - | 44636 |

**CALPUFF dispersion model**

Odour impact assessment has been carried out using CALPUFF model which been designed by Earth Tech Inc. for the California Air Resources Board (CARB) and the U.S. Environmental Protection Agency (US EPA). CALPUFF is non-steady-state Lagrangian Gaussian puff 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 rising as a function of the distance from the source, the influence of the orography on dispersion, and the dispersion in case of weak or absent wind. CALPUFF modeling system consists of three main components: CALMET, CALPUFF, and CALPOST (Scire, J.S., D.G Strimaitis, and R.J Yamartino, 2000). CALMET is a meteorological module that creates hourly wind and temperature fields on a 3-dimensional gridded modeling domain. CALPUFF is a transport and dispersion model that describes “puff” of material emitted from modeled sources, simulating dispersion and transformation processes along the way. The basic equation for the contribution of a puff at the receptor is:

$$C = \frac{Q}{\pi \sigma_y \sigma_z} g \exp\left[\frac{-d_a^2}{2\sigma_x^2}\right] \exp\left[\frac{d_c^2}{2\sigma_y^2}\right] \tag{1}$$

$$g = \frac{2}{\sqrt{2\pi}\sigma_z} \sum_{n=-\infty}^{\infty} \left[\frac{(H_e + 2nh)^2}{2\sigma_z^2}\right] \tag{2}$$

Where C is the ground level pollutant concentration (OU), Q is the product of odor strength in the puff and the puff volume (OU $m^3$), $\sigma_x$ is the standard deviation (m) of the Gaussian distribution in the along wind direction, $\sigma_y$ is the standard deviation (m) of crosswind direction, $\sigma_z$ is the standard deviation (m) of the Gaussian distribution in the vertical direction, $d_a$ is the distance (m) from the puff center to the receptor in the along-wind direction, $d_c$ is the distance (m) from the puff center to the receptor in the cross-wind direction, g is the vertical term (m) of Gaussian equation, He is the effective height (m) above ground of the puff center and h is the mixed-layer height (m).

For modeling purposes two groups of meteorological data has been provided: data from ground stations (wind speed and direction, cloud height, cloud cover, air temperature, relative humidity, atmospheric pressure) and soundings data from aerological stations (atmospheric pressure altitude, air temperature, wind speed and direction with altitude at which they occurre). Such developed database enables model to determine wind fields, which are necessary for odour dispersion calculations. Meteorological data was put into model with 1 hour interval (ground stations) and 12 hours interval (aerological stations). Topography and land use of the analyzed area is defined for each grid point separately, based on a database or digital maps.

Model calculations were conducted for the grid size 3 x 5 km, which includes neighboring residential areas, which are exceptionally exposed to odours.

## RESULTS AND DISCUSSION

The calculations using the CALPUFF model has been carried out for summer (July) and winter (November) seasons what allowed to assess odor impact range of analyzed WWTP for different meteorogical conditions and to determine the shape and spatial variability of odor plume. Calculations has been made for six day periods (144 hours). Input emission rates shown in table 1 were constant for both seasons. Field inspections and determined odour concentrations from selected odour sources indicated that primary clarifiers and thermal drying plant are the probable cause of odour nuisance in the vicinity of the WWTP, so that dispersion modeling has been carried out for those two sources.

Dispersion modeling of primary clarifiers odour showed that during summer, maximum odour concentrations on site are very high (range of 4 - 7100 $ou_e$ $m^{-3}$ - figure 1) comparing to winter season (range of 0 - 85 $ou_e$ $m^{-3}$ - figure 2). In summer, odour impact range (odour concentrations > 1 $ou_e$ $m^{-3}$) of WWTP covers all analyzed site, including big residential areas in the east and northeastern part where odour concentrations can exceed 500 $ou_e$ $m^{-3}$, while in winter in the eastern part of the site odour concentrations do not exceed 1 $ou_e$ $m^{-3}$ and it can be assumed that this areas are not exposed to odour nuisance caused by primary clarifiers. These significant differences of impact range of WWTP for winter and summer season are the result of meteorogical conditions as well as complex topography of the site. In spite of the fact that in July the most frequent wind directions are west and north-west results of the modeling presented on figure 1 show that shape of the plume is strongly affected by the site topography. Highest odour concentrations are in the river valley and decrease with rising altitudes.

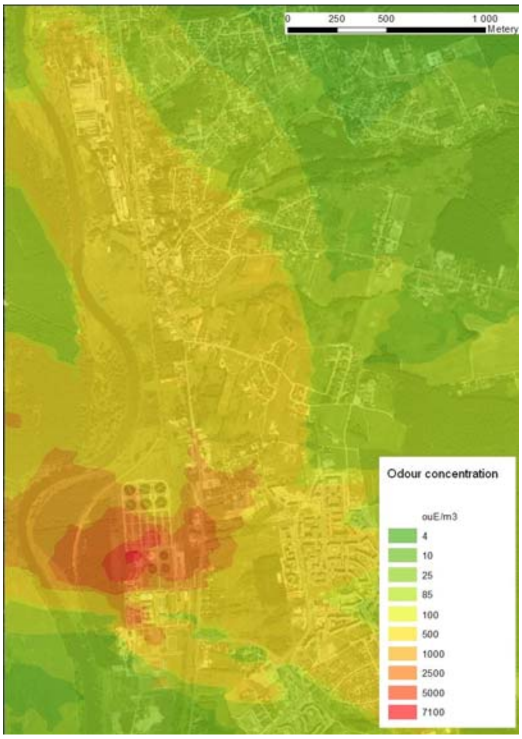

Figure 1. Maximum odour concentration - primary clarifiers, summer season.

