Development of an Odor Concentration Model and Software for Modeling Peak Odor Concentration
ABSTRACT

Odors, once tolerated as a sign of industrial prosperity are now perceived as an evidence of environmental problems. Increasing complaints from citizens regarding the noxious odors has coerced industries into addressing this "odor issue". Properties of odor are unique, due to the nature of requirements for their measurement. This can be attributed to the subjective responses of humans to various odor intensities and also to the fact that barring a few exceptions, it is not feasible to evaluate its intensity by chemical analysis because of its varied chemical composition. This is not to be confused with monitoring air quality, which is measurable. As a result, there has developed a need to quantify the damage caused due to the release of toxic odor. The existing regulatory models omit the effect of peak concentration and hence the estimated values that are obtained using these models are not able to explain the odor complaints due to a source. This paper involves the development and analysis of an odor concentration model that incorporates the peak concentration for a given mass emission rate in terms of odor units per cubic meter (o.u./m³). The highlight of this work is the calculation of peak concentration in terms of odor units. The use of a humanistic model to predict the degree of offensiveness and potential level of source annoyance is included in paper in an effort to present a tool for the development of an effective odor control strategy. The use of the “Odor Concentration Model” (OCM) has been exemplified by using Acetone, Benzene and Petrol (light).

INTRODUCTION

Odors are defined as sensations experienced as a result of the interaction of the volatile chemicals with the olfactory system in a body causing impulses to be transmitted to the brain. The type of odor and amount are both important in fixing the signal sent to the brain. Certain chemicals are virtually non-odorous and cannot be detected at any level. Other substances are odorous but quickly desensitize the human odor sensors resulting in a discontinued sensation of the odors. Downwind concentration and community impact are the important factors that are used to quantify the effects of odors.

Very low concentration of an odorous substance can produce an odor sensation indicating the presence of the odor vapors. This is the odor detection threshold. At this level, the brain may not be capable of recognizing the specific odor. At higher concentrations, the odor sensation becomes recognizable. This is this odor recognition threshold. The difference between the detection and recognition threshold varies by concentrations in the range of 2 to 10 fold for certain chemicals. A solid material can also release odorous gases due to its volatility. Small particles (10 micrometers and smaller) can be inhaled into the respiratory system and these particles interact with body fluids to create a flavor, which could give an apparent sensation of odor. Many odorous vapors are also absorbed in the body fluids of the respiratory system and we, therefore, taste them.

There are many methods, experimental and analytical, to estimate the odor concentration. One of the most popular models for estimating odor concentration is the use of classical Gaussian Dispersion model. Most plume dispersion models used are based on models developed by regulatory agencies for predicting the impact of pollution sources. These regulatory-based models focus on estimating hour-to-hour variations for typical annual distributions of meteorological variables. These models ignore short-term concentration
fluctuations, and use the hour-to-hour mean values as a measure of mean concentration variability. For intervals less than an hour, averaging time effects are ignored. These models estimate the concentration in terms of micro grams per cubic meter (µg/m³), which is not useful in interpreting the odor level.

The community impact of odors usually shows up in the form of citizen complaints, especially in summer, when windows tend to be kept open. These vary with duration of exposure, type of odor, age of the individuals and other physical and humanistic factors. Very little has been done to relate odorous episodes to community health problems. Although laboratory studies with animals have shown that some odorants can cause marked physiological and morphological changes in terms of cardiovascular and respiratory performances, there is very little information available about the toxicity or hazardous effects of odorous substances on man. In some cases, changes can occur without being perceived by the person undergoing them. In communities close to odorous sources, there may not be excess disease or infirmity, but there certainly is not a state of complete mental, social or physical well being.

However, public complaints alone cannot be a very useful measure without quantification of source and ambient odor levels. There is no validated odor model that predicts the community impact of an odorous substance. A three-step procedure was developed for quantifying the impacts of odorous sources on their surrounding communities. To solve a community problem due to odor it is necessary to establish:

- Whether a community problem is recognizable.
- How bad the odors are.
- How much odor is present.

