DOI: 10.2478/cdem-2022-0010 CHEM DIDACT ECOL METROL. 2022;27(1-2):165-181

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ENVIRONMENTAL EMISSIONS DISPERSION MODELLING, PRINCIPLES AND ALGORITHMS; CROSS-BORDER CZ-PL COURSE FOR MASTER'S STUDENTS

Abstract: Regular mathematical modelling of the dispersion of emissions from large sources is required by law in all EU countries. It is also used in risk analysis to predict releases of toxic substances from various technologies, from volcanic activity and possibly also terrorist acts. However, there is a shortage of experts in this very specific and demanding profession in the labour market in most EU countries. In a collaboration between academicians from neighbouring University of Hradec Králové and University of Opole and experts from important ecological companies of both regions we designed and verified as a part of a four-year pedagogical project supported by the EU a comprehensive education system in mathematical modelling of emission dispersion with exchange field trips and internships of students during cross-border Polish-Czech university education. The paper consists of two separate parts. The first part is focused on implementation of innovative lesson ”Principles, algorithms, and differences of environmental dispersion emissions models”, used on both sides of Polish-Czech border region. An example of the use of the educational package of the Gaussian plume model with PC Templates, who was modified in cooperation between teachers from both cross-border universities and experts from professional companies is presented here too. Our four-year experience with student motivational field trips to professional companies in both border regions and exchange one-month professional internships for interested students to two Czech professional companies, where students learn to work with to the Gaussian plume model and one Polish professional company, where students are introduced to the Gaussian puff model is also discussed. The following separate second part will be focused on the innovative lesson of multivariate statistical methods of environmental data analysis, which are required for processing materials for modern mathematical modelling of the dispersion of emissions in practice. The target users of this two-part innovative courses are students of the MSc degree in Physical Measurement and Modelling at the University of Hradec Králové and students of the MSc degree in environmental studies at the University of Opole. However, it is also open to other Czech and foreign students and professionals.

Keywords: emissions dispersion modelling, mathematical foundations, PC template, curricular practice

Introduction

In the central part of the Czech-Poland border area, there are two significant sources of emissions on the Czech side, the Opatovice and the Chvaletice power plants and the Opole

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power plant on the Polish side. All have an exceptional position due to their location located in a densely populated area around the regional cities. Their emissions also cover the Czech-Polish recreational area with several national parks. Related to this are the demands on emission abatement technologies, continuous measurement, mathematical modelling of their dispersion and support for air pollution monitoring. But the central part of the Czech-Poland border region, is characterised by the highest unemployment of graduates of science and technology. There is a demand for places for qualified performance of activities and services, especially in the technical and technological environmental protection and mathematical modelling of emission dispersion. Regular mathematical modelling of the dispersion of emissions from large sources is required by law in all EU countries. There are using computer programs that contain algorithms for solving mathematical equations describing the dispersion of pollutants in the air. It is used to estimate the concentration of pollutants and toxic substances emitted from sources such as coal-fired power plants, large industrial enterprises and road transport. It also serves to model the leakage of toxic substances from various technologies, from volcanic activity and possibly also terrorist acts and to predict these dangerous phenomena [1]. However, there is a shortage of workers in this profession on the labour market in most EU countries, which is beginning to pose a serious societal problem. Demand for experts for these legally enshrined activities results primarily from the need to prepare expert assessments of the mathematical modelling of emission scattering in high-temperature coal combustion on both sides of the Czech-Polish border region.

In this communication, we focused on the results of our four-year cross-border CZ-PL project supported by the EU, implemented in 2017-2021, entitled "Cooperation between UO and UHK expanding the possibilities of applying graduates on the cross-border labour market", which deals with increasing students' motivation to study this demanding on physical environmental technical and technological focus. In cooperation with teachers from two cross-border faculties of the Faculty of Science, University of Hradec Králové and of the Faculty of Science of the University of Opole and with experts from important ecological companies of both regions, Idea-Envi (CZ), EMPLA AG (CZ) and ATMOTERM S.A. Opole (PL) we designed a comprehensive education system in part Mathematical modelling of emission dispersion.

The problem of air pollution is never the result of isolated events, but of subsequent chains of events: from the creation of pollutants in the process of emission generation with subsequent purification of waste gases, dispersion and chemical transformation in the atmosphere, to receptor uptake, impact on nature, human health and wellness effect. A full understanding of the air pollution problem and knowledge of all the steps in the process is essential for quality professionals in modelling the dispersion of emissions from large sources [1].

As the best motivational element also for university student's motivational excursions and internships are recommended [2, 3].

Educational exchange study field trips

Field trip to the coal-fired power plant

During the full-day training students participate in:

- Introductory lectures Reducing and continual measurements of microparticle and heavy metals emissions from the coal-fired power plants

- Field trip on the ecological program Reducing and continual measurements of emissions in coal-fired power plant
- Students obtain data from continuous measurement of emissions, which they will process independently in the course Modern multivariate statistical methods of environmental data analysis

Field trip to emissions measurement with a mobile laboratory

During the full-day training students participate in:

- Introductory lectures
- Continual mobile measurements of emissions from power plant fly ash in the field
- Students obtain data from continuous measurement of emissions, which they will process independently in the course Modern multivariate statistical methods of environmental data analysis

Field trip to the station of automatic immission monitoring

During the full-day training students participate in:

- Introductory lectures Physical principles of automatic immission monitoring
- Field trip on the station of Automatic Imission Monitoring
- Students obtain data from continuous measurement of emissions, which they will process independently in the subject Modern multivariate statistical methods of environmental data analysis. Reciprocally similar educational exchange study field trips was completed by Czech students during four-day field trips to Opole.

