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Critical Elements in the Measurement, Monitoring and Prediction of Odors in the Environment

Yael Laor*[a], David Parker[b], Thierry Pagé[c]

[a]Agricultural Research Organization, Institute of Soil, Water and Environmental Sciences, Newe Ya'ar Research Center, Ramat-Yishay, Israel.
[b]West Texas A&M University, Canyon, Texas.
[c]Odotech Inc., Montreal, Canada.
*laor@agri.gov.il

The main challenge in the field of odor management is that the measured response is a perception. Nevertheless, it is necessary to quantify the problem in an objective manner using the best available approaches. While the field of odor science has evolved considerably in recent years, there are still different viewpoints and approaches as to proper methodologies for measuring and predicting environmental odors. Scientists, engineers, and regulators need a balanced and critical understanding of how to respect odor assessments and predictions based on currently existing methodologies and the uncertainties associated with them. Although multiple sources of uncertainty are associated with each step in the process of odor sampling – quantification – dispersion modeling, the need to rely on actual odor measurement with human panelists remains the preferred approach for many environmental regulators and emission sources operators. Considering the complexity of odor mixtures and odor perception, and the inability of chemical approaches to quantify odor problems, it is anticipated that odor-based regulations will continues to expend and technically sound standardization initiative will progress in the future. The best is to become fully aware of the limitations and uncertainties associated with currently available odor sampling, measurement, monitoring and dispersion modeling approaches and use best practices. This presentation is largely based on a recent critical review work of the authors covering over 200 references (Laor et al., 2014) and additional illustrations.

1. Key elements in the process of odor measurement and prediction

Several of the tools used in the field of environmental odors have been adapted from earlier studies on air pollution, but challenges still exist with regard to odor sampling, analyses, and the use of prediction models developed for air contaminants. Figure 1 illustrates key elements in the process of odor measurement and prediction by means of odor sampling and quantification using olfactometry, or electronic nose, and the use of odor dispersion models. Measurements obtained by discrete sampling followed by standard olfactometry or real-time data obtained from olfactometry-based trained electronic noses may be used as inputs in dispersion models to predict odor impacts in surrounding communities. Odor dispersion modeling can be static based on discrete odor sampling and representative local weather conditions, or it can be dynamic based on electronic nose inputs and on-line measured local meteorology. The first is used for worst case-based odor prediction and the latter is used for continuous odor monitoring.

Notably, each element in this scheme contains sources of uncertainties which must be well understood and potentially be minimized.

