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EXTENSION OF ODOR IMPACT ASSESSMENTS BEYOND NUISANCE EVALUATIONS AND THE DILUTION-TO-THRESHOLD PRINCIPLE

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ABSTRACT

Current odor impact assessment methods based on statutory nuisance laws or the dilution-to-threshold principle are unsatisfactory. The Odor Impact Model (OIM) represents a significant improvement on current methods for quantifying odors by incorporating the persistence and offensiveness of an odor into estimates of the impact of odorous emissions on surrounding communities. This allows odors to be judged not only in terms of the quantity of the emission but also, just as importantly, its quality. Dispersion modeling can be used in conjunction with the OIM to estimate the impact of an odor on the surrounding community by providing a measure of the fraction of the population who will be exposed to the odor and their corresponding degree of annoyance.

I. INTRODUCTION

Of the various categories of air pollutants, odors have been ranked as the major generators of public complaints to regulatory agencies in North American communities. The National Research Council Committee on Odors (1979) estimated that more than 50% of the complaints related to air pollution deal with exposures to odors. In a 1994 survey of regulatory agencies, an analysis of 25 responses indicates that in excess of 60% of air pollution complaints were related to odors with an estimated total of over 12 000 registered complaints in that year (Leonardos, 1996). These complaints originate as a result of a wide variety of industries and operations including agriculture, sewage treatment works, paint, plastics, resin and chemical manufacturers, refining operations, rendering plants, pulp mills and landfills, among others. (Leonardos, 1996).

In communities exposed to odorous emissions, even though there may be no apparent diseases or infirmities, there certainly is not an atmosphere of complete mental, social, or physical well-being. It is recognized that prolonged exposure to foul odors usually generates undesirable reactions in people. These reactions can vary from emotional stresses such as unease, discomfort, irritation or depression to physical symptoms including sensory irritations, headaches, respiratory problems, nausea, or vomiting (National Research Council Committee on Odors, 1979). Sub-irritant levels of odorants may trigger acute symptoms through non-toxicological, odor-related mechanisms. These mechanisms have been postulated to include innate odor aversions, odor

exacerbation of underlying conditions, odor-related aversive conditioning, stress-induced illness, and mass psychogenic illness (Shusterman, 1992).

The studies quoted above indicate that odor problems occur with sufficient frequency and sufficient impact to warrant intervention. As such, regulatory agencies and industries are often expected to deal with community odor problems. However, to-date they have no truly objective strategies for assessing the impacts of odorous emissions on populations. The lack of such methods prevents authorities from establishing standards which would eliminate, or at least minimize, community odor nuisances. In addition, the offending industries lack a methodology to aid them in predicting their potential impact and for testing odor reduction technologies prior to full-scale implementation.

Therefore, the objectives of this paper are to: describe current odor impact assessment methods; identify their shortcomings; and propose a new strategy of odor impact assessment, which attempts to overcome these shortcomings.

II. ODOR IMPACT ASSESSMENT

The public usually reacts to an objectionable odorous episode by registering complaints with either the local regulatory authorities (police, fire, board of health), regional agencies and/or the odor emitter. In general, assessments of the impact of odors on a community are usually based on either the complaints which can be used to classify the odor as a nuisance, or technical assessments based on the dilution-to-threshold principle.

Odors Assessed as Nuisances

Historically, direct legal control over odorous emissions has been, and often still is, exerted primarily through public nuisance provisions of common law. Under these regulations, an odor which has a substantial negative impact on the quality of life of a community is considered to be a nuisance. For example, in Ontario, Canada a prosecutor must successfully demonstrate that the odor causes: (1) physical damage to neighbourhood land, buildings, works, or vegetation; and/or (2) undue interference with a person's comfort and the normal use and convenient enjoyment of property. Specifically, section 6 of Regulation 308 of the Environmental Protection Act of Ontario states that "No person shall cause or permit to be caused the emission of any air contaminant to such extent or degree as may, (a) cause discomfort to persons; (b) cause loss of enjoyment of normal use of property; (c) interfere with normal conduct of business; or, (d) cause damage to property" (Government of Ontario, 1990). Clearly, "discomfort", "loss of enjoyment" and "normal use" are subjective terms which are open to individual interpretation.