Innovative materials for cross-border CZ-PL higher education

Reducing and continual measurements of microparticle and heavy metals emissions from the coal-fired power plants

At present, in all developed countries of the world, as well as in Europe, the pressure to shut down large coal-fired power plants and to replace them with renewable energy sources is increasing. The problem, however, is that the renewable resources used require full compensation in the event of unsuitable climatic conditions. However, coal-fired power plants have many negative environmental impacts in their operation. Their emissions are usually divided into three groups. The first group includes sulphur oxides, solid particles, halogens and heavy metals (group of elements with a density higher than 4.5 $g\cdot cm^{-3}$). In the environment, this designation has been used for the whole wider group of pollutants, which, however, should rather be referred to as toxic metal elements), the second group includes nitrogen oxides and carbon monoxide, and the third includes carbon dioxide, which is the main product of perfect coal combustion. During coal combustion, the heavy metals present are distributed between the bed ash (slag), fly ash, gaseous aerosol and gaseous emissions, where they are condensed and absorbed on the surface of solid particles. Due to the large specific surface area, their highest contents are on the smallest particles, which are very difficult to remove by means of separation devices. It’s known that PM10 refers to particles with a diameter below 10 μm can be inhaled into human lower respiratory tract and cause respiratory problems [4]. Impact PM2.5 is mainly reflected in health effects on humans. Larger particulate matter can only reach the throat because of the large diameter of the particles. The PM2.5 has a small particle size and can travel through the nasal passages along the respiratory tract to the bronchi and lungs, affecting the gas exchange process, and causing the body to suffer from respiratory diseases. Because PM2.5 has a larger specific surface area, it can easily carry heavy metals and toxic organic substances harmful to humans, and the toxic substances carried by PM2.5 can be dissolved in the blood and enter the blood circulation, causing cardiovascular diseases. Particle fractions with an aerodynamic diameter below 2.5 μm form the most stable aero disperse systems characterised by a long residence time in the atmosphere and capable of long-distance transport [5].

Highly toxic heavy metals with the combined effect of lead, cadmium, arsenic and mercury are considered to be the main anthropogenic inorganic pollutants. They damage the respiratory system, after settling in the lungs they migrate to other parts of the body, where they can damage other organs, they are carcinogenic and teratogenic. Their organometallic compounds and precursors are considered to be particularly dangerous because they react very easily with organic substances. These are mainly organomercury and organolead compounds as well as mercuric and lead chloride. Heavy metals can cause hematopoietic disorders, damage to the nervous system and serious disorders of some internal organs. Heavy metals are not broken down in the human body and some have the ability to bioaccumulate. Mercury in particular is a very potent neurotoxin that accumulates in food chains. It enters the human body mainly by inhalation of mercury vapour, which has a relatively long half-life in the atmosphere, where it occurs in both elemental and oxidised form or is also bound to very fine-grained particles in aerosols [6].

During high-temperature coal combustion, the heavy metals present are distributed between the bed ash (slag), fly ash, gas aerosol and gaseous emissions. Due to the fact that the finest fly ash fractions have the largest specific surface area, the concentration of heavy metals in these fractions is also the highest. The maximum concentration of heavy metals is found in the finest fraction of fly ash with a particle diameter below 10 μm. Enrichment with all the above-mentioned metals occurs in fly ash probably due to the adsorption or condensation of these vapours on the surface of fine particles. As, Cd and Pb were found in the submicron fly ash fractions, which are volatile at medium temperatures in all circumstances. The mechanism of this transport is usually described as volatile heavy metals leaving the hearth during combustion due to the high temperatures in the combustion zone. After leaving this zone, there will be a significant drop in temperatures and thus a cooling of the flue gases with fly ash particles and heavy metal vapours. This leads to their condensation and adsorption on the surfaces of the microparticles. Heavy metals that enrich bed ash are not volatile at the temperature in the combustion zone and remain in a condensed state Due to the fact that in industrial combustion plants bed ash is quickly removed from the combustion zone, its contact with these elements is short and does not enrich. Most of the heavy metals found by the authors in the gas phase and in fly ash have low boiling points. In contrast, most heavy metals found in bed ash have a high boiling point. The distribution of heavy metals between bed ash and fly ash is determined not only by the boiling point of the respective metal, but also by the form of its occurrence in coal. Heavy metals in coal often occur in the form of aluminosilicates, inorganic sulphates or organic complexes. Aluminosilicates do not decompose during coal combustion and the elements contained in them turn into bed ash in most cases. Conversely, elements bound to sulphates or the organic fraction of coal are released during the first phase of combustion and go into a gaseous state. In the next stage, they can be oxidised to form less volatile oxides, which allows them to condense or adsorb on the surface of fly ash solids [7]. Mercury is bound in the fuel to inorganic parts, especially pyrites, sulphides, and markensites. Black and brown coal contain comparable concentrations of mercury, but black coal is characterised by a lower chlorine content and a higher calcium content compared to brown coal. Because the melting point of mercury is relatively low, 357 °C, and more than 1600 °C is commonly achieved in coal combustion, more than 800 °C in the case of fluidised bed boilers, mercury transitions to the gas phase in the form of Hg^0. When the flue gas temperature drops to values in the range of 650 °C to 380 °C, part of the mercury oxides to the Hg^{2+} form, mainly due to the reaction with Cl to mercuric chloride. Black coal flue gases therefore contain higher amounts of Hg^0 compared to lignite flue gases, where Hg^{2+} is the dominant component of mercury. In general, mercury is present in coal flue gases from 20 % - 50 % as Hg^0, from 50 % - 80 % as $HgCl_2$ and from 1 % - 5 % in the form of organomercury compounds. The form of mercury occurring in the flue gas affects the proportion of mercury trapped in the combustion plant. After further cooling of the flue gas to temperatures 380 °C - 180 °C, Hg binds to the surface of the fly ash contained in the flue gas and trapped in the solid separators, designated Hg^p.

