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DOI: 10.1515/cdem-2017-0008 CHEM DIDACT ECOL METROL. 2017;22(1-2):135-150

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INNOVATIVE EDUCATIONAL COURSE II: MODELLING OF ODOUR DISPERSION FROM AGRICULTURAL BIOGAS PLANTS

INNOWACYJNY KURS EDUKACYJNY II: MODELOWANIE DYSPERSJI ODORANTÓW Z BIOGAZOWNI ROLNICZYCH

Abstract: In recent years, the European Union is putting a growing emphasis on constructing agricultural biogas plants, especially in the Czech-Polish border region. In this region, there are large areas of agricultural land which can provide biomass as a substrate used in biogas plants. Biogas plants connected to cogeneration units are a useful renewable source of thermal and electrical energy, but they can cause also some problems. Probably the most serious issue is that inadequately technologically operated biogas plants are the source of unpleasant odour which may affect the surrounding population. Therefore, we prepared a continuation of our educational course focused on biogas plants intended for a study program "Physico-technical Measurements and Computer Technology" at the Faculty of Science at the University of Hradec Kralove and for the education of internshipers from the Faculty of Natural Sciences and Technology at the University of Opole. In this part of the course, the students will learn about the problems with odour released from inadequately technologically operated biogas plants and about the ways how to measure and model the odour contamination in the vicinity of the odour source. An important part of this educational course is a practical exercise on the mathematical modelling of odour contamination from an inadequately technologically operated agricultural biogas plant. Thus, the students will be able to perform the odour modelling using the SYMOS'97 methodology which is approved and used as an official tool for air pollution modelling in the Czech Republic. Students will learn that a biogas plant which is well-operated and correctly located in relation to local hydrometeorological conditions does not annoy local residents by odour.

Keywords: agricultural biogas plants, odours, modelling of odour dispersion

Introduction

Agricultural biogas plants represent a promising, environmentally friendly way of using biomass from waste and energy crops. Besides the production of biogas itself, a biogas station can serve also as a useful alternative source of electricity and heat when a cogeneration unit is associated with it. In recent years, the European Union promotes the construction of new agricultural biogas stations on its territory. This trend occurs also in the Czech-Polish border region, which will create new work positions here. Therefore, an increasing demand for skilled workers in this field can be expected. For this reason, the

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University of Hradec Kralove in cooperation with the University of Opole focuses also on improving the teaching of various aspects of biogas stations.

In our previous article [1], we proposed an innovative approach to teaching physico-technical subjects which consists of theoretical lectures, excursions and practical exercises in a computer classroom. By this approach, the students gain good knowledge about biogas stations. The course described in this paper builds on this knowledge and extends it. Instead of anaerobic fermentation and biogas production processes discussed in [1], now we focus on a significant problem associated with the operation of biogas stations, which is the odour caused by various gaseous products of biochemical processes, for example hydrogen sulphide or ammonia. The odour intensity is affected by the kind of input substrate and it also depends on the technical design of the biogas plant [2]. Due to the production of odours it is needed to place biogas stations at suitable locations with respect to the surrounding settlements and prevailing wind directions at the site considered.

In our course we deal above all with measuring and modelling of odours dispersion, which allows to assess the impact of odours on neighbouring inhabitants. We compare the advantages and limitations of mathematical modelling of odours, subjective odour assessment and automatic instrumental odour measurement. In this way, we show the students that each problem has several different solutions and it is always necessary to choose the right approach for the given situation. When teaching instrumental odours measuring, we demonstrate the interconnection of various natural and technical disciplines on which this modern measurement method is based: physics, chemistry, electronics, informatics, mathematics etc. Thanks to this, the students see that nowadays it is not possible to professionally restrict themselves to a single narrow discipline, but it is necessary to have a professional overlap into related fields, continuously learn new things and collaborate with experts from neighbouring disciplines.

Theoretical background

Odour is a subjective sensory response of a person to inhalation of air which contains a specific chemical or a mixture of chemicals. Both intensity and type of odour are important to evaluate this response. Odour primarily causes annoyance, however in more serious cases direct health problems such as nausea, headache or breathing difficulties may also occur. Longer exposure to odours causes psychological problems such as feeling cramped, irritability, loss of appetite and insomnia. To quantify odour, the European Odour Unit (EOU) is used. EOU is the amount of odorous substances which after evaporating into 1 m^3 of neutral gas under standard conditions (temperature 298.15 K, pressure 101.325 kPa) induces in the members of the assessment team the same sensory perception as the European Reference Odour Mass (EROM), i.e. 123 μg of n-butanol, dispersed in a volume of 1 m^3 neutral gas under normal conditions [3].

The nature and general characteristics of odorants

Odorants are mixtures of volatile compounds which can be detected by humans or animals by their olfactory organs. Odour can be smelt when odorant is dispersed in the air at a sufficient concentration and its molecules get to the olfactory system. Some odorants are composed of a single chemical compound, other may contain a few compounds of which only one is the dominant odorous component. Odorants from organic sources are very often composed of hundreds of different chemical components, all of which can contribute to the resulting odour. Even a tiny change in relative amounts of chemical substances in such an odorant can be recognized by a human nose as a change in perceived odour [4].