Some agencies have attempted to add a degree of objectivity to the identification of a nuisance by specifying the conditions under which an odor nuisance exists. For example, a nuisance situation may be considered to exist

when a specific number of complaints or a specified proportion of the residents in the affected region complain and consider the odors to be objectionable. For example, the Government of Manitoba, Canada has proposed the definition of an odor nuisance to be "a continuous or repeated odor, smell or aroma in an affected area, which is offensive, obnoxious, troublesome, annoying, unpleasant or disagreeable to a person ... subject to at least 5 written complaints ... within a 90 day period ... from 5 different persons who do not live in the same household" (Government of Manitoba, 1996).

Nuisance-based assessments have several important merits which cannot be ignored. A nuisance suit which is supported by reliable and credible witnesses can be more convincing evidence of a community annoyance than any scientific attempt to prove the same. In addition, court decisions can be made that provide relief that is appropriate to the case and which are not bound by specific guidelines. The leeway available in making such decisions can provide a solution which best fits the needs and interests of all concerned parties.

However, the assessment of odor impact using traditional nuisance law has several shortcomings which prevent it from adequately protecting the public from objectionable odors. Often, it is left to the officials of the local agency to determine if there is any "interference" and, if so, is whether or not it is "unreasonable." In certain instances, the local investigator can become the judge, jury and prosecutor of the alleged source of the odor nuisance. In some jurisdictions, the inspector can initiate an investigation without any registered complaints from the local populace (Duffee, 1996). When required, court proceedings tend to be very costly, time-consuming and risky for the plaintiff to undertake. A large burden of convincing evidence is required which must be backed up by the testimony of many credible witnesses. Persons with high sensitivity are usually unsatisfied by the verdict. Even if the rights of the plaintiff are substantially impaired, the source of the odorous emissions may not be held liable. Often, when the plaintiff succeeds in demonstrating that an odor source is a nuisance, the remedy will be an award of damages, rather than a court order forcing the defendant to abate the odor. When no lawsuits are sought, due to lack of initiative or funds on the part of the plaintiff, objectionable odorous emissions continue to escape unregulated. Perhaps most importantly, since a nuisance must occur before any action is taken this form of impact assessment serves only to abate objectionable odors but not to prevent their occurrence.

Dilution-to-Threshold Principle

Odor threshold measurements are used in an attempt to introduce a measure of objectivity into odor impact assessments. Odor impact assessments based on the dilution-to-threshold principle are based on the assumption that a sample of odorous air can be described in terms of the volume to which it must be diluted for its intensity to be reduced to the sensory threshold level. That is, the more dilutions that are required to make an odor sample undetectable, the stronger the sample must be. The detection threshold (ED_{50}) of an odorous gas

is the most popular measure of odor concentration and is defined as the dilution (or concentration) at which 50% of a panel of odor judges notices a stimulus as being different from odor free blanks. It is often estimated as the geometric mean of the individual thresholds (i.e. the best estimate threshold, BET) of the members of a panel of odor judges who are exposed to a range of dilutions of the original odor sample. The ED_{50} is calculated for a group of N panelists with individual thresholds (BET_i) as follows:

$$\log_{10}(ED_{50}) = \frac{1}{N}\sum_{n=1}^{N}\log_{10}(BET_i) \qquad (1)$$

The ED_{50} of a population, expressed in terms of dilutions, defines the number of "odor units" in an odor sample. An "odor emission rate" from a source may be defined as the number of odor units discharged per unit time and is determined by multiplying the threshold by the volumetric gas emission rate. The total odor emission rate from a plant is the sum of the individual emission rates from each source. Measurements of odor thresholds and odor emission rates provide several different approaches for the quantification of odors.

Sometimes regulatory agencies limit the odor concentration at the source to a specified level. This method involves the collection and analysis of odor samples directly from the point of emission. For example, if a regulatory agency were to limit the source concentration to a specific number of odor units, it would be relatively simple to determine whether a source is in compliance with the regulation. However, this method has a serious limitation. For example, if two sources within a community were emitting the same odor at the same concentration but at different flow rates, the impact of each source on the surrounding community would clearly be different. Generally, the source with the higher flow rate would have the greater impact on the neighbourhood. Thus, if this plant were to increase its emission output (in terms of volumetric flow rate, not concentration) it would still be in compliance but the impact of the odor on the community would increase, perhaps to an intolerable level. Alternatively, if the plant with the lower flow rate increased the concentration of its output above the acceptable number of odor units, it would no longer be in compliance even though it may still have a negligible impact on the community. In such a case, the more serious offender would be safe from prosecution whereas the less serious offender would be in danger of being prosecuted. Therefore, impact assessments based solely on the source concentration are inadequate.

