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Real-time Odour Dispersion Modelling for Industrial Sites Application: State of the Art and Future Perspectives

Giulia Uvezzi, Marzio Invernizzi*, Selena Sironi

Politecnico di Milano, Department of Chemistry, Materials and Chemical Engineering “Giulio Natta”, Piazza Leonardo da Vinci 32, 20133 Milano, Italy
marzio.invernizzi@polimi.it

In the field of odour impact assessments resulting from industrial activities, the use of atmospheric dispersion models appears to be crucial. These mathematical tools are able to estimate the ambient air odour concentration at the receptors nearby a plant, as indicated in some guidelines and laws. Generally, the odour concentration is evaluated through emission olfactometry monitoring, and subsequently, based on the dispersion modelling software, impact maps are created at specific percentiles (odour concentrations that are reached for a certain number of hours a year). However, in this way, it is not possible to know the specific odour event as it occurs; therefore, it would be ideal to have a real-time estimation of the odour fallout in the plant's surroundings. Currently, there exist some scientific papers and several commercial which propose some kind of real-time odour monitoring. Overall, these tools aim to monitor the odour events that occur on-site in real-time and to model atmospheric dispersion. The present work seeks to summarise what is currently available for real-time estimation of odour emission and dispersion, with the purpose of highlighting the potential, the eventual limitations, and the principal aspects to be studied and investigated. These considerations may help to develop a newer approach in order to stimulate the research towards the highest possible accuracy of these systems.

1. Introduction

Odour annoyance is actually one of the major causes of environmental complaints around the world and, in some countries, are frequently the cause of the majority of environmental reports from citizens to regulatory authorities.The odour legislation tends to be very diversified, sometimes there is no specific mention in the environmental legislation. On the contrary, in some other cases, the approach to be adopted is carefully described with precise indications about the sampling of odour sources, the odour dispersion modelling, the environmental odour monitoring, and odour control procedures (Brancher et al., 2017, Bokowa et al., 2021)
A common approach to evaluate the Odour Impact Assessment (OIA) involves the measurement of odours either at the sources (CEN:2022) or in places where odour may be present, by conducting direct odour monitoring with a field inspection (CEN:2016). The measurements carried out at the sources foresee the calculation of the odour emission rate, given by the odour concentration multiplied by the volumetric flow rate of the source. Successively, dispersion modelling is carried out to estimate the dilution of odorous emissions in the surrounding environment: this process takes into account the topographical and meteorological data of the site. This technique determines the distance that can be reached by the plume from the emission source and the odour concentrations falling back to sensitive receptors. Once the odour concentration statistics have been calculated, these are usually compared to a judicial entry standard, called Odour Impact Criteria (OIC), to define compliance. OICs are based on the odour concentration threshold, the accepted probability of exceeding the concentration (often expressed as percentile), and the average time used to calculate concentrations using atmospheric dispersion models (which may linked to the peak-to-mean factor to use (Invernizzi et al., 2017)) .
This type of approach relies on the estimation of the odour fluxes, which for some sources can be overly complex. Furthermore, the odour measurements at the source are generally carried out over a few days, and the evaluation of the relapse of the odour concentration is carried out ex-post. This implies that variability related to plant operating conditions and different meteorological parameters is not considered, as the odour concentration is kept constant in the dispersion model. In this regard, various studies have shown that for

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wastewater treatment plants (WWTPs), liquid temperature (Invernizzi et al., 2019) and wind speed (Tagliaferri et al., 2021 and Bellasio & Bianconi, 2022) can influence the measured odour concentration, hence there exist a variability in the phenomenon linked to meteorology. In addition to this, some authors highlighted that for certain sources, such as chimneys and floating roof storage tanks (Invernizzi & Sironi, 2021), also the variability of the operating conditions (e.g., airflow sent to chimneys, the handling and the filling level of the tank) can have a certain degree of influence on the emitted odour concentration. Further studies have highlighted the importance of time-varying emission with respect to the compliance with OIC (Brancher et al., 2021).
Based on the foregoing, the ex-post modelling, which is commonly used and indicated as the approach to be followed in various guidelines, usually only considers the meteorological variability in terms of direction and modulus of wind speed, while it is not taken into account how other meteorological and operational parameters influence the measured odour concentration. Furthermore, all these aspects affect the instantaneous perception of odour and in an ex-post simulation based on percentiles (odour concentrations that are reached for a certain number of hours a year), it is not possible to know what occurs above the specified percentile.

