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New International Handbook on the Assessment of Odour Exposure Using Dispersion Modelling

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A new development towards the first worldwide guideline on the assessment of odour exposure by using dispersion modelling is taking its first steps. At this stage, there are many initiatives around the world related to odour dispersion modelling but there is no specific handbook or guidance document for odour modelling to our knowledge. Modelling odours is complex and many of the guidelines on modelling published around the world fall short in treating this vector. Odour modelling often requires forgetting traditional dispersion modelling operating modes and focusing on exposure. Odours are perceived in seconds or minutes, not hours, and this is key in calculating their impact in the ambient air. Most odour incidents are generated during calm or very low wind speeds which do not facilitate the dispersion of an odour and that makes modelling extremely challenging.
Development of this guideline is an initiative promoted by over 50 experts around the globe in the area of modelling odours. The group is led by Carlos Diaz (Spain), Jennifer Barclay (New Zealand) and Günther Schauberger (Austria). The first meeting took place in August 2020, and there are planned monthly meetings. The aim of this paper is to report on the advances being made for this initiative.

1. Introduction

Odour issues are currently one of the major causes of environmental grievances around the world and, in some countries, are routinely the cause of most environmental complaints to regulatory authorities (Schusterman, 1992; Kaye & Jiang, 2000). There continue to be multiple reasons for the prominence of odour complaints, including an unrelenting urban expansion of residential areas into land use areas once predominantly agricultural with few largely isolated facilities; increases in facility operations and their size; increasingly higher aesthetic, environmental expectations of citizens, who are less familiar and tolerant of odours than in the past, and concerns over potential health risks from airborne odorous substances.
In most countries, environmental regulations cover most types of common air pollutants including NO_2 or SO_2, with the criterion being based on the occurrence of health effects following short- and/or long-term exposure to the pollutants. As such, there is little health risk variation between jurisdictions, states, and countries. However, odour regulation tends to be much more varied across a wide spectrum: from having little to no specific mention in environmental legislation to extensive and rigid requirements that include a combination of odour source testing, odour dispersion modelling, ambient odour monitoring, setback distances, process operations, and odour control procedures. Odour legislation can be highly variable from one country to the next and it can also be highly variable from one jurisdiction to the next, within the same country (Bokowa, et al., 2021).
For regulatory purposes, much of the focus of attention in the last couple of decades has been in trying to establish odour guidelines in the hope of bringing a degree of consistency to the control and regulation of odours. With the focus on setting regulations, less effort has been spent in a variety of jurisdictions on

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assessing the best tools suited to compute odour impacts with respect to accurate emission rates, source characterization, and the important role of local meteorology, interpretation of modelled results, or the suitability and applicability of one dispersion model over another. The handbook aims to address several of these key issues central to the theme of effective management and odour regulation.
A principal aim of the proposed handbook on odour dispersion modelling will be to provide some guidance on this complex topic in a way that will be of benefit to countries with advanced odour regulations and to those countries that are looking to create regulations surrounding odour management. The handbook will be a collaborative work by more than 50 international odour experts from seventeen countries including; Belgium, Italy, France, Austria, Spain, United Kingdom, Germany, Ireland, Brazil, Chile, Peru, Ecuador, United States of America, Qatar, Australia, China, and New Zealand.
The world odour dispersion model group meet once per month via teleconference while the special task groups, of which there are 6 also meet every month. Each task group has between 5 and 10 members who are responsible for writing and reviewing individual sections within each task group. The task groups are as follows:

- TG1 - Definitions;
- TG2 - Meteorology;
- TG3 - Emissions and Source characterization;
- TG4 - Dispersion Algorithms;
- TG5 - Dose response; and
- TG6 - Reporting.

Each task group is guided by a set of principal themes which are central to the document, and are as follows:

- The resulting document will be a handbook rather than a guideline. This is to prevent conflict with those jurisdictions\states\countries that already have guidelines and regulations.
- The document is to be of benefit for jurisdictions\states\countries that have strict odour regulations and for those who are just beginning to consider odour legislation.
- Rather than focus on any individual model and country how they apply odour regulation, the focus of attention will be on the parameters themselves.
- Valid, workable references are a key component of the document which will include live links wherever possible.
- Individual task groups will focus on the pros and cons of key subject areas. It is not the handbook intent to disregard any existing regulations. There are many countries with advanced odour legislation that is outdated, and it can take a long time for new guidelines to progress.
- The handbook will be forward-looking making the best use of the experts' experience as well as recognizing that changing regulations can take a long time.