The volatility of molecules, which is needed for their transport to the olfactory organ, depends on the type of chemical bonds between them: non-polar molecules are more volatile in comparison with polar molecules. Most aromatic molecules have maximally one or two polar functional groups, because molecules with more these groups are generally not volatile. Odorant molecules are characterized also by specific structures (e.g. heterocyclic rings) which contribute to the molecule shape and are responsible for a particular olfactory sensation. Molecular masses of odorous compounds are usually relatively low (between 30 and 300 $g \cdot mol^{-1}$) [4].

Perception and evaluation of odours

The relative degree of odour perception by a person is described by a psychological quantity called odour intensity. To these degrees, a verbal description and a numeric value can be assigned. The relationship between odour intensity and odorant concentration is expressed by the Stevens's law [5]:

$$I = k \cdot (C - C_0)^n \quad (1)$$

where I is odour intensity, k and n are constants depending on the odour type, C is the current odour concentration and C_0 is a concentration corresponding to odour detection threshold. For odorous substances from agricultural sources [6], the following relationship was experimentally verified:

$$I = 1.068 \cdot (C)^{0.464} \quad (2)$$

The effects of odorous substances from different sources can interact with each other, for example one substance masks the other or vice versa enhances its effect. Odorous substances can also be transformed in the atmosphere due to changes in temperature, air humidity and sunlight in a manner which is not yet described satisfactorily.

When using dispersion models, the shortest time interval for which the average concentration is predicted is usually 1 hour. During this period, the concentration of odorous substances may fluctuate around this average value in a wide range. On the other hand, human sensual response to odour is very fast, usually in the order of milliseconds, longest in the order of one breath. Odour can be felt already when the average concentration of odorous substance reaches $0.1\ EOU \cdot m^{-3}$ [5].

Properties of an odorous substance can be described also by its hedonic tone which expresses whether the odour is perceived as pleasant or unpleasant [7]. Usually, a range of hedonic tones is used to express the degree of pleasantness, respectively unpleasantness of the substance. For example, we can use a scale in which number +4 is assigned to the most pleasant odour and number –4 to the most unpleasant odour; the higher the number is assigned, the more pleasant the odour is. When the odour is perceived as neutral, number 0 is assigned. The degree of hedonic tone can decrease when the intensity of perception increases, which means that even a pleasant odorant can become annoying. Repulsive odours (with a low hedonic tone) such as faecal or decomposition odours are generally considered unpleasant; these kinds of odours are typical for biogas stations. On the contrary, the evaluation of hedonic tone of more pleasant substances is a considerably subjective matter, i.e. smell from a bakery or pastry shop can be by someone considered as pleasant, but by someone else as annoying.

Odours can be characterized also verbally by using descriptors such as floral, moldy, earthy, fish etc. Such terms describe more the character of odour than its hedonic tone and they facilitate determining the origin of the smell.

Sources of odours from biogas stations

In general, different types of substrates differ in their odour properties. Decomposition processes of typical substrates start quite fast and cause significant changes of the composition and character of the produced odour. These changes in odour are caused by aerobic as well as anaerobic processes and they are affected by various factors, such as pH whose value is changing during the biochemical processes [8].

Most biomass of plant origin which is not processed by ensiling is odourless when stored properly. Typical examples of these substrates are cereal straw, rape straw, bran, chaff and waste from grain cleaning, flax and hemp waste etc.

Silage, if it is fresh and stored properly, has only a weak smell of milk fermentation, but if bacteria of butyric acid fermentation grows in silage materials, a repulsive odour of lower volatile fatty acids arises. In this odour, the smell of butyric acid usually prevails. However, if a proper technological procedure is performed, fatty acids are completely degraded and the resulting digestion residues do not have their odour.

An important source of odour in biogas stations is manure from animal production. Raw manure from pig farms has significantly worse odour effects than beef manure, due to its higher content of rapidly degrading proteins caused by a relatively incomplete digestion of pigs. The intensity and composition of pig fattening is also important: high-energy pig fattening with high protein doses produces nitrogen-rich manure which smells strongly during its decomposition.

The main odour components of animal excrements are as follows:

- ammonia, aliphatic amines and alkylammonium compounds
- sulphane (H_2S) and ammonium hydrosulphide (NH_4SH)
- organic sulphides, disulphides and mercaptans
- fatty acids
- nitrogen heterocycles (indole derivatives)
- monovalent phenols

The hedonic tone of manure requires taking effective measures to reduce the odour leakage from storage.

When a biogas station is operated properly, the main threat of odour leakage to outdoor environment occurs during input substrates transport. In reality, odour emissions are caused also by leakage of odorous substances from receiving tanks or storage containers, mixing and homogenization tanks, insufficiently reacted solid digestion residues or insufficiently processed and non-recycled residual liquid (called fugate) [8].

Odorous substances contained in the produced biogas do not constitute a problem, because the biogas is stored in airtight containers and subsequently used for various purposes such as for electricity production, in cogeneration units or as a motor fuel [9]; in these combustion processes the smell vanishes.