2. State of the Art: Literature and Commercial tools

In reference to what has been reported in the previous section, to overcome the limits associated with the widely used odour dispersion models, which are useful to comply with compulsory OIC, a real-time odour dispersion model could be used instead for early warning of odours events.
Nowadays, there exist various bibliographic studies that have set as a goal the development of a real-time odour dispersion model, and moreover, have begun to come to light several commercial software and instruments that aim to monitor in real-time the relapse of odour in the surrounding of the industrial site.
Among the existing scientific works on this subject, those of Chirmata et al., 2015, Giveleta et al., 2012 and Burgués et al., 2021 appear to be remarkably interesting.
Chirmata et al., 2015, sets as a goal the search for solutions to odour problems in the city of Agadir, Morocco. Specifically, the authors carried out an odour assessment on an industrial site that led to the recognition, characterization, and categorization of the different sources of odours, and the identification of parameters generating these nuisances. Moreover, a commercial system by Odotech was employed, which enabled to integrate data from the six electronic noses and those coming from the meteorological stations; and furthermore, through an atmospheric dispersion software (AERMOD) to model the dispersion of odours and visualize the plume in real-time. In this way, it was possible to monitor the dispersion of odours and identify the odour levels perceived by residents. The authors underline how a system of this type made possible to understand how to act on the operational management of the site to minimize the emission of odours, and in some cases to opt for the introduction of new technologies.
In Giveleta et al., 2012, the Nose Platform has been used at AMETYST Waste Methanization Facility in Montpellier, France. This platform allowed the real-time monitoring of critical factors influencing the odour emissions of a site, as well as the corresponding impact on the surrounding environment. In detail, the real-time odour concentrations data, associated to the various sources, were derived from dedicated sensors and electronic noses. Then, the software enabled the real-time displaying of the odour dispersion plume and furthermore, it generated operational alarms regarding on-site odour management based on specific user-defined threshold values. One of the peculiarities of this platform is the possibility of integrating operational data with data on odour emissions, allowing the actual operating conditions of the site to be considered during the real-time assessment of the fallout.
Burgués et al., 2021 have developed a portable electronic nose by using small drones, specially designed for real-time odour monitoring in a Wastewater Treatment Plant facility in Spain (Depuracion de Aguas del Mediterraneo). Specifically, the electronic nose was equipped with 21 different sensors and a system capable of communicating data in real-time to a base station allowed the operator to visualize the e-nose signals in real-time, log the measured data, and plot the calibrated e-nose output (ou_E/m^3) as a 2D odour concentration map. Therefore, according to the authors, the installation of the e-nose on a drone would allow conducting odour measurements even in hard-to-reach places and in the near future would be employed to identify the main sources of odour and to map the concentration of odours over large areas. In addition to the literature works mentioned above, over the past few years in the commercial field various tools for real-time odour monitoring have been designed and produced. One of these tools is, for instance Odowatch developed by Odotech Inc (recently acquired by EnviroSuite Limited), which was employed in the work of Chirmata et al., 2015. This real-time monitoring platform requires the knowledge of certain physical parameters of the source, such as temperature, flow, and velocity if the source is a chimney or a vent, while for sources like an open basin the length, width, and height are required. Then, for the calculation of the emission rate, it is necessary to know the odour concentration which is measured in real-time through electronic noses installed at the source.

Subsequently, through an atmospheric dispersion model, AERMOD or CALPUFF, the fallout concentration is computed in real-time, and it takes into consideration the current weather conditions (e.g., wind direction, wind speed, temperature, atmospheric pressure, solar radiation, etc.), measured by a weather station installed on-site.

A very similar approach is the one proposed by Olfasense GmbH, manufacturer of the Ortelium tool; here as well the installation of e-nose or specific sensors at the source is foreseen. Regarding the meteorological input, it is possible to use a weather station installed on-site if the modelling relies on a Gaussian Plume model; instead, WRF data should be used in a CALPUFF model. Besides, the real-time flow rate data can also be implemented, if the site allows the access to the SCADA system; alternatively, it is possible to manually insert and plan operational processes, and thus represent discontinuous processes in the modelling.