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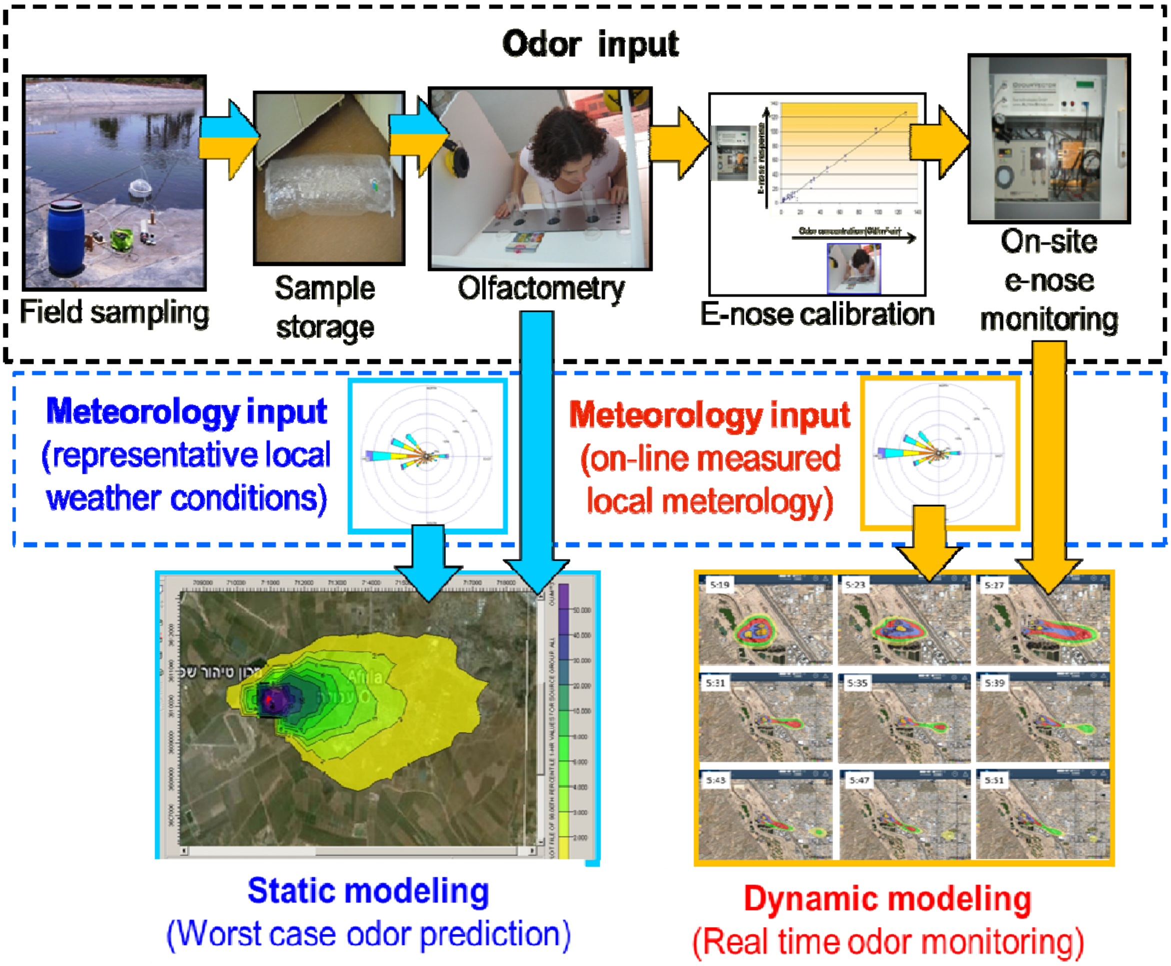

Figure 1. An illustration of key elements involved in the process of odor sampling, quantification and prediction.

2. Uncertainties associated with odor measurements and predictions, efforts to minimize, and gaps of knowledge

2.1. Uncertainties associated with odor sampling

Odor sampling is enabled at various types of emitting sources (point, area, fugitive and volume sources) with the purpose of subsequent laboratory analysis under controlled conditions. There are three main elements contributing to uncertainties associated with odor sampling that need to be considered and minimized:

Sampling devices and sweep air flow conditions. Sampling of passive area sources is especially complex and controversial and the collection of air emissions from such sources needs standardization. Passive area sources with a liquid-gas or solid-gas interface (e.g. evaporation ponds, sedimentation tanks, open composting piles, land applied with manure or biosolids) present particular difficulties in sampling because - unlike point sources such as smokestacks which can be measured directly - there is usually no well-defined airflow rate associated with them. The emissions from such sources are usually governed by evaporation and diffusion, whereby a concentration gradient provides the driving force for the transfer of odorants from solid or liquid surfaces to the air.

During sampling of passive area sources (liquids or solids of varying moisture content), the two alternative approaches commonly used (flux chamber or wind tunnel) have shown differences up to two orders of magnitude in measured odor emission rates. It is probable that different methodologies would better fit different odors, depending on odor composition. Future fundamental studies on sampling effects may help to improve and validate sampling methodologies. Such fundamental issues are well illustrated from preliminary data obtained by Parker showing the effect of flow rate conditions applied to a flux chamber on volatile organic compounds (VOC) emissions. It appeared to be dependent on the compound Henry's constant which in turn determined if emission was gas- or liquid-film controlled. E.g. as the air flow rate increased in the flux chamber, the concentration ratio of dimethyl sulfide (liquid-film controlled) to 2-mercaptoethanol (gas-film controlled) decreased from 20:1 to 4:1 (Fig. 2).