The well-soluble oxidised form is captured during the desulphurisation process at the wet limestone flue gas scrubber. It is assumed that the mercury released in the flue gas is in atomic form and its residence time in the atmosphere can be up to 1 year. The limit of dust particles for large stationary sources has been very tightened, it sets the maximum value of particulate matter at 8 mg · m^{-3} in flue gases [8]. Research on the concentration of heavy metals in microparticles emitted from coal-fired power plants continues with the introduction of advanced physical micro methods [9].

The Opatovice Power Plant (EOP) is a lignite cogeneration power plant with a terminal electrical output of 300 MW, with six production units with combined heat and power generation installed. There are four units the state-of-the-art recommended BAT (Best Available Techniques) listed in Directive EU for environmental technologies, is used to remove of microparticle (PM) from the flue gas. These are low-pressure, high-volume Bag filters with pulse regeneration, with a guaranteed maximum PM value of 8 mg · m^{-3} from Hamon Research-Cottrell GmbH. As the flue gas passes through the filters, dust particles are trapped on the fabric filter and the cleaned flue gas then continues through the smoke fan to the desulphurisation line. The captured particles fall into the hoppers in the lower part of the filter and are transported by pneumatic transport for further processing [10]. Two fabric filters are installed on each block, each filter consists of 12 bundles and each contains 388 eight-meter filter sleeves. Thus, there are 9312 of them on the block. Each sleeve forms an 8 m long tube with rounded ends measuring 8 m x 0.127 m with a filter area of 3.19 m^2 with a retracted metal structure to maintain the shape of the filter cloth and make its cleaning more efficient. The sleeves are cleaned by pulse blowing a large volume of air into the open ends of the sleeves. This not only inflates the fabric and, as a result, drops the fly ash deposit into the hoppers, but also re-blows it and cleans it more effectively.

Measurements behind the separators are performed with the DR-290 device from the DURAG company. The device works on the principle of double transmittance, where a pulse measuring beam with a wavelength of 500 nm to 600 nm passes through the measured channel to the opposite wall, where the reflector is located, and returns through a semi-transparent mirror to the photodiode. The control unit then measures the decrease in beam intensity caused by scattering on the dust particles and converts this value into an electrical quantity.

Students individually receive a different part of the data files that they process and statistically evaluate in the course of modern multivariate statistical methods of environmental data analysis.

Innovative materials for cross-border CZ-PL course for master's students

Mathematical foundations of emissions dispersion modelling

Modelling of pollutant dispersion is completed using mathematical algorithms. There are several basic mathematical algorithms in use: The Box, Gaussian, Eulerian and Lagrangian model [11].

Box model

The box model is the simplest of the modelling algorithms. It assumes the airshed is in the shape of a box. The air inside the box is assumed to have a homogeneous concentration. The box model is represented using the following equation:

$$\frac{dCV}{dt} = QA + uC_{in}WH - uCWH \quad (1)$$

where Q - pollutant emission rate per unit area [g · s^{-1} · m^{-2}]; C - homogeneous species concentration within the airshed [g · m^{-3}]; V - volume described by box [m^{3}]; C_{in} - species concentration entering the airshed [g · m^{-3}]; A - horizontal area of the box (L×W) [m^{2}]; L - length of the box [m]; W - width of the box [m]; u - wind speed normal to the box [m · s^{-1}]; H - mixing height [m].

Although useful, this model has limitations. It assumes the pollutant is homogeneous across the airshed, and it is used to estimate average pollutant concentrations over a very large area. This mathematical model is very limited in its ability to predict dispersion of the pollutant over an airshed because of its inability to use spatial information [11].

Gaussian models

The Gaussian model of pollutants dispersion in the atmosphere is based on the analytical solution of convective-diffusion equation:

$$\frac{\partial c}{\partial t} = \nabla(D\nabla c) - \nabla(uc) + R \quad (2)$$

where c - scalar function describing concentrations of pollution [g · m^{-3}]; t - time [s], D - diffusion coefficient; u - particle velocity [m · s^{-1}]; R - source function emitting pollution [g · s^{-1} · m^{-3}].