A further solution is the one proposed by EnviroSuite Ltd (EVS), which offers the possibility of monitoring odours in real-time through the use of electronic noses in parallel with local meteorological data. The nose is designed to support real-time management of air quality and odour problems; actually, the data are fed directly into the EVS Omnis platform to provide useful information to manage odour emissions. In addition, threshold alerts for emission events can be implemented. Additionally, it is also possible to define the efforts required for odour mitigation and plan operational activities while maximizing productivity, for instance by conducting operational maintenance activities in periods of low meteorological risk or emissions.

Further to the systems described above, there is also the one developed by Osmotech S.r.l., Total Odor management system (TOM), which, similarly to the others, provides a perfect representation of the real-time odour impact of the plant, calculated using mathematical dispersion modelling. Therefore, having available odour concentration and fluxes data of the specific emissions detected by the electronic noses, installed on the sources or on the perimeter of the same, and the data of the meteorological conditions transmitted by the system control unit, TOM processes the emissive plume instant by instant.

Finally, similar to what has already been presented above, Arianet S.r.l. has also developed the ARIANET NOSE® Vision360 tool which allows measuring atmospheric emissions at sources, (e.g., odours and tracers) and atmospheric concentrations at receptors. Generally, a sonic anemometer is installed, and sensors that detect the concentrations of pollutants, tracers, or even directly the intensity of odour (electronic noses) are employed for defining real-time emissions from particular sources, to validate the results calculated by the dispersion model and, if necessary, to self-calibrate the model in case of high uncertainty.

There are also future-time odour dispersion models, which take into account only the atmospheric variability such as the one proposed by Prolor, which is specifically designed to predict the odour impact of an industrial facility up to 72 hours earlier, using forecast meteorological data instead of data in real-time. Furthermore, another big difference is linked to the estimation of the odour concentration; actually, in this specific case is achieved through dynamic olfactometry, therefore the installation of an e-nose is not necessary.

3. Discussion

In the previous section, the currently existing real-time models and commercial software were presented.

Some of these, such as the one proposed by Prolor, appear to be particularly simple and user-friendly since it only requires the knowledge of the atmospheric variability. This type of solution certainly represents a step forward compared to ex-post modelling, as in addition to being in real-time, it is possible to opt for forecast data that give indications up to 72 hours in advance. However, the greatest limitation is associated with the use of constant odour concentration data measured through an olfactometric campaign conducted on-site.

Some other commercial tools, in addition to ensuring a real-time update related to meteorology, suggest the installation of electronic noses at the plant borders or, as an alternative, at the sensitive receptors. The installation at the plant boundary is an interesting solution, which can be used as an independent data source to check and someway validate the modelling results, instead of feeding the model dispersion itself. Moreover, the e-nose data can be helpful to verify if the site is responsible for complaints coming from the residents. Here as well, the model has as input data those coming from dynamic olfactometry unless there are sensors or noses at the source. Thus, the sensors used on the fence or at defined receptor points are actually measuring "impact" rather than emissions; furthermore, recalculating the emission rates from these would most likely not give very accurate results. This is mainly due to the fact that robust methods are not currently available for computing the emitted fluxes for data supplied by an electronic nose and measured at a certain distance from the source and not inside it. Finally, the tools that come closest to the concept of real-time modelling, are those that provide a continuous measurement of the odour concentration at the source, directly usable for the estimation of Odour Emission Rate. In this way, the real-time dispersion model is able to take into account both the atmospheric variability and the variability of the odour concentration associated with the management of the industrial plant. This solution is attractive if installed in an industrial facility with a limited number of sources and for which it is possible to perceive a difference in odour in terms of typology.

Considering this latter aspect, it must be remembered that the electronic nose can be a very fascinating and powerful tool, but site-specific. Consequently, training in laboratory and in field is required, as well as a phase of data processing and algorithm implementation, which requires trained and expert personnel. Only in this way is it possible to have a characterization of the source both quantitative (odour concentration value) and qualitative.

An alternative to the existing solutions presented so far could be the development of a completely different approach, that does not involve the installation of any continuous odour concentration measurement instrument, but still allows to implement a real-time dispersion modelling (Figure 1). Therefore, the goal would be to find a proper correlation function between odour concentration and the parameters that seem to influence it the most. To do this, it would be necessary, only in the first instance, to carry out some olfactometric campaigns on-site at different times of the year, so as to evaluate the influence of meteorology on each source (e.g., temperature and solar radiation), the operating conditions, and the management of the industrial plant.