Most hazard assessment models require estimates of peak concentrations that occur over intervals of a few seconds during a time-varying release that itself may last only for minutes, whereas regulatory agencies use hourly averages in concentration calculations. In response to the above needs, two approaches are currently being used to estimate the concentration peaks. They are:

1. The dispersion equations that predict long-term ensemble averaged mean concentrations are assumed to apply to short-term peaks. The vertical and horizontal plume spreads are adjusted empirically to match the equations to measured peak values from a few field experiments.

2. The second method uses averaging time adjustments to simulate short-term peaks. The equation for calculating the mean concentration is also used for peak concentrations, and the concentration in the plume centerline is adjusted from some arbitrary reference time to some very short time, typically a very few seconds. This short-term average is then interpreted as the peak concentration. If these "peak" concentrations agree with the maximum values observed in field experiments, the method is considered to be validated. If the agreement is poor, a few seconds are added or subtracted from the arbitrary short-term "peak" averaging time to force agreement.

Both these approaches are fundamentally incorrect because they are based on adjusted mean concentration and this cannot account for all the factors that influence real
concentration fluctuations. The only aspect that makes these approaches work in a practical sense is their reliance on field data to tune the coefficients in the model and force agreement with the reality for at least some conditions.

Hence this paper focuses on the estimation of peak concentration fluctuations by taking the mean concentrations and its variance, and using them in a concentration calculation to determine the value that is exceeded some specified fraction of the time. The software developed to calculate the odor concentration uses the Gaussian Dispersion equations except that the concentrations are calculated during the mean concentration and variance. Therefore, the final concentration is the one estimated at its peak. The model takes both rural and urban terrain into consideration and is applicable to all wind conditions. It was developed for a simple terrain in which the effects of building downwash are neglected. The results obtained using the humanistic model called the "Odor Impact Model" can be used to provide solutions while adopting a particular odor control strategy.

EXISTING ODOR MODELS

Historically, a tool developed to quantify trade-off between control and isolation distance, and to evaluate whether the odorous ambient air is acceptable is the dispersion model. The USEPA has developed, validated, and employed such models for the last three decades. Their purpose is to use the source parameter emission rate, source velocity, area and height, with typical meteorology, to calculate representative ambient concentrations at designated receptors. However, odor impacts have long been difficult to quantify. One school of thought perceives odor to follow the Weber-Frencher law like most physiological responses \(^5\). This states that the sensation of odor is expected to be proportional to the logarithm of concentration, not the concentration itself. Another system of describing intensity, dating back at least as far as 1920 uses a scale ranging from 0 - 5. This number system is subjective and represents the opinion of each member of a panel \(^6\). The basic drawbacks of these methods lie in the fact that they do not recognize the odor detection threshold, which is an important factor to be considered when predicting the odor impact.

Defining only a threshold (i.e., zero intensity) value for a compound is insufficient for understanding its odor as an air pollutant, because the slope of the concentration-intensity line is equally important in determining its effects on a community. The slope defines the rate of decay of odor sensation with successive decreases in concentration, or with successive dilutions. The range in intensity from 0 to 5 covers 8 log cycles of concentration for ethyl mercaptan, 6 for butyl thioether, 4 for crotonaldehyde. The safest number to use for atmospheric diffusion or downwind calculations is the threshold concentration. Therefore it is evident from literature that an appropriate answer is not obtained by using the graph to predict the concentration. Hogstrom developed a method \(^7\) for predicting odor frequencies from a point source on the basis of a fluctuating plume model. It is used to give odor frequencies around a point when the odor threshold of the material emitted is determined by sensory methods. A fluctuating plume puff model was developed by Bowne at TRC, which incorporated the puff dispersion coefficients developed by Hogstrom. This predicts the number of occurrences of specified odor dilution ratios during a specified period, such as 1 hour. The staff at the Odor Science and
Technology, Inc has developed a variant of this model 8. The main drawback in using this model to predict the downwind odor concentration is that it does not take into account the short-term concentration fluctuations.