Some agencies may choose to limit the total odor emission rate from a source to a maximum number of odor units per unit time. This method has some validity when applied to small volume emissions because it takes into account both the odor concentration and flow rate associated with the source. However, it is questionable when applied to large volume emissions of low odor concentration. For example, for a facility with an extremely large volumetric emission rate, a limit on the odor emission rate may restrict effluent odor concentrations to levels which are technologically or economically unattainable,

even when the odor has no identifiable impact on the surrounding community. Therefore, impact assessments and, hence, regulations based solely on source emission rates appear impractical.

Some agencies choose to limit the concentration of the odor in the ambient air beyond the property line of the plant. This approach, in principle, provides protection for the public from odorous emissions by preventing the concentration of any odors from reaching objectionable levels in the community. Some 15 agencies in the USA define an odor nuisance in terms of the ambient standard based on the number of dilutions required to render the odor undetectable. Most agencies with this type of regulation such as those in Colorado, Missouri, Kentucky and Cincinnati, specify that the ambient air in residential and commercial areas must become odorless after mixing with 7 parts of odor free air (Duffee, 1996). However, in practice, ambient odor limits have been found to be unenforceable due to difficulties such as identifying the odor source, sampling for ambient odors, and accurately measuring ambient odor concentrations.

Even though it is possible to use measurements based on the dilution-to-threshold principle as indicators of potential odor impacts on communities, there are some doubts about the validity of their use. For example, the measurement of a threshold fails to provide any information related to the impact of an odorous stimulus on a neighbourhood in terms of complaint potentials or degrees of annoyance. In addition, detection threshold measurements fail to take into account the potency or the persistence of certain odors. That is, with large changes in concentrations, some odors are accompanied by relatively small differences in perceived odor magnitude (Shusterman, 1992). These variables are the extremely important dimensions for quantifying an odor nuisance in a locality.

III. ODOR IMPACT MODEL

The Odor Impact Model (OIM), developed by Poostchi (1985) and modified by Nicell (1994), is an extension of the currently used method of threshold evaluation using the forced-choice principle. The extension involves the use of olfactometry to establish dose-response relationships for the odor rather than a single threshold. Odor judges are presented with a descending series of dilution levels of the odor. At each dilution level of the odor sample, each odor judge's ability to detect the odor is assessed by forcing him/her to choose which of a series of ports is emitting odorous gas (one emits a known dilution of the original odor sample and the others emit only clean air). The first dilution level beyond which an individual judge makes continuous correct choices is taken as the basis for the evaluation of that person's individual threshold. The fraction of odor judges that are able to correctly identify the presence of the odor at a particular dilution level is a measure of the probability of detection. Results are plotted, as shown in Figure 1, to produce the S-shaped curves of probability of detection (P, in %) versus the logarithm of the number of

dilutions (D) of the original odor sample. Details of this methodology are summarized in Nicell (1994).

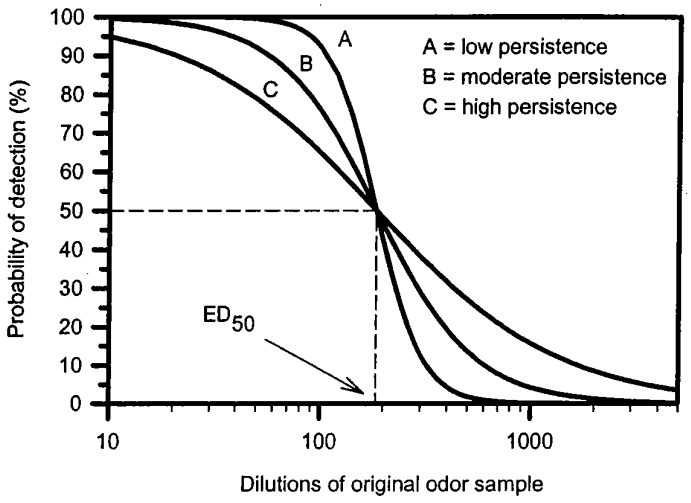

Figure 1: Probability of detection curves for three odors (A, B and C) with the same detection threshold but different levels of persistence.

Figure 1 illustrates three typical S-shaped curves which correspond to odors of low, moderate and high persistence. The term persistence is a reflection of the number of dilutions required to change the odor from a condition where it is fully detectable (P = 100%) to a condition where it is undetectable (P = 0%). A more persistent odor is characterized by a shallower slope in the probability versus dilution curve. Persistence is also a measure of the variation amongst individuals' abilities to detect an odor. A high persistence corresponds to an odor for which individual BETs are highly variable. In the three cases shown in Figure 1, all of these odors have the same detection threshold (ED_{50}) but different levels of persistence.