2. Content of the Handbook

Each of the key sections of the handbook are briefly summarised below.

2.1 Definitions and References

The aim of Task Group 1 (TG1) is to gather a list of commonly- used odour terms and provide a detailed definition of each terms meaning. By far the majority of odour terms are common throughout the world, but there are some important exceptions, which require an explanation otherwise the term could be mis-understood. An example of two such confusing odour terms is:

- the definition of odour and its unit.
- FIDOL vs FIDOS vs FIDO.

In Australasia (New Zealand and Australia), USA, and Europe the term, 'odour unit' is the common term for the unit of measure of odour concentration. In Australasia and the USA, this term is known as 'ou', and in Europe is known as ou_E/m^3. They have the same meaning, but one is expressed as dilutions and the other as dilutions per cubic metre. The main difference between them is that when an emission rate, for an area source as an example, is calculated, ou_E/m^3 gives an emission rate of $ou_E/m^2/s$ whereas ou gives an emission rate of ou.m/s (Galvin, 2005) the former being a more logical way of expressing emission rates per unit area.
Critical to the guideline is the definition of odour unit. One *odour unit* is the amount of odorant(s) that, when evaporated into one cubic metre of neutral gas at standard conditions, elicits a physiological response from a panel (detection threshold) equivalent to that elicited by one Reference Odour Mass (ROM), evaporated in 1 m^3 of neutral gas at standard conditions.

The most known ROM is *the European Reference Odor Mass* (EROM) that corresponds to 123 µg of n-butanol defined in the standard EN 13725. The *odour concentration* is the number of *odour units* in a cubic metre of gas at standard conditions for olfactometry.
A commonly used acronym used to define an *odour impact criteria* (OIC) is the term *FIDOLS*, that stands for *Frequency, Intensity, Duration, Offensiveness, Locatio*n and *Sensitivity*. Whilst the first 4 factors are well described in the literature, the one that refers to Sensitivity is not that well described. In classical psychometrics, there are four basic factors that affect the sensitivity of individuals and those are: *experience, expectations, motivation* and the *degree of alertness* of the receptor. In the field of odour management, there are other factors that affect receptor sensitivity (Rossi, et al., 2015) such as, the *population affected* (large city, town, scattered houses), *land use* (industrial, rural, hospital, school), *housing uses* (continuous, occasional, fortuitous, repeated passage), or even the *type of protection* that the impacted area may have (historical site, natural site).
These are examples of just a couple of the commonly used odour terms whose use and meaning can be entirely different depending on where you are located so the Task Group aims to define all of the main odour terms as well as ensure the handbook is consistent in its use of terms throughout the document.

2.2 Meteorology

Task Group 2 (TG2) has identified 4 major section titles:

- Meteorological conditions;
- Types of meteorological data;
- Meteorological models, parameters and how they deal with meteorological data; and
- Model performance assessment and reporting.

There will be discussion about processing weather station data, the use and relevance of single station observation data versus that from numerical weather prediction models, and when to use single meteorological station data versus 3D data for odour assessments. The discussion will also cover complex meteorological conditions, the length of meteorological data (how many years), and the relevance of comparing the modelled meteorological data against the long-term historic records.
Rather than discuss any one model, TG2 will focus on a number of regulatory models around the world including (CALMET, AERMET\AERMINUTE, ADMS, GRAL, AUSTAL, SWIFT) and focus on how they use critical parameters. For example, 'roughness length' is an important meteorological parameter used by all models to express the roughness of the surface. It affects the intensity of the mechanical turbulence and the fluxes of various quantities above the surface. Most models use roughness length the same way, but some models such as AERMOD are very sensitive to roughness length, while others such as CALPUFF are only moderately so.
Advice will be provided on the validity of meteorological\dispersion models according to the complexity of the study. For example, in flat terrain, sources grouped together, with no obstacles and moderate winds (steady state conditions) from a single weather station it may be appropriate to use a simple steady state Gaussian plume model. But, for complex atmospheric environments (non-steady state conditions) such as coastal zones and complex terrain it is necessary to develop the meteorological data from three-dimensional diagnostic and or prognostic numerical meteorological models.
An important section of TG2 is model evaluation and how to report the meteorology used in the dispersion modelling. Meteorology is usually the most important input component of dispersion modelling alongside the emissions data. This section will provide advice on appropriate and useful analysis and evaluation tools and will explain how to use these tools to evaluate the meteorological data.