So far all studies have restricted themselves to estimating the downwind concentration. Very little attempts have been made to measure the annoyance caused by odors. Pootstchi 3 proposed a procedure for quantifying the impacts of odorous sources on their surrounding communities. Until the Pootstchi study no documented procedures were available for accessing the magnitude of community annoyance due to odors. Based on his ideas, a fast simple and accurate method was developed. This is called the Odor Impact Model (OIM). This model includes the needed probabilities of detection and complaint as well as the predicted degree of annoyance. The approach takes into account the short-term concentration fluctuations for accurate peak concentration predictions. The downwind concentration will be calculated based on the mass emission rate obtained at peak concentration.

**METHODOLOGY AND MODEL DEVELOPMENT**

It was planned to develop the proposed model by combining in parallel a variant of the Gaussian Dispersion model and the Odor Impact model. The improvements in the Gaussian model are the introduction of peak concentration ($C_{\text{peak}}$), calculation of the odor emission rate in terms of odor units and the estimation of the maximum downwind concentration in terms of odor units. The Odor Impact model is used to determine the Degree of Offensiveness (DO) and Potential Level of Source Annoyance (PLSA). These values of DO and PLSA along with the maximum downwind concentration can be used to map an effective odor control strategy. The diagrammatic representation of the proposed model is shown in Figure 1.

**MODEL ASSUMPTIONS**

The basic assumptions in this model are:

1. The emission rate $Q_o$ is constant and continuous.
2. The horizontal wind velocity and mean direction are constant.
3. The use of $\sigma_y$ and $\sigma_z$ as constants at a given downwind distance assumes homogeneous turbulence throughout the plume.
4. The plume is not intermittent, and $i = c'/c$, where $\gamma$ is intermittency factor, $i$ is the fluctuation intensity, $c'$ is standard deviation of concentration, $c$ is the average concentration.
5. $L_c$, the eulerian length scale of concentration fluctuations as taken as 0.5 since $k_{\text{cut}}L_c = 10$.
6. The cut off wave number $k_{\text{cut}} \equiv 20\text{m}^{-1}$.

**ODOR MODELING STRATEGY**

*The Peak Concentration $C_{\text{peak}}$:*
C<sub>peak</sub> modifies the hourly averages to estimate the peak concentration taking into account the short-term fluctuations. Wilson proposed a method to calculate the peak value for a specific averaging time 't<sub>s</sub>'. His work is based on a statistically correct definition for peak concentration. Hence C<sub>peak</sub> is defined as "the concentration that is exceeded 'n' times in a statistically independent ensemble of 'n' repeats of an event". According to this definition, the peak value is exceeded on an average once per event in a large ensemble of events. This peak value C<sub>peak</sub> is calculated as shown in the definition below:

\[
\frac{C_{\text{peak}}}{C} = \frac{0.260n_{\text{cut}}^{2/3}t_s i}{T_c^{1/3} \left( \ln(1 + i^2) \right)^{0.5}} \exp \left[ \frac{\ln \left( \frac{C_{\text{peak}}}{C} \left(1 + i^2\right)^{0.5} \right)}{2 \ln(1 + i^2)} \right] 
\]

\[\ldots \ldots \ldots \ldots .(1)\]

where,

- C<sub>peak</sub> peak concentration
- C mean concentration
- t<sub>s</sub> continuous sampling time, s
- n<sub>cut</sub> U K<sub>cut</sub>/2π ,
- n<sub>cut</sub> frequency at high cutoff, Hz
- \(\pi\) mathematical constant, 3.14...
- U wind speed, m/s
- K<sub>cut</sub> cutoff wave number of concentration fluctuation, 1/m
- i fluctuation intensity (ratio)
- T<sub>c</sub> Eulerian integral time scale of concentration fluctuations about the mean C, s
- L<sub>c</sub>/U Eulerian concentration length scale, m

**The threshold-crossing rate \(N^+\)**

In order to find the number of times a particular concentration level \((C^*)\) is exceeded, the threshold-crossing rate is monitored. Following the definition for the peak concentration, when \(C^* = C_{\text{peak}}\), the concentration must be exceeded only once per sampling time \((t_s)\) i.e.,

\[N^+ = t_s^{-1}\]

**The concentration fluctuation intensity 'i'**

This term is defined as the ratio of standard deviation \(c'\) to the mean \(C\) of the concentration values.