Modelling dispersion of odorous substances

Since 1998 a methodical guidance “Methodical directions of the department of air protection of the Ministry of the Environment for the calculation of air pollution from point and mobile sources SYMOS’97” has been established in the Czech Republic [10]. The meaning of the “SYMOS” abbreviation is “System for Modelling of Stationary Sources”. According to this methodology, a simulation software called SYMOS’97, which is used for mathematical modelling of pollutants dispersion in the air, was created. The basis of the SYMOS’97 methodology is given by the Gaussian model of pollutants dispersion in the air [11]:

$$\bar{c}\,(x,y,z) = \frac{Q}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(z-h)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+h)^2}{2\sigma_z^2}\right)\right] \tag{3}$$

where $\bar{c}$ stands for averaged concentration of pollutant in the position [x, y, z], Q is the mass flow rate of pollutants emitted from a continuous source [$\mathrm{mg \cdot s^{-1}}$], $\bar{u}$ is averaged velocity of flow along the x axis [$\mathrm{m \cdot s^{-1}}$], σ_y and σ_z are transverse scattering parameters, y has the meaning of perpendicular distance of the point at which the concentration is calculated (so called “reference point“) from the plume axis, z is a difference in height between the reference point location and the effective height of emission source, h is the effective height of the source (the physical source height added to the thermal plume rise) and x is the length of the plume axis.

Gaussian models represent one of the most widespread types of mathematical models of transport and dispersion of emissions in the atmosphere. The introduced basic form of the Gaussian model is in practice modified by a number of corrections which extend the possibilities of using this model. For us it is now important that a modified version of SYMOS’97 software can be used also for odour modelling.

When modelling transmission and dispersion of odorous substances, further difficulties and uncertainties are added to usual uncertainties connected with applying dispersion models. These complications result from the above mentioned specifics in odour perception and quantification [5, 6]:

- Difficult and subjective quantification of odour and complicated structure of odour sources cause bigger errors in determination of odorous substances compared to common pollutants.
- The effect of odorous substances is usually not cumulative, odorous substances from one source can completely mask substances from another source. Therefore, it is not possible to simply add the contributions of concentrations from various sources and it is recommended to model odorant dispersion only from one source.
- Odorous substances can be transformed in the atmosphere due to temperature changes, air humidity and solar radiation in a way that has not been satisfactorily described yet.
- Models, including SYMOS’97, usually calculate hourly concentrations, while the perception interval of odorous substances is commonly in the order of milliseconds, longest in the order of one breath. Perception intensity is determined by the peak values of concentration, so conclusions based on an average concentration would lead to underestimation of odour effects. Hence an option for calculating instantaneous concentrations must be available in the odour modelling tool, or a peak-to-mean ratio (P/M ratio) approach must be used.

The model calculations allow to indicate directions of odour plumes propagation, which makes it possible to identify places where the greatest odour degree is to be expected. The models can be also used to compare the proportions of individual sources on total odour infestation, estimate the consequences of a potential source failure or evaluate the effect of measures proposed for the source. If the needed meteorological data are available, it is further possible to determine the probable frequency of exceeding limit values on specified locations, which is useful for establishing zones for protection against odour.

The adaptation of SYMOS'97 for modelling of odours is relatively simple, so most input data management as well as calculation procedures can be done in the same way as in the basic version of SYMOS'97. The process of odour dispersion modelling can be divided into the following steps:

1. Input meteorological data and source parameters are inserted to the SYMOS'97 software.
2. Maximum possible hourly concentrations are calculated for each reference point in a defined grid.
3. These concentrations are recalculated into peak values using appropriate P/M ratio coefficients. Values of these coefficients depend on the source type, atmospheric stability class and the distance from the reference point to the emission source.
4. It is also possible to calculate the duration of exceeding a specified concentration for each reference point (expressed in hours per year).

In study [6], the outputs from the modified model SYMOS'97 were compared with experimental data and it was found that the modelling results are reasonable and usable in practice. In general, Gaussian models, including SYMOS'97, provide good results especially for flat terrain. Because areas of our interest in the Czech-Polish border region are mostly flat, using the modified model SYMOS'97 is considered to be appropriate for odour modelling in this region [12]. The SYMOS'97 software is, thanks to its clarity and ease of use, suitable also for educational purposes.

Measurement of odorous substances

It is possible to perform odour measurements either subjectively (by olfactory perception of panellists, i.e. a panel of persons with extremely developed sense of smell), or objectively using a device called electronic nose. Recently, also statistics of people's complaints about odours are used to collect useful data about odours in the area of interest and even to identify the source of odour [13].

Dynamic olfactometry

The most widespread procedure for measuring odorous substances is a dynamic olfactometry, which is a subjective method. During an olfactometric measurement, a sample containing an odorous substance is gradually diluted with clean air until half of panellists are not able to distinguish the diluted sample from air without any odorous substance.

These measurements, however, cannot provide direct information about the likely effects of odour - whether it will be considered pleasant or annoying, as well as about its perceived intensity. Another potential issue is olfactory adaptation [14] of panellists to odour during the measurement: when a panellist stays for a long time in an environment with intense smell, his or her olfactory organ adapts to the odour and the intensity of this sensory perception is weaker compared to the first contact with this odorous substance. This must be considered when organizing olfactometric measurements.