2.3 Emissions and Source Characterization

Odour emissions depend strongly on the type of sampling method used. In the case of area sources, the most common odour source, there are two commonly used worldwide sampling methods: the dynamic wind tunnel and the static flux chamber. For both of these systems, the emission rate is calculated as the product of concentration and airflow through the device. Over the last 30 years there has been a long-standing debate about the appropriateness and accuracy of wind tunnels vs flux chambers for quantifying area source emissions as the sampling devices give quite different results compared to each other and emission theory (Smith & Watts, 1994a; Smith & Watts, 1994b; Jiang & Kaye, 1996; Parker, et al., 2013; Lucernoni, et al., 2016; Prata, et al., 2018).The situation is even more confusing if the scientific literature is consulted as little guidance is provided in the selection and operation of sampling devices to obtain meaningful emission rate estimates and how these compare to odour criteria in use.

Task Group 3 (TG3) wants to address the complex issues surrounding odour emission quantification and will focus on the following topics:

- Discuss sampling techniques applied for the different source geometries in order to evaluate the emission rate:
    - punctual like chimney
    - area like aeration tank (wind tunnel vs flux chamber sampling)
    - diffuse like fumaroles from warehouse (field inspection)
- Consider the following factors when sampling:
    - air flow
    - internal and ambient temperature.
    - relative humidity of the sample air; and
    - internal hood/chamber pressure.
    - variability over time of the odour flow rate (emissions variability due to process and raw material inputs and how to account for the variability in the model)
- Evaluate the different methods for different source types, e.g., liquid or solid surfaces, active or passive sources; should they be treated differently in the model configuration and assessment criteria?

2.4 Dispersion Models and Algorithms

Task Group 4 (TG4) will consider the following with respect to dispersion models and their algorithms:

- the role of dispersion models in the frame of odour applications;
- description of dispersion model algorithms;
- operational existing models;
- general well-known problems/limitations and solutions such as peak to mean ratio and problems related to the emission or meteorology;
- model suitability;

Dispersion models can be used to predict impacts at a location, or to calculate an emission rate based on concentrations at a location. There are four types of regulatory air pollution models used in the world, of which three types are more commonly used. First, there are the steady-state Gaussian plume models such as AUSPLUME (EPA Victoria, 2004), AERMOD (US EPA, 2019), ADMS (CERC, 2016) and ISCST3 (US EPA, 1995), then the non-steady state Lagrangian puff models such as CALPUFF (Exponent, 2011), then chemical Eulerian models such as CMAQ and CALGRID (Yamartino, et al., 1992), and finally Lagrangian Particle Dispersion Models such as Australia's 'The Air Pollution Model', (TAPM) (Hurley, 2008), SPRAY (Tinarelli et al., 2000), LAPMOD (Bellasio et al., 2018) and GRAL (Oettl, 2016).

Steady-state plume models (AUSPLUME, ADMS, AERMOD) assume straight-line trajectories and steady-state meteorological conditions. They have spatially uniform meteorological fields, have no memory of the previous hour's emissions, and assume a non-zero wind speed. They are ideally suited for screening cases and near-field, flat terrain applications away from the coast, where conditions are expected to be steady-state.

The second type of model, the Lagrangian puff approach, solves a set of equations that mathematically follows the release of pollution parcels, named 'puff' as the plume moves through the atmosphere. The CALPUFF model allows, in such a system, to follow curved trajectories along the plume centrelines and simulating the dispersion through gaussian or non-gaussian puffs around them. The 3D meteorology has full spatial variability in the winds and turbulence fields. The model retains information from previous hours of emissions and is well suited for modelling stagnation, fumigation, and recirculation events typical of worst-case dispersion of odours.