\[i = \frac{c'}{C}\]

The 'In-plume' conditional statistics are obtained by excluding the zero-concentration time periods

\[i_p = \frac{c_p'}{C_p}\]

**Intermittency Factor \((\gamma)\)**

The intermittency factor, which is the fraction of time source material is present at the receptor, is calculated as given below
Based on the assumptions mentioned earlier the Wilson's formula for the threshold crossing rate is given as shown below:

\[
N^+(t) = \frac{0.542(K_{cut}L_c)^{2/3}}{4\sqrt{\pi}L_c} \left[ \frac{c'}{C_{peak} \left( \ln(1 + i^2) \right)^{0.5}} \right] \exp \left[ -\left[ \frac{\ln \left( \frac{C_{peak}}{C} \left(1 + i^2\right)^{0.5} \right)}{2 \ln(1 + i^2)} \right]^2 \right] \tag{2}
\]

Substituting into the equation (2) the relationships derived in the above section of the odor modeling strategy, we get the final equation of \( C_{peak} \) as shown in equation (1).

**ODOR INTENSITY IN TERMS OF ODOR UNITS (O.U.)**

Using threshold concentration as a basis, an attempt must be made to arrive at some quantitative value on odor in order to estimate the odor intensities which can in turn be plugged into the diffusion equations to predict the downwind concentration\(^9\).

The ratio

\[
\frac{\text{ml odor-free air} + \text{ml odorous air}}{\text{ml of odorous air}} \tag{3}
\]

gives the number of odor units/cubic meter in the source gas. This ratio is the odor intensity. Converting it into concentration units the ratio becomes

\[
\frac{C_g}{C_1} = \frac{\text{Original Concentration}}{\text{Threshold concentration}} \tag{4}
\]

For example, to say that a sample of gaseous emissions contains 10 odor units/ ft\(^3\) means that when one part of the sample is diluted with nine parts of odor-free air, the resultant mixture will have a barely detectable odor. It is a concentration, but it states nothing in terms of pounds per minute. Therefore, as in the case of particulate matter discharges, it is necessary to know the air flow rate in the duct or stack in cubic feet per minute (cfm).

The product of flow rate times its odor intensity gives the odor units emitted. To be specific, if an odor source has a concentration of 10-odor units/ft\(^3\), and a flow rate in the vent or stack of 10 cfm, the odor output would be

\[
10 \text{ odor units/ft}^3 \times 10 \text{ cfm} = 100 \text{ odor units / minute}
\]

It is this value, 100-odor units/minute, which can be used in the atmospheric diffusion equations in the same manner as the pounds of SO\(_2\) per minute used in these equations. While this approach is not strictly dimensionally correct, it does allow for numerical computation of odor emission by diffusion equation\(^10\). When the downwind concentration is calculated for peak concentration, the ratio given in equation (4) becomes

\[
\frac{C_{peak}}{C_1} = \frac{\text{Original Peak Concentration}}{\text{Threshold concentration}} \tag{5}
\]
where, $C_{\text{peak}}$ is given by equation (1)

**ODOR EMISSION RATE, $Q_0$**

For odor modeling purposes, the mass emission rate is calculated in terms of odor units, i.e., the product of the measured odor intensity given by equation (5) and the volumetric flow rate\(^8\). Hence when this product which is the odor emission rate is used as an input to the model, the results are also in odor units. It is given in odor units/ min.

$$Q_0 = \text{Odor Intensity} \times \text{Flow Rate} \quad \text{…………………………….}(6)$$

**CONCENTRATION MODEL**

Generalized Gaussian Dispersion Equation for continuous point source plume can be used to estimate odor levels. In terms of the odor problems, the primary concern is usually with their ground-level concentrations. For that case, the ground-level centerline and crosswind concentrations are obtained by the following equation:

$$C = \frac{Q_o}{2\pi u \sigma_y \sigma_z} \exp \left[ -\frac{1}{2} \left( \frac{y}{\sigma_y} \right)^2 - \left( \frac{h_e}{2 \sigma_z} \right)^2 \right] \quad \text{………(7)}$$

where,

$C$ concentration of emissions, o.u., at any receptor located at,
\(x\) meters downwind
\(y\) meters crosswind (from centerline)
$Q_o$ odor emission rate, o.u/min.
$\sigma_y, \sigma_z$ standard deviations of the vertical and lateral concentration distributions, m
$u$ mean wind speed at the release height in m/s
$\pi$ mathematical constant equal to 3.1415926...
$h_e$ effective height of the centerline of the plume, m

The values of $\sigma_y, \sigma_z$ at a particular downwind distance can be obtained using the formulae proposed by Pasquill-Gifford, Briggs and others. This model also requires specification of a wind profile exponent for each P-G stability class.