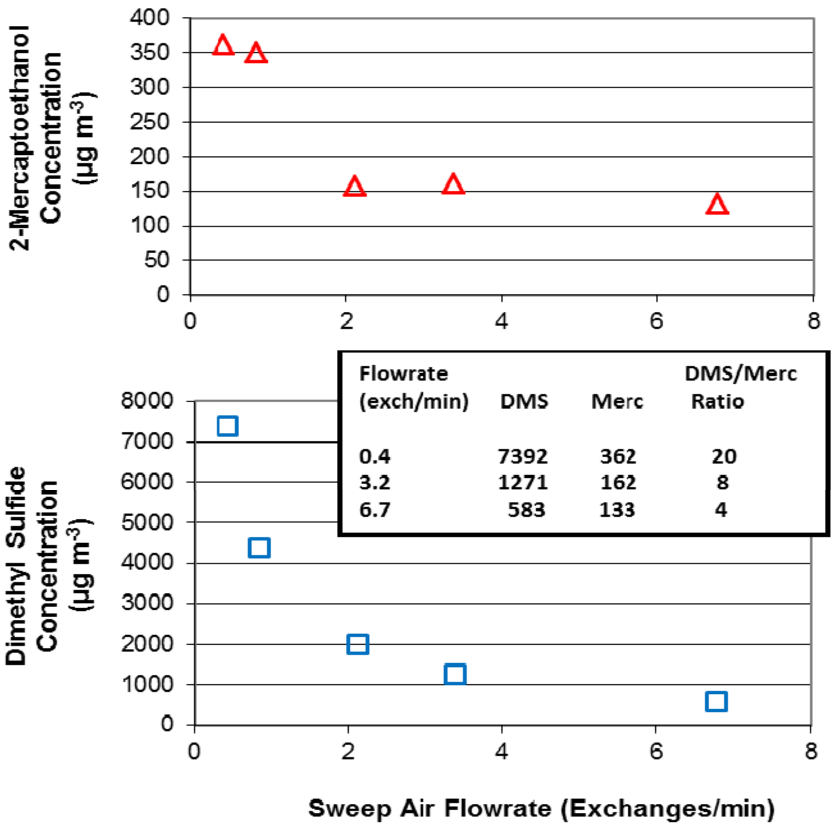

Figure 2. Emission of 2-mercaptoethanol (top) and dimethyl sulfide (bottom) as a function of sweep air flow rate in a flux chamber.

Moreover, there are cases where it is not straightforward to define the source as active or passive. For example, open windrow compost piles are exceptionally complex systems for odor sampling. Unlike classically categorized passive or active emission sources – a full cycle of windrow composting is dynamically involved with both, considering the following phases: i. Initially, mainly passive emission from the new set piles is expected. At this stage, fresh materials emit intense odors and therefore those passive emissions are relatively high. ii. As the pile heats up, the role of active emission from patched surface area increases due to self-ventilation by convective buoyant airflow ("chimney effect"). Active emissions are high during this initial stage of the thermophilic phase. Concomitant passive emissions are also expected from other surface patches. iii. Upon periodic turnings, there are bursts of active emissions of odorants (partly carried by particulate matter). After turning, there is a short phase where the pile is relatively cool and therefore passive emissions should become more dominant again. This behavior is expected to continue until the end of the thermophilic phase, whereas the gross trend of emission intensities declines with time. iv. During compost maturation and curing (post thermophilic phase) passive emissions become again more dominant, although gross emission is much lower. This concept is yet not supported by experimental data and has not been 'translated' into a full-cycle odor sampling strategy (Fig. 3).