Odor judges are also asked to register their degree of annoyance at each dilution level upon considering their reaction if they were exposed to similar odorous stimuli for an average period of eight hours. The panelists are advised to rate their annoyance on a scale of 0 to 10 by matching their response to a series of descriptors and cartoon images (Nicell, 1994). The arithmetic average of the annoyances expressed by each of the panelists is calculated at each dilution level and forms the basis for the degree of annoyance curves, shown in the typical profiles shown in Figure 2. Odors are highly variable in their offensiveness, resulting in the variety of curves shown in the figure.

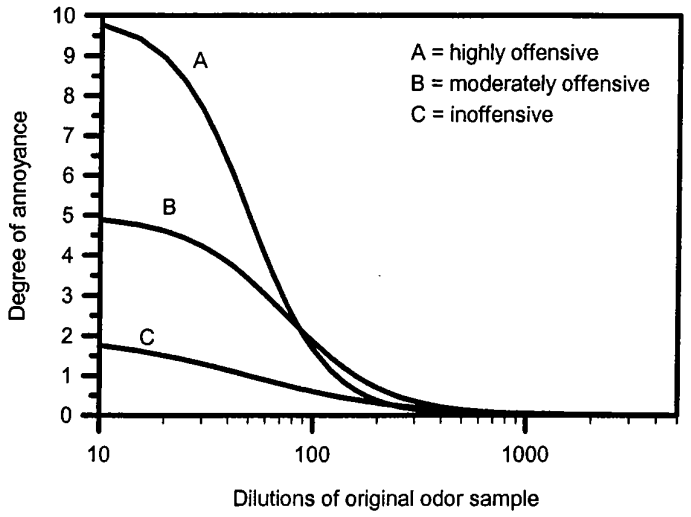

Figure 2: Degree of annoyance curves for three odors (A, B and C) with different levels of offensiveness.

Figures 1 and 2 demonstrate that the detection threshold (shown as a single point in Figure 1) does not capture all of the significant characteristics of an odor. For example, odors can have the same detection threshold (e.g. odors from sewage works, a distillery, and a fried chicken outlet) but very different levels of persistence and degrees of annoyance. Clearly the impact of these odors on a community would be quite different.

Odor Impact Model Coupled with Dispersion Modeling

In order to quantify the impact of a particular source on its surrounding community, it is necessary to assess the ambient odor levels in the neighbourhood as a result of atmospheric transport over different distances with consideration of meteorological and topographical characteristics of the region. There are variety of models which are used to predict short-term contaminant concentrations arising from dispersion. For example, some dispersion models can be used to describe the concentration of a contaminant that is being released in a continuous plume from a stack under steady-state conditions. Other models can be used to predict contaminant concentrations when the plume is emitted as a series of puffs of a given frequency and magnitude. And finally, other models are used to assess the impacts of sudden releases of very high concentrations of contaminants from a facility. The type of model which is to be chosen depends entirely on the situation being investigated.

All of these models require inputs of meteorological data, source characteristics, and site specific parameters. Some of the input data which are

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necessary to describe the source include the emission rate of the contaminant of interest, the stack height, the stack gas velocity and temperature, and the height and width of adjacent structures. Additional information must be supplied with regard to the conditions under which an emission is to be modeled, including the following: period of time being modeled (day, hour); wind direction and speed; mixing height which is a function of location on a continental scale and time of day; ambient air temperature; atmospheric stability class (a measure of atmospheric turbulence); potential temperature gradient describing the decrease in temperature with height above ground level; and a wind profile exponent describing the variation of wind speed with height above ground level. Some of the more complex models now available also require the input of information to describe the topography of the region.

Normally, dispersion models are used to calculate the concentration of a contaminant in the ambient atmosphere. However, by normalizing the predicted ambient concentrations with respect to the concentration of the emission at the source, the models can be modified to predict the dilutions of the contaminant in the ambient air. By combining the dose-response relationships from the OIM with the dilution predictions from a dispersion model, it is possible to predict the levels of annoyance and probability of detection experienced in the community surrounding an odorous source. These predictions can then form the basis for odor impact assessments.