**ODOR IMPACT MODEL**

The Odor Impact Model is developed based on an extension of the detection threshold determination using a 5 or 6 level dynamic dilution olfactometer\(^11\). The intensity of annoyance to each panel member is measured on a scale from 0 (no annoyance) to 10 (maximum measure of annoyance) as subdivided:

0 to 2 Tolerable
2 to 4 Unpleasant
4 to 6 Very unpleasant
6 to 8 Terrible
8 to 10 Unbearable
The intensity of an odor can be determined in terms of an experimentally determined dilution level at which the panel members complain. Such a dilution level is defined as the maximum dilution level (MDL) at which 100% of the panel members complain about the odor under consideration (designated as MDL @ 100 PPC). It is nothing but the Odor Intensity \( \frac{C_{\text{peak}}}{C_t} \) at which the odor is detectable. Hence this value is obtained from equation (5).

The magnitude of annoyance at any dilution level accounts for the hedonics of the odor. The measure of the hedonics is provided by the degree of annoyance at 100% probability of complaint, designated as PDA\(_{100}\). This quantity is not an accurate one since it varies from person to person depending upon the physiological responses.

The offensiveness of the odor is determined by its

- intensity (MDL @ 100 PPC) and
- hedonics (PDA\(_{100}\))

On this basis, it is possible to quantify "how bad" an odor is in terms of what can be considered as the degree of offensiveness (DO). It is defined by:

\[
DO = (\text{MDL @ 100 PPC }) (PDA_{100})
\]

where,

- MDL@ 100 PPC = Odor Intensity, odor units/ft\(^3\) or ft\(^3\)/ft\(^3\)
- PDA\(_{100}\) = predicted degree of annoyance at the 100% complaint threshold on a scale 0 to 10

The degree of offensiveness (DO) is only a measure of "how bad" an odor is at the source. It does not say anything about the impact on a downwind receptor. In spite of its importance, the degree of offensiveness (DO) is not a true measure of the odor impact of any particular odor source on a community without consideration of the amounts of odor emitted per unit time. A low emission rate of an odor with a high DO can be less serious than a high volumetric flow rate of an odor with relatively lower DO in terms of impact on a downwind community or degree of control required at the source.

The potential level of source annoyance (PLSA) establishes how much odor is at source. Since a low emission rate of an odor with a high DO can be less serious than a high volumetric flow rate of an odor with a relatively lower DO, the PLSA is a means of ranking the seriousness of various odor emitting sources. The PLSA is evaluated as

\[
\text{PLSA} = (\text{DO}) (V_o)
\]

where,

- DO Degree of Offensiveness from (8)
- Vo source volumetric flow rate, cfm.
These calculated values of DO and PLSA, along with the downwind concentration at peak concentration can be used to map an effective control strategy.

**THE SOFTWARE DEVELOPMENT**

The steps in the execution of the computer program are outlined in detail below:

1. A terrain choice directs the program to calculate either rural or urban dispersion coefficients.
2. An option which specifies either
   (I) atmospheric stability classes A, B, C and, D or
   (II) atmospheric stability classes E & F.
   so that the program may select the appropriate plume rise equations to use.
3. An option to choose the specific pollutant.
4. Choice to enter the initial downwind receptor distance at which ground-level concentrations for the specified pollutants are to be calculated.
5. Once the input values are taken in and the specific choices are made, the variables are initialized.
6. The output is produced as a report which has iterative values of distances calculated.
7. The program provides flexibility to calculate the average concentration and the peak concentration with.
8. The start subroutine calls the other functions like $u_{he}$, $h_e$, $n_{cut}$, $C_{peak}$.
9. The final concentration will be calculated once all the other functions are called and the respective values substituted in the final equation.
10. The final output screen has the values of maximum concentration which had occurred in the 10 iterations. Then the Degree of Offensiveness and Potential Degree of Source Annoyance (PLSA) values are also provided for the maximum concentrations for a specific sampling time.