After adjusting and neglecting the advection term, we obtain the generally valid Navier-Stokes equation to maintain the mean concentration of the passive impurity in approximation to the incompressible fluid:

$$u\nabla c = u_x \frac{\partial c}{\partial x} + u_y \frac{\partial c}{\partial y} + u_z \frac{\partial c}{\partial z} \quad (3)$$

After performing the reduction on the equation describing turbulent diffusion, assuming isotropy, temporal and spatial homogeneity of turbulence, where we consider turbulent diffusion as two-dimensional, and after introducing Gaussian standard deviations as scattering parameters we get the resulting form:

$$c^*(x,y,z) = \frac{Q}{2\pi u_x \sigma_y \sigma_z} \cdot \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \cdot \left(\exp\frac{z^2}{2\sigma_z^2}\right) \tag{4}$$

where $c^*(x,y,z)$ - concentration of the substance at point (x, y, z) [kg · m^{-3}]; Q - pollutant mass [g]; u_x - wind speed [m · s^{-1}]; σ_y, σ_z - horizontal, respectively vertical scattering coefficients [-].

The original Taylor model completed by Sutton in the 1930 is called the Gaussian scattering model [11]. It is one of the simplest and probably the most commonly used models designed for lighter-than-air gases or, generally, for describing the passive scattering phase. It is based on the assumption that the substance concentration is normally distributed both on the horizontal and vertical axes. For a continuous escape from an elevated point source of height H, the concentration at (x, y, z) is given by:

$$c^*(x,y,z) = \frac{M}{2\pi \sigma_y \sigma_z u} \cdot \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \cdot \left(\exp\frac{-(z-H)^2}{2\sigma_z^2} + \exp\frac{-(z+H)^2}{2\sigma_z^2}\right) \tag{5}$$

where M - substance leakage rate [kg · s^{-1}]; H - source height above terrain [m].

The validity of the relationship is based on the assumption of low height and without the occurrence of inversions and convections, is called „Gaussian PLUME Model” [12].

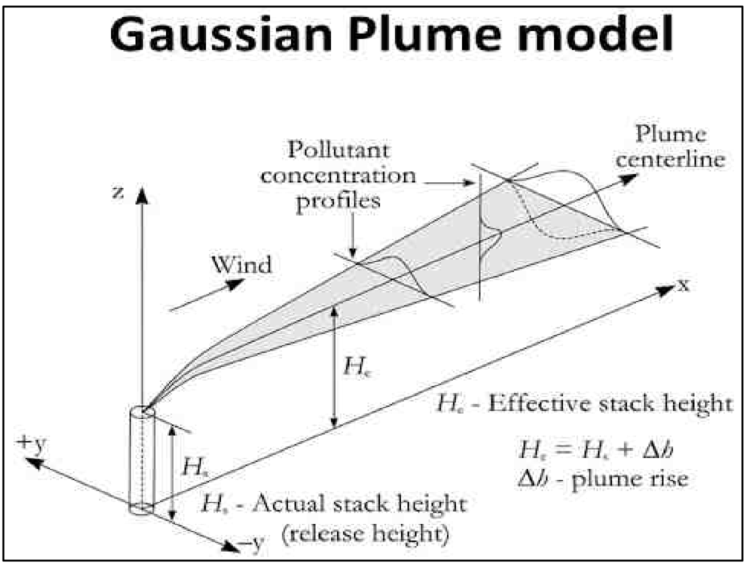


Fig. 1. Schematic figure of a Gaussian plume model [13]

Equation (5) describes a mixing process that results in a Gaussian concentration distribution both in crosswind and in vertical directions, centred at the line downwind from the source Figure 1. The last term of Eq. (5) expresses a total reflection from the ground. Gaussian models have an extremely fast response time, because they only calculate a single formula or Figure 1. Schematic figure of a Gaussian plume model. The effective stack height He and the crosswind and vertical deviation of the profile are the key parameters of the model [13].

Determination of the chimney height with respect to the fulfillment of the limit values

To calculate where the chimney outlet is negligible by its dimensions compared to calculated distances, it is necessary to know the following data: source location x_Z, y_Z [m], altitude z_Z [m], the height of the outlet above the ground *H* [m], for new sources this height can be calculated, annual operating time of the technology P_r [hour·year^{-1}], volumetric flue gas flow V_S [N·m^3 ·s^{-1}] from the outlet, converted to normal conditions, i.e. temperature 0 °C and pressure 101325 kPa according to the relation:

$$V_S = V \cdot \frac{273.15}{273.15 + t_S} \cdot \frac{p}{101325} \tag{6}$$

where t_s - exhaust air temperature [°C], p - air pressure [Pa], V - flue gas volume flow under actual conditions [m^3 · s^{-1}]:

$$Q = 10^{-3} \cdot V_S \cdot c_s \cdot (t_S - t_0) \tag{7}$$

where V_s flue gas volume flow under normal conditions [Nm^{-3}· s^{-1}], c_s - specific heat of exhalation of value 1.371 kJ · m^{-3}· K^{-1}, t_S - exhaust gas temperature [°C], t_0 - ambient temperature, we assume a temperature of 0 °C.

Another Gaussian model is "Gaussian PUFF Model". This model uses a cloud of pollutants, while it is possible to take more account of the influence of the surroundings (terrain, wind change, etc.) [13].