Illustration of the Method

A simple dispersion model will be used for illustrative purposes. For example, a simple Gaussian dispersion equation which can be used to predict the ground level concentration of a gaseous contaminant at a location (x, y) is as follows (Beychok, 1994):

$$C(x,y) = \frac{M}{\pi u \sigma_z \sigma_y} e^{-\frac{y^2}{2\sigma_y^2}} e^{-\frac{H^2}{2\sigma_z^2}} \qquad (2)$$

where C(x,y) = concentration at a point x, y (mass/volume)
x = distance directly downwind from source (length)
y = perpendicular (crosswind) distance from source (length)
M = emission rate of pollutant from source (mass/time)
u = horizontal wind velocity (distance/time)
H = plume release height above ground (distance)
σ_z = vertical dispersion parameter
σ_y = horizontal dispersion parameter

The values of σ_z and σ_y are both a function of downwind distance (x) and are often calculated using the following empirical correlation of dispersion with distance:

$$\sigma = e^{a+b(\ln x)+c(\ln x)^2} \tag{3}$$

for which the coefficients a, b and c corresponding to σ_z and σ_y are available for different conditions of atmospheric turbulence (Beychok, 1994).

In the case of odors, it is of interest to calculate the dilutions of the original odor which are experienced at any location downwind. The number of dilutions at a point (x,y) is equal to the odor concentration at the point of release, C_o, divided by C(x,y). In addition, the mass emission rate, M, is equal to the source concentration, C_o, multiplied by the source volumetric emission rate, Q (volume/time). Therefore, it can be shown that the dilutions at any point, D(x,y), can be calculated from:

$$D(x,y) = \frac{\pi u \sigma_z \sigma_y}{Q} e^{\frac{y^2}{2\sigma_y^2}} e^{\frac{H^2}{2\sigma_z^2}} \tag{4}$$

where Q is the volumetric emission rate of odorous gas (volume/time) from the source and all other variables remain the same.

Figures 1 through 4 illustrate an application of the proposed methodology. The profiles corresponding to Odor B in Figures 1 and 2 represent an OIM developed for an actual odor sample (of moderate persistence and offensiveness) collected from the stack of a large industrial operation. The ED_{50} of this odor was evaluated to be 185 dilutions. The height of the stack (H) at this facility was 12.3 m and the volumetric emission rate (Q) was 230 m^3/s. On a particular day when an odor problem was noted, the wind velocity (u) was 4 m/s and the atmosphere was unstable. Thus, under these conditions the parameters of equation (3) are $a = 4.694$, $b = 1.0629$ and $c = 0.0136$ for σ_z and $a = 5.058$, $b = 0.9024$ and $c = -0.0096$ for σ_y according to Beychok (1994).

Figure 3(a) represents the ground-level dilutions predicted along the centreline of the odor plume (i.e. $y = 0$) using equations (3) and (4). The number of dilutions is very high for $x < 50$ m because the gaseous plume has not yet reached the ground level as it disperses downward from its point of release. At distances of $x > 50$ m, the number of dilutions are much lower because this is the region in which the gas plume impacts upon the ground. For distances further downwind, the gas become increasingly diluted as ambient air is entrained in the dispersing gas.

A classical method of odor impact assessment calls for the prediction of the number of odor units at any location. The number of odor units is equal to the ED_{50} of the source gas divided by the number of dilutions predicted at any point. The results are shown in Figure 3(b). According to this method of assessment, the impact of the odor is primarily confined to the region in which the number of odor units is greater than one (i.e. 40 m < x < 420 m). That is, within this region more than 50% of the resident population will detect the odor. As mentioned previously, some jurisdictions specify that an odor problem exists

when the number of odor units exceeds 7. As shown in Figure 3(b), this can be seen at a distance between approximately 75 and 125 m downstream of the source. In this particular example of an industrial facility, this zone of impact still remains within the property of the facility and would not be expected to present a problem based on the criterion of 7 odor units.

However, if the detection profile for Odor B (see Figure 1) is mapped onto the dilutions of Figure 3(a), curve B in Figure 3(c) is produced. This curve demonstrates that within the region of 75 to 125 m downwind of the source, where more than 7 odor units are experienced, approximately 98 to 100% of the population should be able to detect the odor. In addition, within 40 to 420 m, where the number of odor units is greater than one, more than 50% of the population will detect the odor. These zones match the impact zones noted in the discussion above and illustrated in Figure 3(b). However, it is noted that even at distances of 600 and 800 m, approximately 25% and 10%, respectively, of the population should still be able to detect the odor. The classical method virtually ignores the impact on this substantial fraction of the population. Clearly the zone of impact can extend well beyond the boundary defined by the classical approach.