This method also takes into account the odour mixture as a whole, so it is not able to distinguish individual chemical compounds [15]. It was also found that odour assessment results can be affected by psychological aspects of panellists too, because in some cases the panellists tend to guess the correct result instead of impartial assessment [16].

Odour field inspections

Odours present in outdoor areas of interest can be subjectively determined by field inspections [17] perceived by trained panellists. For this purpose, so called "grid method" and "plum method" are used. In the grid method, the panellists are located at nodes of a specified grid (Fig. 1). The aim is to characterize the odour exposure level in the area of interest, which provides information about the impact of this odour on resident population. Each panellist has to distinguish odorous and non-odorous time periods at his or her place. The measurements must be performed under representative meteorological conditions, which are typical for this area. The whole measurement process should last at least six months and within this period, minimally 13 measurements should be done at each point. The measured values are subsequently statistically evaluated and as a result, a map of odour exposure in the area of interest is obtained.

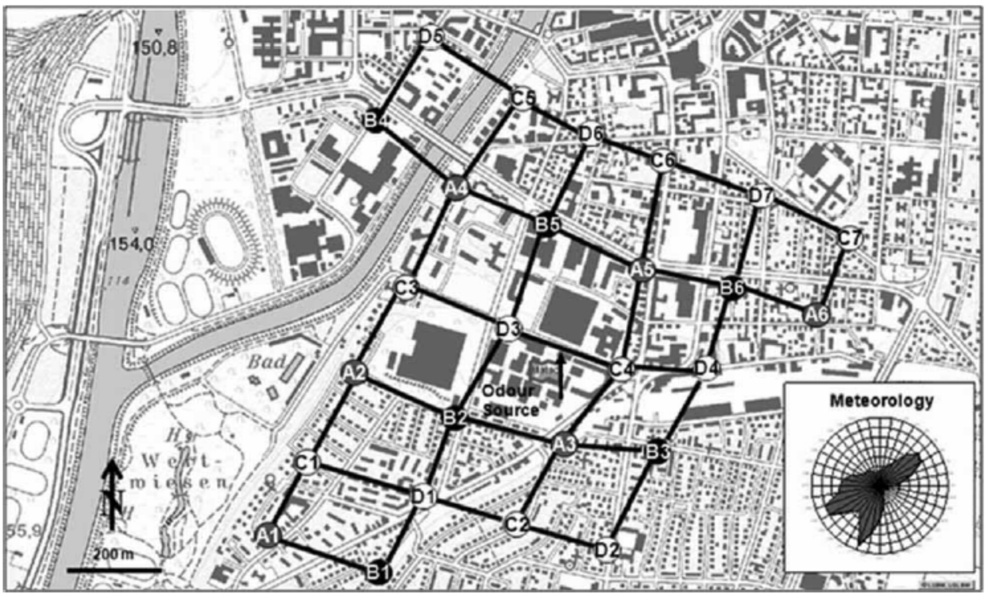

Fig. 1. Measuring grid used for the field inspection of odour [17]

The plum method [18] is, compared to the grid method, a short-term experiment. It consists of several repeated measurements which last approximately half a day. Within the plume method, a specific source of odour has to be chosen first. Then the panellists are located to defined places predominantly in the direction of odour plume from this source. The task of each panellist is to determine whether he or she perceives the odour at his place, or not. A recommended procedure for determining the presence of smell is the following: Every 10 seconds, each panellist has to write on a special form whether he or she perceived odour or not. This is done 60 times, so the whole estimation takes 10 minutes. The aim of the measurement is to determine the extent of recognizable odour from this source - the boundary of the area affected by the odour is laid to the transition from absence to presence of recognizable odour.

Usually, the points at which the panellists are staying are located according one of the schemes given in Figure 2. It is needed to point out that reaching these formations can be problematic or even impossible in a difficult terrain. If this situation happens, other approach has to be used, e.g. the panellists can walk from far away from the source towards the source and stop when they think they smell the odour. At this point they stay for a while and estimate the odour according a recommended procedure. This can help to find approximate location of the odour boundary.

Also this type of field inspection must be done under specified meteorological conditions, because the spreading of odour from a source depends on current dispersion properties of the atmosphere. More details about the odour field inspection methods can be found in [17].

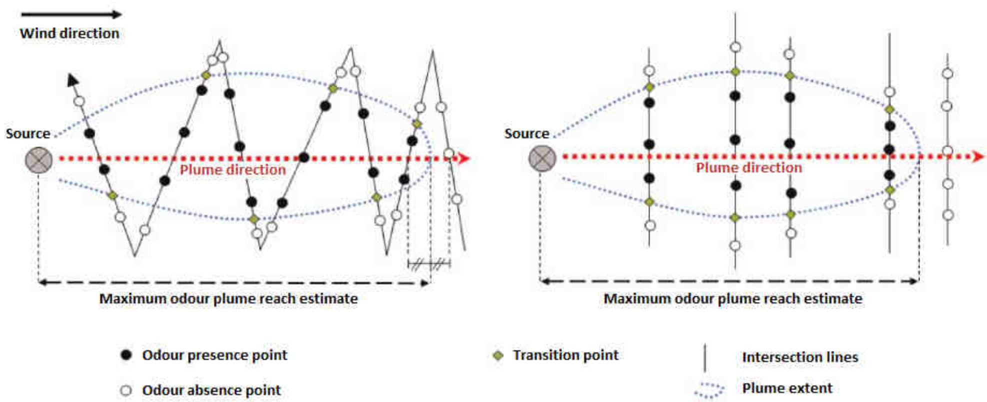

Fig. 2. Two main types of panellists' location during plume field inspection (adjusted according [18]). Panellists are located at white and black points: those at black points will perceive the odour, while those at white points not