The basic equation for the contribution of a puff at a receptor is:

$$C = \frac{Q}{2\pi\sigma_y\sigma_z} g \exp\left(-\frac{d_a^2}{2\sigma_x^2}\right) \exp\left(-\frac{d_c^2}{2\sigma_y^2}\right) \tag{8}$$

where C - ground-level concentration [g · m^{-3}]; Q - pollutant mass in the puff [g]; $\sigma_x, \sigma_y, \sigma_z$ - standard deviation of the Gaussian distribution; d_a, d_c - distance from the puff center to the receptor in the along-wind and the cross-wind direction [m]; g - vertical term of the Gaussian equation:

$$g = \frac{2}{(2\pi)^{\frac{1}{2}}\sigma_z} \sum_{n=-\infty}^{\infty} \exp\left[-\frac{(H + 2nh)^2}{2\sigma_z^2}\right] \tag{9}$$

where H - effective height [m] above the ground of the puff centre and h is the mixed-layer height [m]. For a horizontally symmetric puff, with $\sigma_x = \sigma_y$, is reduced to:

$$C(s) = \frac{Q(s)}{2\pi\sigma_y^2(s)} g(s) \exp\left[-\frac{d^2(s)}{2\sigma_y^2(s)}\right] \tag{10}$$

where $d(s)$ [m] is the distance from the centre of the puff to the receptor, and s is the distance [m] travelled by the puff. By integrating of the equation, we get the average concentration *C*:

$$\bar{C} = \frac{1}{ds} \int_{s_0}^{s_0+ds} \frac{Q(s)}{2\pi\sigma_y^2(s)} g(s) \exp\left[-\frac{d^2(s)}{2\sigma_y^2(s)}\right] ds \tag{11}$$

where s_0 - value of s at the beginning of the sampling step.

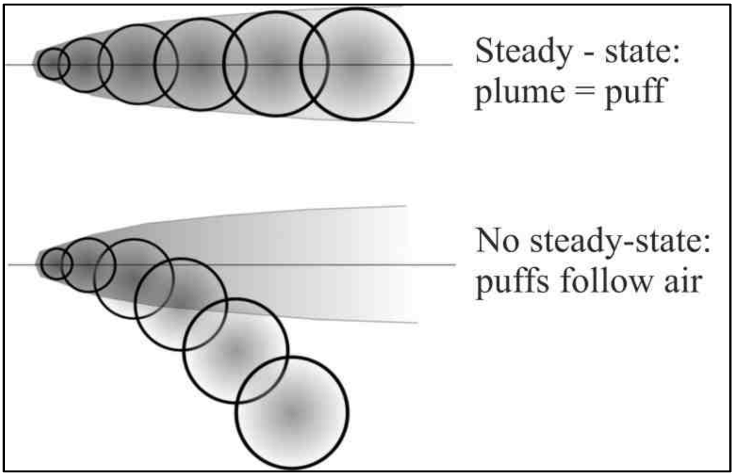


Fig. 2. Schematic representation of the basic difference between Gaussian plume and Gaussian puff models [14]

On the Figure 2 is showing the basic difference between schematic representation of Gaussian plume and puff models. Puff models still estimate a Gaussian dispersion, but are able to take into account temporal and spatial wind changes.

Puff models treat the pollution as a superposition of several clouds, "puffs" with a given volume, and calculate the trajectories of these puffs. Puff models separate the model physics by scale: the sub-puff scale processes are treated with Gaussian approach Eq. (8), while above the puff size are calculated Eq. (11).

In PLUME modelling a continuous plume is calculated and a steady state is assumed between the source and the calculation location. In PUFF modelling inflating puffs are calculated and the effect of a significant change in terrain and wind can be taken into account when moving them. For small distances (approx. up to 20 km) the results of both models coincide, at longer distances they begin to differ.

Eulerian model algorithm

Eulerian models solve a conservation of mass equation for a given pollutant [15]. The equation generally follows the form:

$$\frac{\partial\langle c_i\rangle}{\partial t} = -\overline{U}\cdot\nabla\langle c_i\rangle - \nabla\cdot\langle c_i'U'\rangle + D\nabla^2\langle c_i\rangle + \langle S_i\rangle \tag{12}$$

$$U = \overline{U} + U' \tag{13}$$

$$c = \langle c\rangle + c' \tag{14}$$

where U - wind field vector $U(x, y, z)$; $\overline{U}$ - average wind field vector; U' - fluctuating wind field vector; c - pollutant concentration [g·m^{-3}]; $\langle c\rangle$ - average pollutant concentration; c' - fluctuating pollutant concentration; D - molecular diffusivity [m^{2}s^{-1}]; S_i - source term [g · s^{-1} · m^{-3}].

Lagrangian model algorithm

Lagrangian models predict pollutant dispersion based on a shifting reference grid [13]. This shifting reference grid is generally based on the prevailing wind direction, or vector, or the general direction of the dust plume movement. The Lagrangian model has the following form:

$$\langle c(r,t)\rangle = \int_{-\infty}^{t} \int p(r.t|r',t')\, S(r',t')dr'dt' \tag{15}$$

where $\langle c(r,t)\rangle$ - average pollutant concentration at location r at time t [g · m^{-3}]; $S(r',t')$ - source emission term; $p(r.t|r',t')$ - the probability function that an air parcel is moving from location r' at time t' (source) to location r at time *t*.