This deficiency may be further illustrated using odors of equivalent ED_{50} but of differing persistence. As shown in Figure 3(c), if the dilutions of Figure 3(a) are mapped onto the three odor profiles of Figure 1, the length of the zone of impact changes dramatically, despite the fact that all of these odors have the same ED_{50}. Odor A (low persistence) results in a shorter impact zone with a higher fraction of people being able to detect the odor within that zone. At the other extreme, odor C (high persistence) has a very long impact zone but the fraction of people detecting odor C at any point in the zone is lower than odor A.

It should be noted that odor impact is not constrained only to regions directly downwind of the source since the plume also disperses in a perpendicular direction. This is shown in Figure 4, in which the probability of detection contours are plotted as a function of the x, y position. It can be seen in Figure 4 that the size of the region of impact, termed the "footprint", is directly a function of the persistence of the odor. If the 10% probability contour is chosen as a region of significant impact, then odor A with a low persistence has a small but concentrated footprint (i.e. it is a region with a high probability of detection), whereas odor C has a large but less concentrated footprint. If the 50% probability contour is selected, all contours have the same size of footprint (because they all have the same ED_{50}) but the fraction of people detecting the odor within those zones are quite different. That is, a larger fraction of people detect odor A within the 50% contour than odor C.

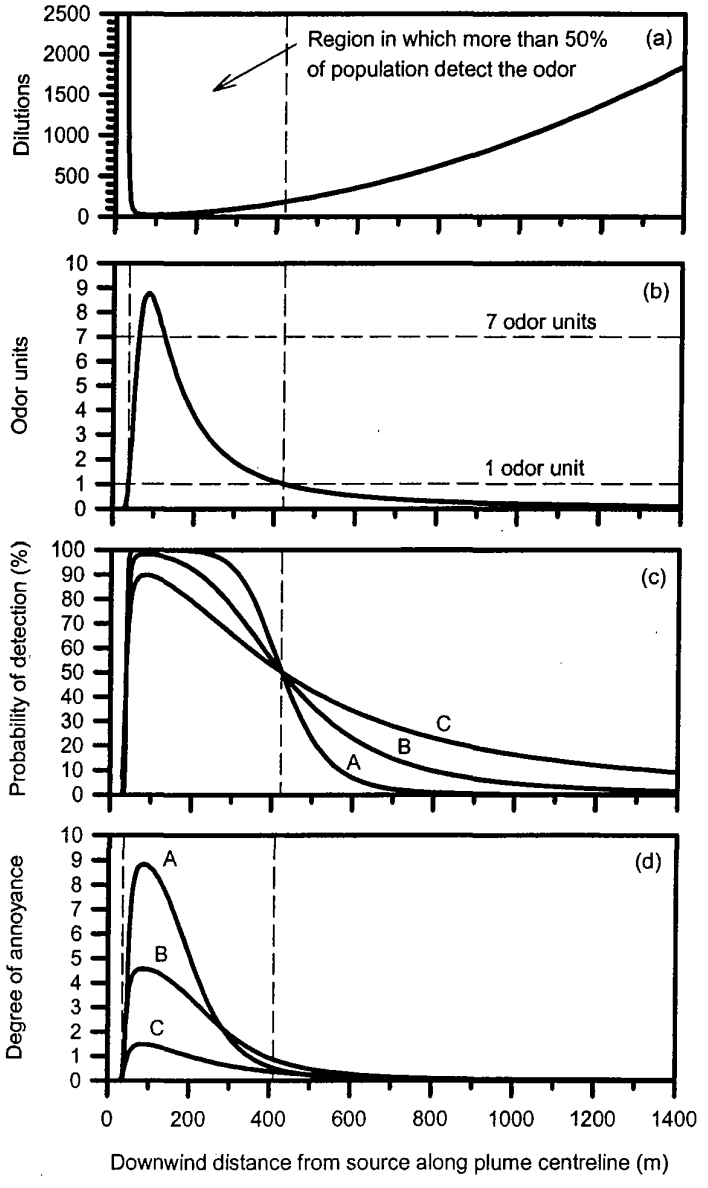

Figure 3: Dilutions, odor units, probability of detection and annoyance predicted at ground level along the centreline of the odor plume.