Eulerian grid models such as CALGRID and CMAQ consider instead a fixed 3D Cartesian grid as a frame of reference where the advection-diffusion equation is numerically solved rather than in a moving frame of reference. These models are best used for explicit chemistry computations in particular ozone, air toxics, and secondary aerosols modelling and are not commonly used for odours. Finally, in Lagrangian Particles Dispersion Models the emitted plumes are split into a large number of computational particles, whose movements follow the local structure of the mean wind and turbulence, allowing a more precise description of both the emission structure and the dispersion in highly sheared environments.

TG4 recognizes that the mechanisms of odorant dispersion in the atmosphere are the same as the dispersion of other pollutants. However, there are some special problems that must be considered when attempting to quantify a source's odour impact with dispersion modelling. Among them are determining the emission rates of the pollutant, the short time period over which odours are observed, the enhancing or masking of odours by the combinations of different odours, and the high degree of subjectivity amongst a population in the perception and intensity of odours.

TG4 considers that two key factors that should be considered in evaluating whether to use a conventional steady-state plume model such as ADMS or AERMOD, or a more sophisticated approach are, whether the steady-state assumption is valid, and, whether the technical parameterizations in the plume model adequately treat the situation to be modelled. The effects of buildings, terrain features, coastal effects, and other flow obstructions, as well as other factors such as source height and receptor distance from the source can all affect the flow and it can be argued that conditions are never steady state.

2.5 Dose Response

The role of Task Group 5 (TG5) is to discuss the dose response to odours, in other words, to assess the odour impact experienced by the community. The community impact of odours has been assessed over time with it generally being accepted that annoyance is linked to odour concentration (Miedema, et al., 2000), the frequency of impact is critical (Winneke, et al., 2004), and that the impacts of odour can go beyond annoyance effects leading to potential health impacts (Schusterman, 1992) if not correctly managed.
The acronym FIDOLS features strongly in this section (frequency, intensity, offensiveness, duration, location, and sensitivity), where each parameter is discussed in depth. Several attempts have been made in order to describe a mathematical function that addresses all of the FIDOLS factors, but there are no mathematical functions describing FIDOLS factors that are integrated within dispersion models due to the subjective nature of odours. As a consequence, the result produced by modelling an odour emission rate, unfortunately cannot be used as the only proof that an impact is not made when there is an evidence of odour complaints in area.
TG5 discuss in depth, FIDOLS factors, percentiles and peak to mean ratios.

2.6 Reporting

The final chapter of the handbook will be ‘Reporting’ which will be prepared by Task Group 6 (TG6). The aim of this Chapter is to discuss how much and what information should be included in an odour assessment technical report. The main objective of an odour dispersion model study is to determine the significance of the effects of the odour discharged from a particular source. The results must therefore be reported effectively and concisely in a manner suitable for the purpose for which they were produced. This means the results must be communicated in a way that can be understood by people who may not be experienced in interpreting input data or the model outputs. TG6 recognises that there two elements to this: first, to report the modelling results themselves in an easy-to-understand manner; and second, to evaluate the implications of the results in terms of the potential effects of the predicted ground level odour concentrations on nearby sensitive receptors.
In addition to producing the model results in tabulated and graphical form as concisely and as accurately as possible, TG6 believes the report also needs to include important information, such as accounting for and reporting of the model error and uncertainty. The report should clearly set out the assumptions on which the modelling has been based and should especially consider the uncertainty associated with the model inputs and the validation of monitoring data for inclusion in the study.

3. Conclusions

To date, the world odour dispersion model groups have met monthly since the idea of the ‘worldwide odour dispersion model group” was conceived. Individual members of the group recognize the advantages of collaborative research and learning, which includes;

- Development of higher-level thinking, oral communication, and leadership skills.
- Exposure to and an increase in understanding of diverse perspectives.
- May provide opportunities where multiple different world-wide approaches may be applied to existing problems and lead to the development of innovative solutions.
- Discussions amongst colleagues can stimulate new ideas and increase creativity.

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