Statistics of complaints

Another way of obtaining information about odours in some territory is collecting data from statistics of people's complaints [13, 19]. The public can react to an increased level of unpleasant odour by filing complaints to a local authority or a company which produces the odour. The complaints often serve as important means of informing authorities about the problem with obtrusive smells. However, data collected from the complaints is not a reliable indicator of the extent and severity of odorous effects. Different people differ in their efforts to file complaints. A large part of population never officially complains, many people file claims only when the odour annoyance level is very significant. The absence of complaints therefore does not mean automatically that there is no problem with odour. On the other hand, some people file complaints also in minor cases. The will to file complaints is also determined by social factors, for example by behaviour of local authorities and by belief that the complaint will be taken seriously and will have a positive effect. Complaints can serve as o good indicator of sudden and unpredictable event, such as an accident in a factory connected with leakage of odorous substances.

Electronic nose

The function of electronic nose is actually analogical to the function of human olfactory system which consists of two basic parts: olfactory receptor cells in the nasal mucosa and an olfactory centre in brain. In the human olfactory system, a molecule of a detected chemical substance firstly gets with inhaled air to the nasal mucosa and is captured on the olfactory receptor cells. Here the molecule must permeate through a receptor membrane which is mediated by membrane transport proteins. There are various types of these transporters and each of them is able to bind only certain kinds of molecules. The receptor sensitivity to a given chemical substance is determined by the presence of corresponding transporters on the receptor membrane. A molecule which penetrates into the receptor raises an electrical signal carrying an information about the stimulation type and level. This signal is conducted by nerve fibres to the olfactory centre in brain where it is evaluated. The evaluation is done in such a way that the received signal is compared to information stored in memory [15]. As a result, the human knows which odour he or she smells (or which of the known odours this sensed odour resembles the most) and whether this odour is pleasant or not. During exhalation the receptors are cleaned, so the olfactory system is ready to process further perceptions.

In the electronic nose, the molecules are at first supplied to sensors with partial selectivity (analogical to olfactory receptor cells). Then a signal is transmitted from the sensors to a signal processing module where it is compared to stored patterns and a corresponding pattern is sought. Finally, the sensors are cleaned from residues of the analysed substance to be ready for the following sensing.

The principle of a typical electronic nose is illustrated in Figure 3. In the beginning, the analysed air is blown on a sensor array. This component can contain also other types of sensors which monitor physical conditions of the measurement, for instance humidity and temperature [20]. The signals from sensors are digitalized using an analog-to-digital converter (ADC) and sent to a computer where they are analysed. The process of data acquisition, digitalization, signal preprocessing and sending the preprocessed data to the computer (eventually showing the results on a display) is controlled by an electronic circuit often supplemented with a microcontroller, as described e.g. in [21] and [22].

The measurement output can be the identification of unknown odorous substance, its concentration estimate, eventually other odour characteristics. The measurement usually takes only a few seconds or maximally minutes. Electronic noses provide objective and reproducible measurement results whose sensitivity is in many cases comparable to the human olfactory system [23].

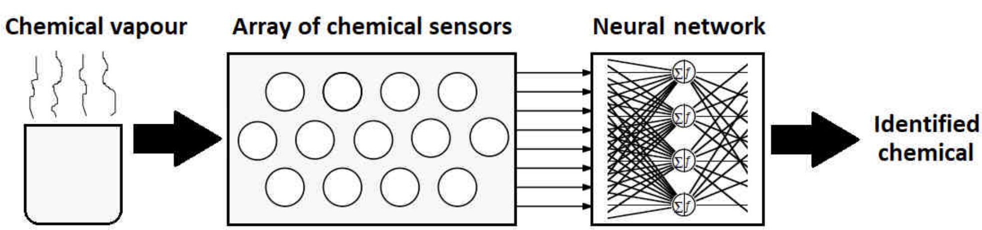

Fig. 3. General scheme of electronic nose principle (created according [24])

In electronic noses, the following types of sensors are often used [15, 20]:

- **Semiconductor sensors based on metal oxides:** molecules of analysed chemical substance triggers an oxidation-reduction chemical reaction in a thin oxide film which leads to the change of the sensor's electric conductivity.
- **Sensors with conductive polymers** work similarly to the above mentioned semiconductor sensors. They have better sensitivity, but they are also more affected by air humidity.
- **Piezoelectric sensors** use changes in piezoelectric crystal natural frequency which are caused by binding of a chemical substance on the crystal's surface. These frequency changes are subsequently evaluated by special electronics. Compared to other types of sensors, piezoelectric sensors have a good sensitivity, selectivity, stability, range of operating temperature, and also resistance to humidity, but they have a disadvantage of quite complex and expensive electronics.
- **Chemical field-effect transistors (ChemFET):** amplification of these transistors depends on the type of the chemical substance absorbed by the control electrode. These sensors can be easily integrated into electronic circuits, but their response time is low, because the analysed substance must first penetrate the electrode surface layer.
- **Sensors based on nanomaterials** use unique physical and chemical properties of nanostructures, for example a large surface area to volume ratio. This property causes that a large number of atoms is located on the sensor's surface, and because these atoms can easily interact with the incoming odorous substance, the interfacial reactivity is improved [25].