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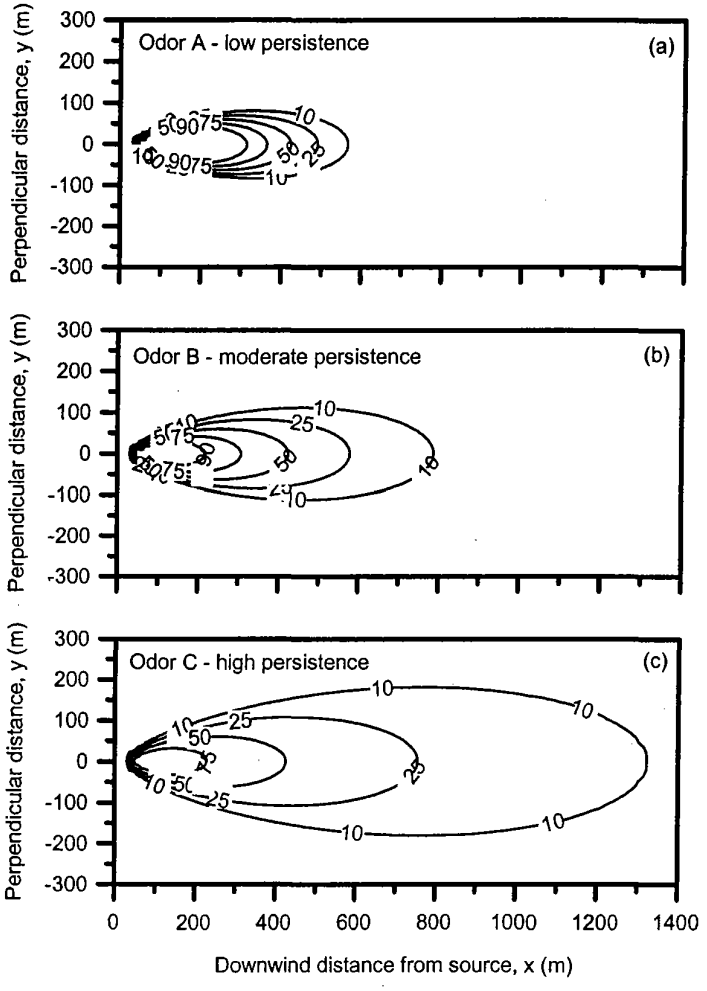

Figure 4: Probability contours for three odors (A, B and C) with equal detection thresholds but different levels of persistence.

A second dimension which is missing from the classical approach to odor impact assessment is the relative offensiveness of odors. As mentioned earlier, it is possible to have two or more odors with the same thresholds and detection profiles but of very different hedonic character. Figure 2 shows how three odors can have very different impacts on the individuals who smell them. Odor A is a highly offensive odor that has a maximum annoyance of approximately 10 on a 0 to 10 scale when it is not significantly diluted. In contrast, odor C only rates a maximum value of approximately 2 on this same scale. By mapping the dilutions of the odor in Figure 3(a) onto the annoyance profiles of Figure 2, the curves of Figure 3(d) are generated. The latter figure demonstrates that the annoyance experienced downwind of the source is quite different and, hence, is likely to generate very different responses in the neighborhood. In addition, it is also possible to generate contours of annoyance just as was done in Figure 4 for the probability of detection. The mapping of these annoyance contours would provide another estimate of the impact of the odor in terms of the annoyance that can be generated in the neighborhood.

IV. DISCUSSION

The classical approach to odor impact assessment which is based on detection threshold evaluations fails to account for the differences in impact that would be felt from the release of odors of different levels of persistence and offensiveness. By excluding these dimensions from impact assessments, the impact of odors upon individuals who are able to detect the odor at concentrations below the threshold are ignored. In addition, the failure to account for odor offensiveness ignores the fact that the impact on the psychological and physiological health of the populations is a function of the annoyance of the population. By including the persistence and offensiveness characteristics of odors in the analysis, the proposed methodology provides better indicators of the true magnitude of the zone of impact and the fraction of the population that is affected by the odor.

When comparing two odors being emitted under the same conditions, it can easily be claimed that the more offensive odor will have the greater impact. However, it should not be claimed that an odor of low persistence is better than an odor of high persistence, or vice-versa. That is, as persistence increases, the peak impact decreases (see Figure 3(c)) but the area of the footprint increases (see Figure 4). Therefore, the degree of persistence cannot be used as a quantifier of odor impact. Rather, the interpretation of odor impact must be based on the results of curves such as those shown in Figures 3 and 4. It is very likely that there will be no single parameter that can be proposed which will provide a quantitative assessment of odor impact. Rather, many different parameters can be proposed, as shown in Table 1.