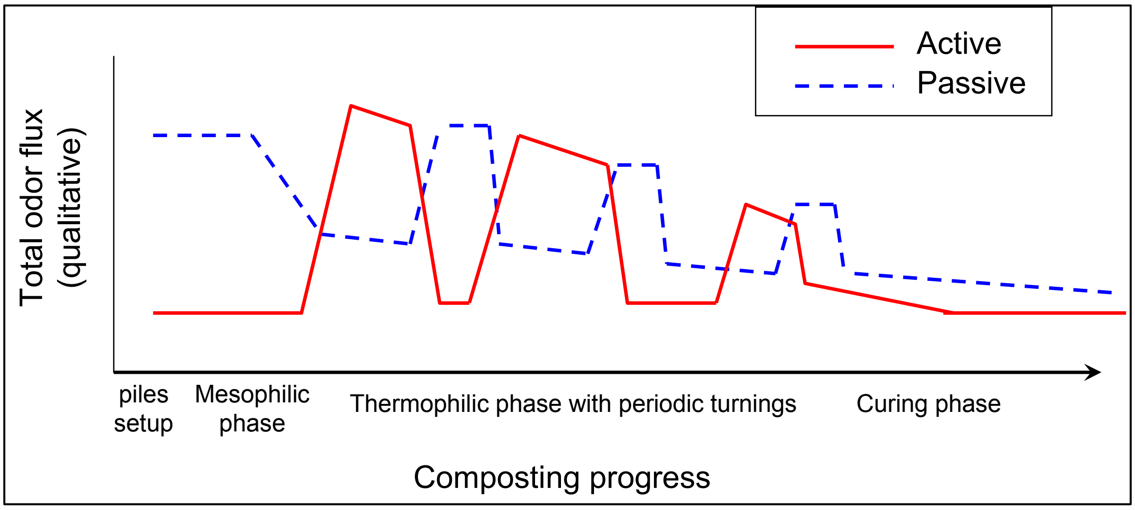

Figure 3. Conceptualized role of active vs. passive odor emissions during a full cycle of windrow composting (described in the text).

Background odors of sampling bags remains an issue although standards prescribe the use of bags made from materials such as Tedlar® (polyvinyl fluoride) or Nalophan® (polyethylene terephthalate). These materials may release odorous chemicals according to their condition of cleanness and storage conditions, thus becoming of concern in cases of samples with relatively low odor concentrations. For instance, the highly diluted sample obtained by means of a wind tunnel can lead to overestimation because the background-affected measured odor concentration is multiplied by the much larger flow rates applied during sampling. The two sources of odor background in sampling bags are the bag film and potential diffusion of VOCs into the bag while being exposed to the field environment during the sampling campaign (as can be evaluated from a “field blank”). Nevertheless, such backgrounds, even if they are measured properly, cannot be simply subtracted from the samples (odors cannot undergo simple mathematical manipulations) and as such, the only management procedure is to minimize those backgrounds with good sampling practices: Careful bag pre-cleaning, choosing bags that show minimum background for sampling weak odors, and keeping the sampling equipment as clean as possible. Because of the uncertainty associated with olfactometry, it is recommended to consider values of real samples that are about half an order of magnitude larger than the background induced by sampling.

Sample storage time is restricted by international standards, yet during this period odor concentrations have been shown to reduce by factors up to five or more depending on bag and odor types. It is suggested that in cases where storage over 4 hours is unavoidable, some preliminary measurements would be taken to assess the loss expected during storage and then use a correction factor to minimize underestimations of odor emissions. In any case, storage time should always be minimized, at conditions close to room temperature (20–25 °C) and samples should not be exposed to sunlight.

2.2. Uncertainties associated with odor quantitation by means of olfactometry

Odor quantification is most commonly performed in a laboratory setting by means of dynamic olfactometry. Assuming that the odor panel is a representative sample of the average perception of normal populations, the value calculated from olfactometry analysis of any odor sample reflects by definition an estimation of the perception threshold (1 OU/m^3). The use of odor concentration units and the resulting calculated emissions rates (OU/s) are often used by scientists, regulators and engineers as this is the only way to use such data quantitatively in dispersion modeling and estimate odor abatement efficiencies. Other approaches exist to assess other odor dimensions (character, intensity and offensiveness) at the suprathreshold level.

Uncertainties associated with odor quantification by olfactometry are partly defined by international standards. The EN13725 strictly defines the limits for a repeatability value based on multiple analyses done with n-butanol. It requires that the measured odor concentrations of two identical samples not be different by a factor larger than three in 95% of the cases. This uncertainty limit is given that two identical samples are analysed in the same lab using the same olfactometer, but may not be analysed on the same day or by the same panel. Although not always practical, this inter-panel variability may be reduced by narrowing the standard deviation of individuals' variability and increasing the number of panelists. Alternatively, if the purpose is to compare between different treatments, it is recommended to evaluate those samples by the same panel on the same session, thus reducing the uncertainty to within-panel variability. The latter variability is typically the lowest as it eliminates the variability associated with the differences between individuals of the panels and the variability associated with changes in the response of individuals on different days. Certainly, replicate samples will decrease the uncertainty of the measured odor concentrations and potentially increase the accuracy (trueness) of this value as well. Notably, the result of any olfactometry analysis is affected by the method of data analysis. Differences in the range of tens of percent were shown for different methods, such as the American or European standards or other mathematical fits to dose-response type curves (Laor, unpublished).