The signal generated by a sensor is most often processed by an artificial neural network (ANN). This software structure consists of a large number of interconnected elements (analogical to neurons) which work in common on analysing the signal. Interconnection of these elements is realized by bindings analogical to synapses in biological nervous systems. As well as people, also artificial neural networks first have to learn. During the learning process, many various chemical substances are supplied one by one to the sensor array. Each substance triggers a specific response in the sensor array and consecutively in the neural network, we talk about so called chemical fingerprint of the measured odour sample [15]. Finally, a correct name of this substance must be assigned to this fingerprint.

The learning process is again analogical to biological systems: in human brain, the activation of synapses occurs, while in artificial neural networks a certain weight (significance) is assigned to the connections between the elements.

It is worth mentioning that besides neural networks, also other methods for processing the measured signal exist, e.g. statistical evaluation or a combination of neural networks, fuzzy logic and a statistical approach [20].

In comparison with biological sensing of odour, the electronic nose has considerable advantages: it is not getting tired and the results of analysis do not depend on a human emotion state. It is also possible to use it for comfortable remote controlled continuous field measurements [15]. Thanks to these properties, electronic noses are suitable for monitoring odour emissions from industrial sources, just like biogas stations are. Moreover, the ability of electronic nose to distinguish individual odorous substances helps to identify the emission source which causes odour at the measurement site [26]. An example of an electronic nose designed for field continuous environmental monitoring is given in Figure 4.

Fig. 4. Electronic nose EOS 507 used for terrain measurements [26]

Practical exercise: assessment of odour contamination from an agricultural biogas plant

In our previous article [1], we proposed an innovative approach to teaching physico-technical subjects which consists of theoretical lectures, excursions and practical exercises in a computer classroom. Excursions for cross-border teaching of Czech and Polish students from the University of Hradec Kralove and the University of Opole in the agricultural biogas plants Lhota pod Libcany were described in the publication [12].

Because we realize the importance of practical trainings for students to gain required professional skills, we created a practical training task consisting in the evaluation of odour contamination from a real emission source. In this exercise, the students are given data corresponding to a biogas plant located in an agricultural area in Lhota pod Libcany. The biogas plant consists of a fermenter with accessories (861 m^2), a storage tank (1,105 m^2), a technological sump (80 m^2), a silage trough (1,800 m^2), an operational building (1,073 m^2) with a gas container, a transformer station and a high voltage connection. Currently, also a stable for fattening bulls is operated in the agricultural area. The nearest residential buildings are located about 270 meters from the biogas plant. The biogas plant works on the principle of organic matter decomposition with the simultaneous production of biogas, which is subsequently used for electric and thermal energy production. The main source of the organic matter is corn silage (6,900 Mg/year), pressed sugar beet pulp (1,500 Mg/year) and cattle slurry (12,800 Mg/year). For production of electricity and heat, a cogeneration unit with the electric power of 536 kW and the thermal power of 531 kW is used.

In this exercise, the students have to determine the odour contamination in vicinity of this biogas plant according the SYMOS'97 methodology modified for odorous substances modelling. The process of solving this task is as follows:

Firstly, the students insert required input data into the software SYMOS'97. These data include the hypsography of the area of interest (including the layout of larger buildings nearby), a wind rose for this area (shown in Figure 5), parameters of the selected odorous substance, biogas plant parameters (source location and geometry, flue gas temperature and output speed etc.), reference points positions and a map of the area of interest for a graphical representation of the modelling results. The odorous substance emission rate is entered in units of $[OU\cdot s^{-1}]$.