These four mathematics models are the basic approaches used for air dispersion modelling. There are many variations based upon these equations. Some variations add statistical functions to represent the randomness of wind direction, wind speed, and turbulence; others include the introduction of site-specific source terms. Because of the increased computational power available via personal computers, the models have become more complex and varied. This has resulted in the creation of a vast number of computer models for air emissions dispersion [16].

Combined special model of microparticles emissions dispersion of volcanic ashes

An example of a combined Gaussian plume and puff models with Lagrangian model is VOL CALPUFF model, quantitative tool for simulating atmospheric dispersal and deposition of volcanic ashes. Is using to simulate a cloud on Mount Etna (Italy). Model predictions are compared to independent observations over a long period of time. Figure 3 shows an example of a combined Gaussian plume and puff models with Lagrangian model VOL-CALPUFF for simulating atmospheric dispersal and deposition of volcanic ashes [17].

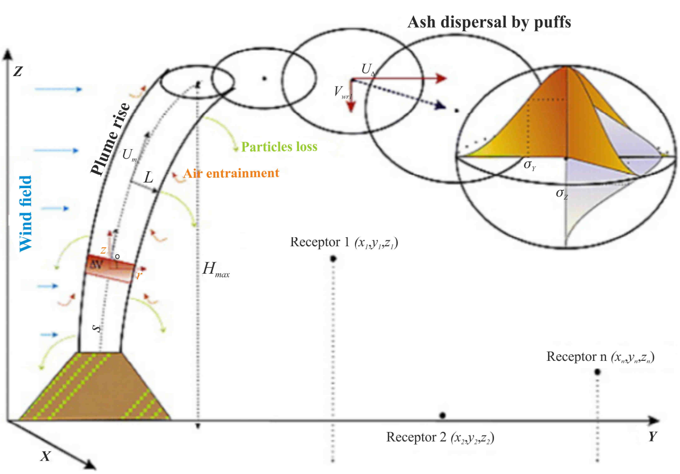


Fig. 3. An example of a combined Gaussian plume and puff models with Lagrangian model is VOL-CALPUFF for simulating atmospheric dispersal and deposition of volcanic ashes [17]

Innovative materials for cross-border CZ-PL higher education II

Simplified dispersion modelling of microparticle emissions using of SYMOS TPST package

In order to determine the amount of the contribution of the monitored source to the immissions in the given area, calculations of the dispersion of smoke sidings of these large emission sources are performed on a regular basis. This is a statutory activity in all EU countries. In the Czech Republic, mandatory calculations of air pollution from point and mobile sources, "Stationary source modelling system" have been introduced for large sources of emissions. Program of the Czech Hydrometeorological Institute [18], managed by experts from Idea-Envi (CZ) is Gaussian plume dispersion model, which is recommended nationwide by the Ministry of the Environment aimed at range (< 100 km). The methodology is designed to develop dispersion studies for air quality assessment [19]. We have simplified and shortened the modelling methodology in cooperation with experts from Idea-Envi (CZ) and Czech Hydrometeorological Institute. The educational package SYMOS TPST (SYMOS-Tutorial with PC Templates) enable:

- calculation of air pollution by gaseous substances and dust from point, line and area sources
- calculation of pollution from multiple sources

For each reference point, the methodology allows the calculation of the following basic air pollution characteristics:

- maximum possible short-term (hourly) values of air pollutant concentrations
- annual average air pollution concentrations
- duration of immission concentrations exceeding certain pre-set values (e.g. immission limits)

According to the methodology, the following characteristics can be additional characteristics:

- determine the height of the chimney with respect to the fulfilment of the limit values
- determine the share of air pollution sources in total pollution within 100 km of sources
- calculate the fallout of dust

Since it is a mathematical model that requires a simplification for the calculation and thus the impossibility to accurately describe all processes in the atmosphere that affect the dispersion of pollutants, the results of the calculation are not entirely accurate. The input climatic data use the average values for the previous period and the terrain profile is calculated according to the reference point heights. Simplified methodology with the use of PC templates is designed primarily for teaching and allows the development of indicative student’s dispersion studies.

Example of simplified modelling using of PC templates

PC templates of the Opatovice Power Plant, resource parameters: annual usage is 1-all year-round operation, daily use is 24 hours - continuous operation, height of the chimney is 160 m, volumetric flue gas flow is 240.07 $m^3 \cdot s^{-1}$, flue gas temperature is 70 °C, internal diameter of the chimney is 8 m, outlet flue gas velocity is 6 $m \cdot s^{-1}$

Modelling procedure

- Starting the program
- Entering the elevation
- To simplify entering the elevation, we will use the input elevation file from the attached directory
- Enter the wind rose
- A pre-set wind rose is used here, which is already inserted in the template itself
- Enter the quantity
- There are pre-set quantities. We can add, remove, modify.
- Entering the source
- The Opatovice Power Plant is present here. We can add, remove, modify and monitor the influence of individual values on the calculation.
- Enter a map

The map is used to facilitate entering sources and reference points, to display results.

The Opatovice Power Plant is pre-set here. To check the correctness of the settings, switch to the "Resources" tab, press the button and check the correct position of the source on the map.

- Entering reference points

After marking the area, we enter the core of reference points. The higher the point density, the finer the calculation, but the higher the time required for modelling.