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Table 1: Potential impact parameters.

Impact Parameter	Impact Quantified
Peak detection	Worse case detection in the neighborhood where the largest fraction of the population detects the odor.
Peak annoyance	Worse case annoyance in the neighborhood where maximum annoyance is experienced by the population.
Area enclosed by probability contours (detection footprint)	Size of the geographical area in which a selected fraction (or greater) of the community detects the odor.
Area enclosed by annoyance contours (annoyance footprint)	Size of the geographical area in which a selected degree of annoyance (or greater) is experienced.
Volume under probability contours	Volume represents the average probability of detection within the selected contour boundary.
Volume under probability contours × population density	Total number of people impacted by the odor within the selected contour boundary.
Volume under annoyance contours	Global indicator of the total "quantity" of annoyance experienced.

Three types of assessment parameters may be formulated: peak, area and volume parameters. Each of these parameters can be used to quantify different ways in which odor impact is experienced. Peak parameters can be used to describe the worst case situation that will be experienced in a neighborhood. Area parameters can be used to describe the extent of the region in which the impact is felt. Volume parameters (the integral under contours) can be used to sum up the total impact on a community in terms of the total number of people impacted or the total "quantity" of annoyance that will be experienced. That is, if the population density in the impact region is known, by evaluating the integral under the probability contours it is possible to estimate the number of people who would be impacted by a particular odor. Therefore, for regions in which there is sparse human habitation, the impact would be low and for densely populated areas the impact would be much larger. This would allow the land-use of a particular impact zone to be incorporated into impact assessment.

In any odor situation, it is of importance to minimize all of the parameters listed in Table 1. However, in any given situation, the influence of one parameter may dominate. For example, a situation could exist in which the peak concentration is low but the area of impact extends over a large and a densely populated area. Alternatively, a high peak annoyance could be confined to a very localized region. Potentially, one or more of these impact parameters may be found which best represent the odor impact on a community. If this is

the case, then such parameters could form the basis for the creation of regulatory standards for odors. For example, regulatory standards can be established which state that no more than a specific fraction of the community should be able to detect the odor. Alternatively (or additionally), standards for odor emissions can be set by choosing a maximum allowable degree of annoyance at any point beyond the confines of the offending industry. Poostchi (1985) suggested 2 as a maximum acceptable annoyance value which must not be exceeded in the neighbourhood as a result of emissions from any odor source. However, further study is required to justify the selection of this or any other value. In particular, future research must concentrate on correlating odor impact parameters with actual conditions in which community complaints have been registered. Also, statistical tests must be performed to evaluate the size and composition (e.g. age and gender distributions) of the panel of odor judges which are required to ensure that odor impact models are representative of the community population.

V. IMPLICATIONS

Through the use of a complete set of meteorological data for a typical year, the dispersion model can be used to identify the meteorological conditions under which the greatest impact would occur. Consequently, the severity of the impacts from different sources in a neighbourhood can be assessed and ranked. Subsequent analyses of the contours and the location of the neighbourhood impact can provide regulatory agencies and plant personnel with a basis for prioritizing their approach to resolving impacts originating from odor sources. The proposed methodology is of practical significance to any facility which produces or has the potential to produce odors. The method can be used by industries who are considering the implementation of various process changes, feedstock changes, or emissions control technologies to reduce odorous emissions. In many cases, the effectiveness of these strategies in reducing odor impact are not usually known until after they have been implemented at the full-scale. However, through use of the proposed procedure, industries will be able to collect OIM data from pilot plant studies and apply the odor impact assessment procedure to predict the odor impact on a surrounding community. The procedure will facilitate the choice of the most effective approach to reducing odor impact before implementation at the full scale. This can translate into monetary savings and improved relations with surrounding populations by allowing industries to quickly resolve conflicts concerning odor impact and by avoiding the implementation of ineffective odor control strategies.

VI. CONCLUSION

Odor impact assessment methods based on statutory nuisance laws and the dilution-to-threshold principle do not adequately meet the needs of industries or regulatory agencies which are expected to deal routinely with community odor problems. The combination of the OIM, improved dispersion modeling

techniques and community characteristics will provide a better basis for odor impact assessment by incorporating the effects of odor concentration, volumetric emission rate, odor offensiveness and persistence, source characteristics, and meteorological conditions into estimates of the impact on a community. The merging of a dose-response relationships and dispersion models may serve as the basis for the development of effective regulations or as a decision-making tool to select odor control options.

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