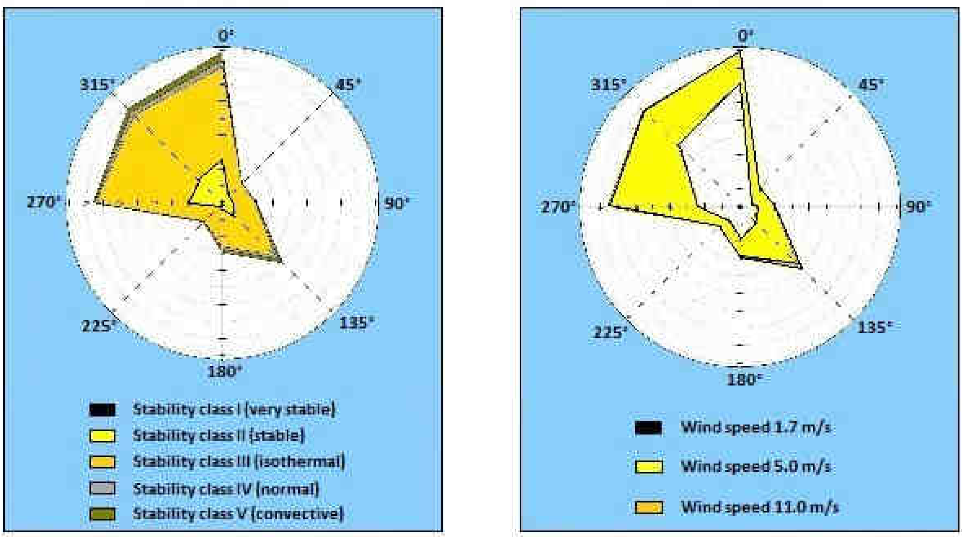

Fig. 5. Stability wind rose (left) and speed wind rose (right) for Lhota pod Libcany

Then a grid of reference points has to be set. In each of these reference points, values of maximal hourly concentrations of the odorous substance (in $[OU\cdot m^3]$) are calculated for eleven different modes of dispersion conditions. In addition, one value of the concentration absolute maximum is calculated in each reference point. The next step is to recalculate these values to the peak concentration values by using appropriate P/M ratio values. Determining the peak values is important because these values give a better information on the odour contamination compared to the hourly concentrations.

When the students complete all the previous steps, they can display the result graphically in the form of concentration isolines drawn on the map of the biogas plant and its surroundings. The result for the considered biogas plant is shown in Figure 6. Odour can be considered obtrusive when its concentration exceeds 5 $EOU \cdot m^{-3}$ during a long-term exposure [27]. In our case, this concentration is only inside the isoline no. 1, so it affects only a small part of the garden area. Therefore, we can see that, considering the neighbouring village, this biogas plant is located appropriately, because the highest odour contamination is in an uninhabited territory. Only some gardens next to family houses in the southern part of the village may be sometimes slightly impacted by the odour, but the residential houses are outside the endangered area. The main conclusion of this exercise is that this biogas plant does not have any obtrusive odour impact on average sensitive population in the adjacent residential area. In this map, also the impact of high buildings on odour dispersion can be demonstrated: the building in the agricultural area marked with a black rectangle significantly influences the shape of the area most affected by the odour (zones bounded by the red isolines).

In a discussion about this exercise, it is necessary to emphasize to the students that the used approach does not take into account a background contamination, i.e. contributions to odour caused by other potential odour sources nearby. If there were other sources of the same odour, the resulting odour level in this area would be higher, but the model results would not reflect it. Generally, we can say that in this exercise the students will learn how to do the odour dispersion modelling, but they will also be informed about the limitations of the dispersion models. They will remember that it is always a human, and not a model, who is responsible for the decisions resulting from the process of modelling.

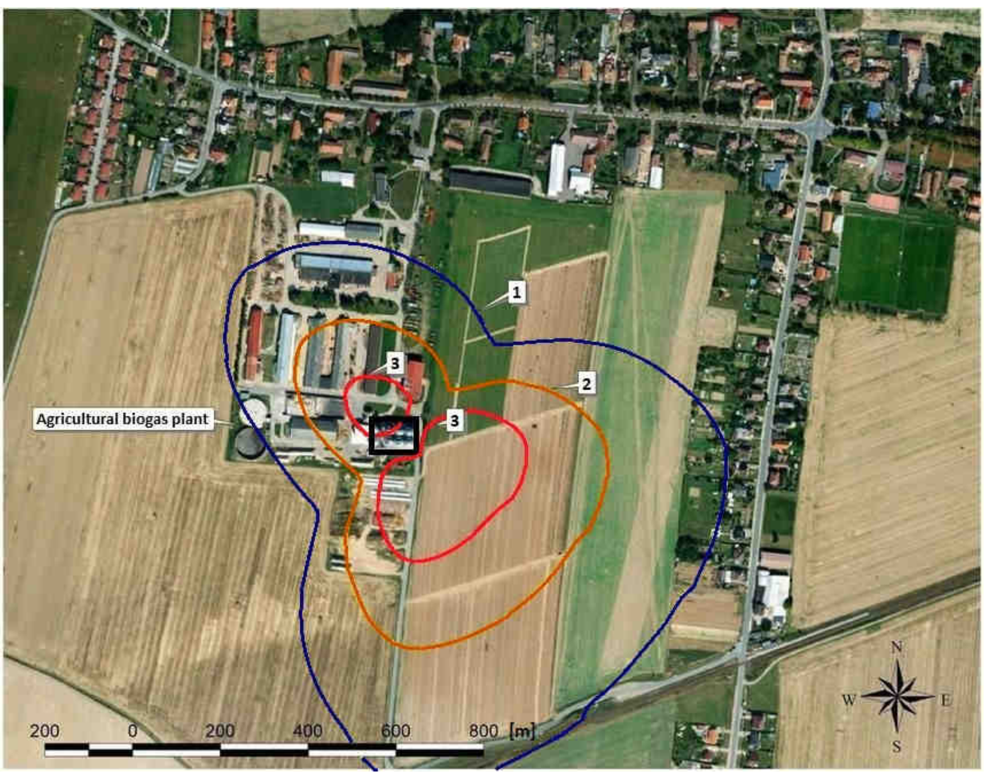

Fig. 6. The result of odour contamination modelling in the vicinity of the agricultural biogas plant. Isoline No. 1: 5 EOU · m^{-3}, isoline No. 2: 20 EOU · m^{-3}, isoline No. 3: 50 EOU · m^{-3}