- Calculation

Next, we enter the rotation of the wind rose relative to the coordinate system in which the sources and reference points are located. Let's start the calculation now. Figure 4 shows an example of simplified students modelling using PC template on a map base. It is emission dispersion modelling of PM10 [$\mu g \cdot m^{-3}$] from coal-fired power plant Opatovice.

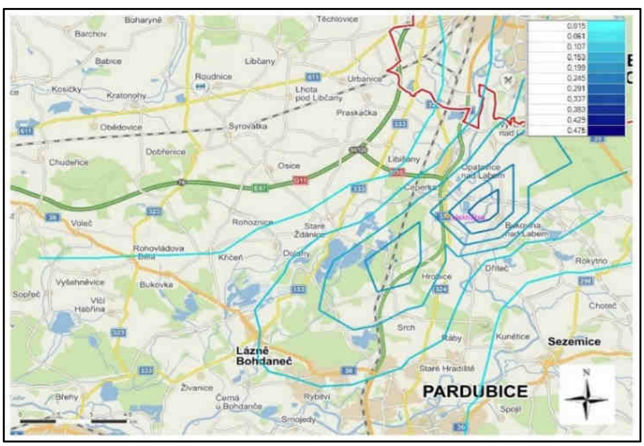
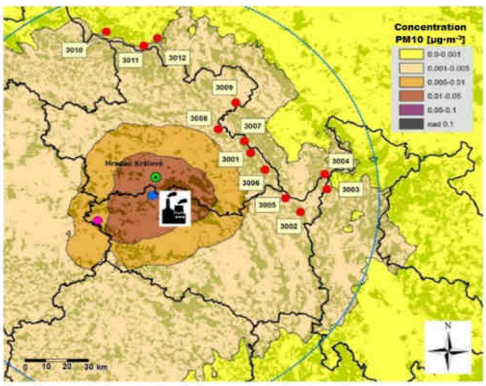


Fig. 4. Example of simplified students modelling using PC template on a map base. Emission dispersion modelling of PM10 [$\mu g \cdot m^{-3}$] from coal-fired power plant Opatovice

Example of using PC templates for practical calculations

One of the most important parameters influencing ground-level emission concentrations in the vicinity of a stationary source is the height of the exhaust above ground level. When modelling the emission dispersion, the so-called effective height of the source is entered into the calculation, which is equal to the sum of the construction height of the source and the cant of the smoke siding Figure 1, where the schematic figure of a Gaussian plume model is shown. The elevation of the smoke siding is given by the flue gas temperature, the ambient air temperature, the temperature stability of the atmosphere and the influence of the surrounding terrain. Atmospheric phenomena cannot be influenced by the operator, but by optimising the flue gas temperature and the construction height of the source, suitable concentrations meeting the hygienic standards valid in the given area can be achieved. When performing software modelling, students will test the effect of a change in the construction height of the source on the calculated concentrations in the ground reference points in the vicinity. Figure 5 and Table 1 show an example of PM10 emission dispersion modelling on a map base from coal-fired power plant Opatovice in PL-CZ reference points, work of a student during a monthly internship in Idea-Envi (CZ).



No ref. p.	Altitude [m]
3001	1015
3002	738
3003	968
3004	1049
3005	667
3006	898
3007	894
3008	569
3009	647
3010	787
3011	957
3012	545

Fig. 5. Modelling of PM10 emission dispersion using PC template on a map base from coal-fired power plant Opatovice in PL-CZ reference points, student’s internship in Idea-Envi (CZ)

On the template of the Opatovice Power Plant on mapping basis they will gradually change the height to 80 m, 120 m and 160 m. It is important that they always select the same colour scales and concentration values when displaying iso-lines. During the practical exercise, the students are given emission concentration values for a model stationary source of pollution. Their task is to design the height of the chimney of this source so that the concentration of emissions at the specified reference point does not exceed the legal limit. The next step is the calculation of the height of the chimney for the specified reduction in the amount of emissions (e.g. by introducing better microparticle separation technology, etc.) followed by a repeated model calculation with a comparison of previous values. For students on an internship at company Idea-Envi (CZ) are assigned to study publication [20], which was created on this topic in cooperation with this company. With an assessment of the impact of emission sources on air quality through using advanced CALPUFF atmospheric dispersion models [21], that can be done with or without taking into account the chemical conversion modules of pollutants. Students get to know the surrounding air during their month-long internships at ATMOTERM S.A. Opole (PL), are assigned to study publication [22] which was created on this topic in cooperation with this company and publication [23].

Table 1

Modelling of heavy metals emissions by SYMOS in CZ-PL reference point from coal-fired power plant Opatovice, student's internship in Idea-Envi

No. ref. point	**Coordinates**		**Average concentrations [ng·m^{-3}]**			
	X	**Y**	**As**	**Cd**	**Pb**	**Hg**
3001	3599450	5575558	0.0006	0.0020	0.0044	0.0016
3002	3621341	5547971	0.0005	0.0017	0.0032	0.0012
3003	3632865	5558659	0.0003	0.0011	0.0028	0.0010
3004	3631929	5565712	0.0004	0.0010	0.0024	0.0007
3005	3614726	5554413	0.0006	0.0022	0.0044	0.0018
3006	3605736	5567770	0.0007	0.0021	0.0049	0.0017
3007	3596806	5581056	0.0005	0.0021	0.0046	0.0016
3008	3585250	5586594	0.0008	0.0025	0.0059	0.0019
3009	3592989	5598946	0.0006	0.0019	0.0038	0.0011
3010	3536377	5632112	0.0002	0.0004	0.0007	0.0004
3011	3552770	5625670	0.0002	0.0006	0.0011	0.0006
3012	3558729	5629131	0.0001	0.0007	0.0010	0.0006