To conclude, a real-time model of this type would require a first effort to characterize the industrial facility, followed by the development of specific correlations, which would allow the creation of a model that would take into account all the factors that affect the variability of the odour concentration, without having to measure it continuously. In addition, by using input data related to plant operation, it would be possible to make a predictive assessment of any emission peaks due to planned changes in the process management or to the occurrence of plant upsets, and moreover, in the case of reports of odour nuisance to verify whether or not the site is responsible.

Table 1. Pro and Cons of the existing software and the possible new approach

	Existing Software	Possible New Approach
Pro	The meteorology is provided in real-time by a weather station installed on-site or forecast data that allow to predict the odour impact up to 48/72 hours in advance. It is theoretically possible to validate a model created with historical data with electronic noses or other specific sensors installed at the plant borders. it is possible to characterize the odour phenomenon in real-time with electronic noses or other specific sensors installed inside the source.	It allows a detailed characterization of the emission sources of greatest interest located in complex industrial plants. It allows to consider the variability of the odour phenomenon associated with different atmospheric conditions (e.g., temperature) or operating conditions (e.g., tank fillings). It doesn’t require the presence of a continuous analyser (i.e., electronic nose and sensors) installed at the source or nearby
Cons	The variability of the odour phenomenon related to different atmospheric conditions (e.g., temperature) is not taken into account. They are not suitable for complex systems characterized by a rather high number of sources, since an odour monitoring tool (i.e., IOMS) should be installed at each of them. The IOMS are complex tools, and they require the assistance of trained and qualified personnel.	Need to build a data set containing all the results relating to the analytical monitoring carried out at the emission sources in different campaigns.

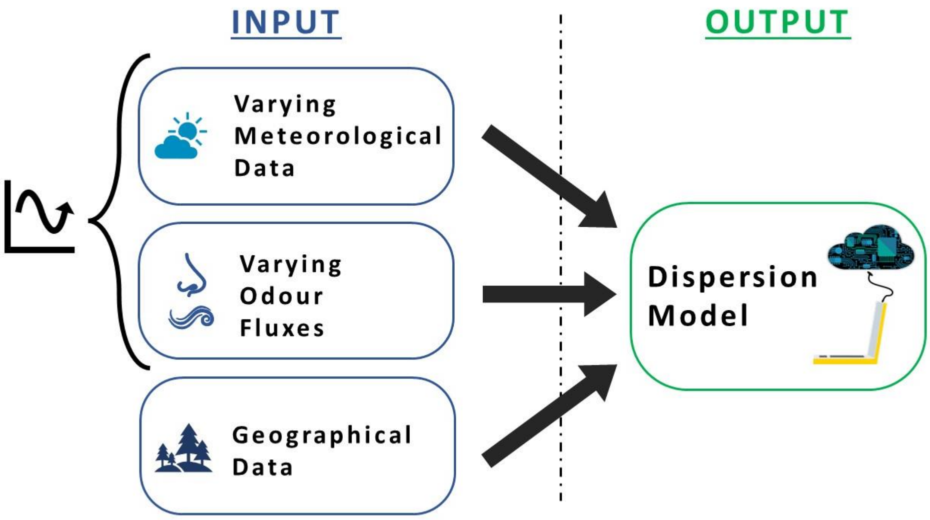

Figure 1. Input and Output of a possible "new-approach" Dispersion Model

4. Conclusion

In conclusion, real-time models are gaining more and more attention since they are able to provide punctual and precise indications on how the industrial plant may cause odour events. Consequently, they are of interest for the site managers and operators because they have the opportunity to intervene in a timely manner if the model reports a high odour concentration could affect the citizenship. Moreover, these tools may make possible to understand if the plant is responsible of the complaints of odour nuisance coming from the population.

As mentioned, the models on the market represent an appealing alternative, especially the ones that measure the odour concentration in real-time with electronic noses and specific sensors at the conveyed emission, but their application is limited to industrial facilities with a limited number of emission sources, given the complexity of the measurement tools.

To overcome these limitations, it would be ideal to develop a new approach for which it is not necessary to have a continuous odour concentration measurement at the source, but which enable to consider the variability of the phenomenon due to the variation of meteorological and operating conditions.

A very fascinating future perspective for these devices, in addition to the approaches briefly described above, would be the use of complex methods, such as Micrometeorological Methods (Lotesoriere et al., 2022) or Backward Models (Wilson et al., 2012,Cesari et al., 2014, Hrad et al., 2021), in order to estimate continuously the emission rate by the measurement in ambient air near the source of at the fence line.

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