Discussion

In this contribution, we introduce an educational course focused on mathematical modelling of odour dispersion and methods of its measurement. This course follows up on our previously described course [1] concerning teaching about biogas stations, so the students will already know the principles and importance of biogas stations. In this follow-up training, the students will be acquainted also with a disadvantage of biogas stations which lies in unpleasant odour emissions. They will learn for what reasons the odour originates here and how it can leak out from the biogas station area. Further, various ways of determining the amount of odorous substances in the environment by measurements and mathematical modelling will be explained to them.

The emphasis is placed on the practical use of SYMOS'97 vers2013 software, which is an official tool for preparation of dispersion studies. These studies are required by the authorities to issue a permit for building sources of odour emissions. A second important learning topic is odour measurement using electronic noses. These devices are used for both qualitative and quantitative measurements. It is possible to easily, safely and comfortably analyze many chemical substances with them, including those which are present in small concentrations in the air. Thanks to the current rapid development and declining prices of electronics and computer technology, it can be expected that electronic noses will become more available, and therefore used more frequently than today.

In this course, a considerable importance is given to practical lessons, because participation in hands-on trainings brings practical experience as well as the ability to work autonomously to the students. These skills are important for most of employers more than theoretical "academic" knowledge with the absence of practical skills. The fact that the lack of experience is a problem for both employers and employees is emphasized e.g. in study [28] where the authors mention that graduates of physical-technical schools without sufficient practical preparation have to improve the needed skills within the work hours and also in their leisure. This is time consuming and may be demotivating for the employee too. We hope that our course will improve this situation, so that the graduates will be better prepared for their future jobs and their employers will be satisfied with them.

Conclusions

Measurement of odorous substances using electronic noses associated with mathematical dispersion modelling represents a suitable combination for evaluation of odours emitted from agricultural biogas plants. Because these odours are a long-term and still current issue and more biogas plants are planned to be built in the CZ-PL border region, teaching this topic with an emphasis on practice seems to be a good step to improve the employability of the University of Hradec Kralove and the University of Opole graduates. It can also contribute to solve the problems connected with the lack of experts in this area which may help to increase energy and resource self-sufficiency in this region.

Acknowledgements

This work was done within a long-term cooperation of the Faculty of Natural Sciences and Technology, University of Opole, PL, the Faculty of Science, University of Hradec Kralove, CZ and IDEA-ENVI Ltd. in Valasske Mezirici, CZ. This work was supported by the specific research project no SV 2707/2017 “Emission dispersion models on map backgrounds with using SYMOS and ArcGIS systems”.

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INNOWACYJNY KURS EDUKACYJNY II: MODELOWANIE DYSPERSJI ODORANTÓW Z BIOGAZOWNI ROLNICZYCH

Abstrakt: W ostatnich latach Unia Europejska kładzie coraz większy nacisk na budowę biogazowni rolniczych, szczególnie w regionie przygranicznym czesko-polskim. W tym regionie istnieją duże obszary użytków rolnych, które mogą dostarczać biomasę jako substrat stosowany w biogazowniach. Instalacje biogazowe podłączone do jednostek kogeneracyjnych są użytecznym odnawialnym źródłem energii cieplnej i elektrycznej, ale mogą powodować również pewne problemy. Najpoważniejszą kwestią jest to, że nieodpowiednio obsługiwane instalacje biogazowe są źródłem nieprzyjemnego zapachu, który jest dokuczliwy, szczególnie dla okolicznych mieszkańców. Dlatego przygotowaliśmy kontynuację naszego kursu edukacyjnego dotyczącego biogazowni w ramach programu studiów "Pomiary fizyko-techniczne i technika komputerowa" na Wydziale Nauk Ścisłych Uniwersytetu Hradec Králové oraz do kształcenia stażystów z Wydziału Przyrodniczo-Technicznego Uniwersytetu Opolskiego. W tej części kursu studenci zapoznają się z problemami związanymi z odorami wydostającymi się z nieodpowiednio technologicznie eksploatowanych biogazowni oraz sposobami mierzenia i modelowania odorów w pobliżu ich źródła. Ważną częścią tego kursu edukacyjnego są praktyczne ćwiczenia matematycznego modelowania odorów z nieodpowiednio technologicznie eksploatowanej biogazowni rolniczej. Studenci będą mogli modelować odory za pomocą metodologii SYMOS'97, która jest zatwierdzona i używana jako oficjalne narzędzie do modelowania zanieczyszczenia powietrza w Republice Czeskiej. Studenci dowiedzą się, że biogazownia, która jest dobrze obsługiwana i prawidłowo zlokalizowana w odniesieniu do lokalnych warunków hydrometeorologicznych, nie obciąża okolicznych mieszkańców odorami.

Słowa kluczowe: rolnicze biogazownie, odory, modelowanie dyspersji zapachów