2.3. Uncertainties associated with odor quantitation by means of electronic noses

Electronic nose-based continuous odor monitoring has been applied in solid waste landfills, composting facilities, wastewater treatment plants, and livestock operations. Electronic noses are arrays of multiple gas sensors which are "trained" by different kinds of data analysis techniques to discriminate between different odors or to determine odor concentrations. To obtain odor quantification by means of odor concentration (OU/m^3), the electronic nose must initially be calibrated against olfactometric analyses. As such, the uncertainties associated with odor sampling and olfactometry also become a source of uncertainty during the training of electronic noses, and the same best operating procedures apply too. The calibration is source and odor specific to a site. If the sources or odors change, additional calibration may be needed. Other technical obstacles may be related to sensor drift or the conditions within the measurement chamber. Temperature and humidity variations are the two most important interfering agents on sensor response and their interferences must be cancelled out for accurate measurements and reproducibility. Temperature variations can be controlled by hardware conditioning devices. The effect of humidity is either taken into account in mathematical algorithms and/or conditioning devices.

2.4. Uncertainties associated by using air contaminants dispersion models for odor predictions

Dispersion modeling, either static or dynamic, defines the predicted relationship between the emission source and the receptor. The success of predicting odor concentrations at the receptor depends on the quality of the model inputs (including: odor emission rates and source characteristics, meteorological data and modeling domain characteristics) and the quality of the dispersion model and its appropriateness to the study area. Uncertainties associated with the use of odor dispersion modeling are directly relative to the uncertainties associated with sampling and olfactometry which can over- or under-estimate the impact radius of an emission source. The use of near source meteorological data and emission quantifications for all transient emission conditions will reduce the errors associated with odor dispersion modeling.

Nevertheless, while dispersion models of specific air pollutants are based on conservation of mass, the use of these dispersion models for odors merely predicts the number of dilutions needed to reach the perception threshold at a certain distance from the emission source. Such predictions cannot entirely predict odor annoyance unless the relationships between odor concentration and perceived intensity and offensiveness are determined at suprathreshold concentrations.

3. Perspectives

While the option of focusing on specific odorants is analytically preferred, because of the complexity of multiple odorants from a single or multiple sources, and of possible synergistic effects, it is often difficult to assess odor impacts based on specific odorants alone. Thus, although multiple sources of uncertainty are associated with each step in the process of odor sampling – quantification – dispersion modeling, the need to rely on actual odor measurement with human panelists remains the preferred approach for many environmental regulators and emission sources operators.

Overall, considering the complexity of odor mixtures and odor perception, and the inability of chemical approaches to quantify odor problems, it is anticipated that odor-based regulations will continues to expend and technically sound standardization initiative will progress in the future. The best is to become fully aware of the limitations and uncertainties associated with currently available odor sampling, measurement, monitoring and dispersion modeling approaches and use best practices. This will first help in minimizing some of the uncertainties by means of appropriate management (minimizing bag background, minimizing storage time or including a correction factor, increasing the number of replicates, narrower selection of lab panelists, careful training of electronic noses, etc.) and to stimulate more studies that will focus on developing and validating sampling methodologies and methods of model validation. The applications of measurement, prediction and monitoring of odors in the environment are broad, and require effective tools to quantify problems based on human perception in an objective manner. These tools are most useful for policy development, odor regulation, complaint assessment, odor impact assessment, odor master planning, odor control efficiency assessment, process design, land use policies, and urban planning.

References

Laor, Y., Parker, D., Pagé, T. 2014, Measurement, prediction and monitoring odors in the environment – A critical review, Reviews in Chemical Engineering. Volume 30, Issue 2, Pages 139–166.