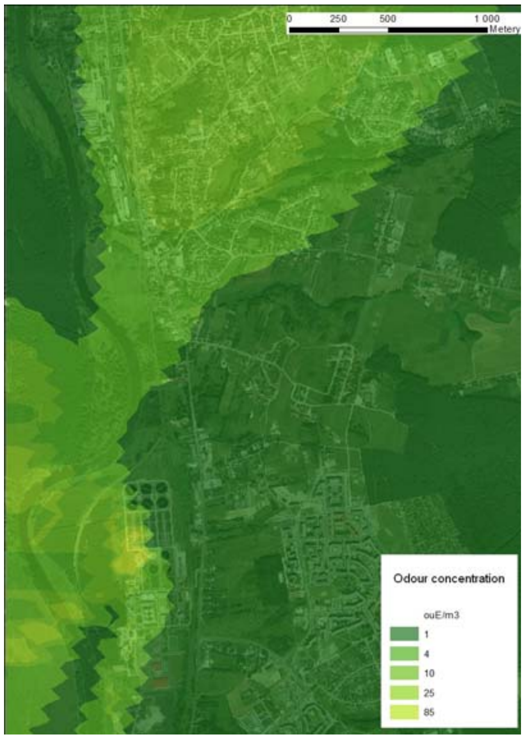

Figure 2. Maximum odour concentration – primary clarifiers, winter season.

Results of modeling odour dispersion concerning emission from thermal drying plant are shown in figures 3 and 4. In contrast to results of primary clarifiers odour dispersion modeling, odour impact range of thermal drying plant is not that significant. Dispersion modeling of thermal drying plant odour showed that maximum odour concentrations on site, especially on residential areas are much lower comparing to primary clarifies - in summer range of 0 - 90 $ou_e$ $m^{-3}$ (figure 3) and in winter season range of 0 - 250 $ou_e$ $m^{-3}$ (figure 4). During both seasons, odour concentrations in the areas in northern part of the site are below 1 $ou_e$ $m^{-3}$. On the most of the site odour concentrations do not exceed 5 $ou_e$ $m^{-3}$ which means the odour will be too faint to become recognizable (Belgiorno, V., V. Naddeo, T. Zarra, 2013).

Residential areas are much less exposed to odour nuisance caused by thermal drying station in winter than in summer because of dominant frequency of eastern winds. During summer residential areas in the eastern part of the site will suffer most from odour nuisance which corresponds to residents' complaints and field inspections.


Figure 3. Maximum odour concentration - thermal drying plant, summer season.

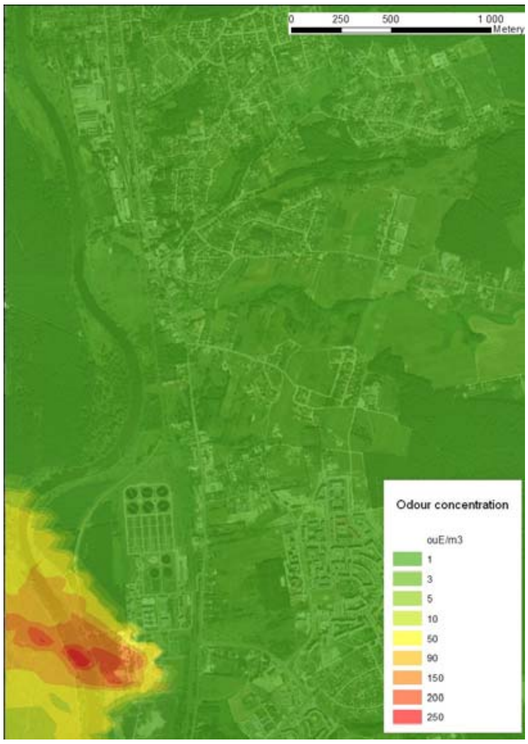


Figure 4. Maximum odour concentration - thermal drying plant, winter season.

## CONCLUSIONS

This paper describes an example odour impact assessment of WWTP placed in the vicinity of residential areas for summer and winter seasons. Study shows that metrological conditions as well as complex topography can significantly affect odour impact range of analyzed object. Using advanced dispersion models enables to evaluate impact range for different meteorogical scenarios allowing to evaluate odour impact range for various periods of the year.

## REFERENCES


Belgiorno, V., V. Naddeo, T. Zarra, 2013: Odour impact assessment handbook., Wiley, 125-174.

Capelli, L., S. Sironi and R. Del Rosso, 2013: Odor Sampling: Techniques and Strategies for the Estimation of Odor Emission Rates from Different Source Types. *Sensors.*, **13**, 938-955.

Sattler, M., S. Devanathan, 2007: Which Meteorological Conditions Produce Worst- Case Odors from Area Sources?. *Journal of the Air & Waste Management Association.*, **57:11**, 1296-1306.

Scire, J.S., D.G Strimaitis, and R.J Yamartino, 2000: A User’s Guide for the CALPUFF dispersion model. Version 5., Earth Tech, Inc., Concord.

Stuetz, R. and F. Frechen, 2001: Odours in Wastewater Treatment: Measurement, Modelling and Control, IWA Publishing, 31-90.

VDI guidelines -3880, Olfactometry - Static sampling. 2009. Berlin, Beuth Verlag,

Polish Norm PN-EN: 13725, Air Quality. Determination of odour concentration by dynamic olfactometry.



*Work carried out under the project:*

*"Development of a dynamic-statistical model of odour nuisance propagation in urban and industrial agglomerations", National Science Centre, Poland, 0188/B/P01/2011/40.*