Discussion

Recently, even in environmental technical fields, the number of graduates who do not work in the field they studied is still growing, despite the fact that the demand for these workers is growing. That is why the EU is increasingly supporting the linking of higher education with practice. In our four-year cross-border CZ-PL project supported by the EU, implemented in 2017-2021, entitled "Cooperation between UO and UHK expanding the possibilities of applying graduates on the cross-border labour market", which deals with increasing students' motivation to study this demanding on physical environmental technical and technological focus, we designed in cooperation with teachers from two cross-border faculties and with experts from three important ecological companies of both regions, a comprehensive education system in part Mathematical modelling of emission dispersion. A total of one hundred students (60 PL and 40 CZ) in bachelor's, master's and doctoral study programs were included in the four-year EU-supported project. All these students participated in four-day cross-border motivational exchange internships in CZ and PL professional companies, 20 CZ of the planned students in the project could not participate due to the Covid pandemic. Fifteen master's students (9 PL and 6 CZ) took part in a monthly exchange motivational internship in Czech and Polish professional companies. All these students received training in emissions dispersion modelling in cooperation with the Czech company Idea-Envi and EMPLA AG (*Gaussian dispersion plum model SYMOS*) and with the Polish company ATMOTERM S.A. Opole (*Gaussian dispersion puff and Lagrange model scattering CALPUFF*). In cooperation with the companies Idea-Envi and EMPLA AG, one bachelor's thesis was created (which was not completed due to the Covid pandemic), one diploma and rigorous thesis and one doctoral dissertation were defended. One doctoral dissertation is nearing completion. In the form of semi-structured interviews, we found that an important motivation for students to choose this very demanding focus is a comprehensive innovation of teaching with an emphasis on understanding the mathematical basis of models and teaching modelling using PC templates. Students also evaluate very positively the possibilities of consulting experts from practice in the processing of their final theses. We will present more detailed results of our four-year research at the end of the second part of this article.

Conclusion

Last time, there is an increasing number of university-level educated specialists in environmental technical branches, who are not active in this field, regardless of the fact that a demand on them has systematically been increasing. Therefore, an interconnection of university education with technical praxis is strongly supported from EU authorities. Regular mathematical modelling of the dispersion of emissions from large sources is required by law in all EU countries, however, there is a shortage of experts in this very specific and demanding profession in the labour market in most countries. From 2020, the United States Environmental Protection Agency (US EPA) recommends for emission dispersion modelling from big sources using the AERMOD modelling system [24]. It is EPA's preferred and recommended Gaussian dispersion model for simulating the concentration of gases and particles at air receptors from surface and elevated stationary sources, which we also have installed on the classroom PC. However, it is a very educationally demanding complex of professional modelling packets which are for beginner students unable to master without thorough prior training in emission dispersion modelling. During the four-year course as part of the PL-CZ project, we verified that the educational package of Gaussian dispersion model SYMOS TPST (*Symos-Tutorial with PC Templates*), which was developed by experts from the Czech Hydrometeorological Institute and Idea-Envi in cooperation with teachers of both faculties simplifies and speeds up this demanding teaching. PC templates processed as model situations of specific large emission sources in the region on map bases are an important motivational factor for students. In this first part of the article, we focused only on examples of the modernisation of the complex system of measures, which should increase the interest of graduates of both universities in the future to focus on Measuring and modelling the dispersion of emissions from large sources. For a students are the crucial result of the study is the remarkable increase in graduates position in employment market, providing a good chance of finding a well-paid job. In this area, teachers from WPT UO and PřF UHK have been working together as part of projects supported by the EU since 2012, we reported on this in 2015 in the CDEM for the first time [25]. Our goal is to educate students in cooperation with professional companies so that they are not afraid to accept this job and are well prepared for further education in this demanding field.

Acknowledgements

The presented research was financially subsidised by the EU-supported cross-border project INTERREG VA (2017-2021), CZ.11.3.119/0.0/0.0/16_022/0001150 „Współpraca UO i UHK zwiększająca możliwości absolwentów na transgranicznym rynku pracy". Our thanks go to the chief PL-CZ project manager Dr. hab. A. Dołhańczuk-Śródka, prof UO, for the leadership and editing of innovative teaching materials. Our thanks also go to the experts from professional companies Ing. R. Srněnský, S. Eminger, Ing. R. Hyšpler, CSc., Ing. I. Šrámek, Mgr. W. Wahlich and B. Śmiechowicz for the innovative lectures, teaching materials and organising of the exchange PL-CZ study trips and monthly student internships. Mrs. prof dr hab. inż. M. Wacławek we thank for Your help with completing of this publication.

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Contacts on professional companies

IDEA-ENVI Valašské Meziříčí (CZ) - https://www.idea-envi.cz/index-en.html
ATMOTERM SA w Opolu (PL) - https://www.atmoterm.pl/
EMPLA AG Hradec Králové - https://empla.cz/