Other than the variables, which depend upon, test conditions and input from users, the equations use constants, which have been incorporated into the code. Some of these constants are already explained i.e., in the assumption section of model development. The code for the above algorithm was written in Access Basic Programming language.

**Input Data**

The input data required for the application of Odor concentration Model include:

a) Source characteristics
b) Topography
c) Meteorology
d) Peak Concentration
e) Database to store the Threshold concentration

**Description of the GUI Application**
The Odor Concentration Model is an application, which estimates the peak odor concentration at any given point on input of the appropriate data. The reason for calling this an application is that it is coded in such a way that the Gaussian dispersion equation is incorporated in the algorithm. Although the algorithm can be coded in any programming language like C or FORTRAN, the windows based GUI is chosen due the ease in use and the popularity of the windows based system. The application is developed in such a manner that even a layman can input data and get results. A tutorial is provided with a detailed explanation of the different terms used and the procedure to use the odor model. The model is a user-friendly, interactive tool, which allows the user to input, values and stores them in memory, until the user presses the result icon. The output generated from the model can be routed to the printer or can be saved on a floppy for future reference.

The application is developed in Access 7.0 on a Windows 95 operating system. Another copy is developed in Access 2.0 on Windows 3.1. The GUI (front end) and the database (back end) for the model have been developed in Access. Although these are the design environments, the application can run on any personal computer having Windows 3.1 or higher. On use of Access 2.0 version of this software on Windows 95, when opening of the application, the convert database option should be chosen. In case the Access software is absent on the computer, the application has to be installed on the computer by running the setup disks. Once the setup is done, the application itself is a stand-alone and can be used without the requirement of the disks. However, if the Access database is present on the computer, then it is not necessary to run the setup disks. The user can copy the files onto the hard disk and run the application.

The application consists of four screens. The switchboard which has the options for data entry, tutorial, and quit. The next two screens are the data entry screens which are self explanatory. The first input screen is the one used to input meteorological data. There are options for going back, going to the next screen and help. Similarly, the second screen too, has the above three options, but instead of the next we have the results option. This screen is used to input source characteristic data. The last screen is the results screen which has the option for Odor Impact Model. Depending on whether the user wants the quantitative measure of the Degree of Offensiveness and the Potential Level of Source Annoyance, this option can be chosen. This prompts for a value in the range 0-10. The detailed explanation about this input value is provided in the tutorial. The model requires lot of input data for calculation. Care has to be taken while entering the input data. Erroneous data, such as alphabetic characters, negative values where not expected and division by zero, must be avoided. The units are already specified and care should be taken to input the values in the same units. Hence, dimensional accuracy has to be maintained to get accurate results.

Upon execution of the application, the close option takes the user to main form. The exit option takes the user out of the application. To run another set of values, after coming to the main form, the same procedure is adopted as before. Finally, if the user wants to quit the application, the exit option can be used. This takes the user out of the application.
RESULTS AND DISCUSSIONS

The literature review clearly indicates that there are several methods available for detecting odor, but the human nose is the best detector with high sensitivity to ascertain chemicals at extremely low concentration. There is no single model, which can be used to calculate the peak odor concentration. This paper aims to calculate the peak downwind concentration by modifying the Gaussian model for a given mass emission rate in terms of odor units. It is also clear from the literature review that, to formulate an operational model for concentration fluctuations that is based on the current state of knowledge of dispersion processes, requires assumptions of arbitrary values. This is due to the lack of knowledge regarding physical parameters needed to model concentration fluctuations.

Due to lack of field data, the results in this paper are presented using a set of input conditions. Therefore, it is difficult to quantify the accuracy of predicted odor concentration. However, proposed model generated concentrations are compared with the USEPA’s SCREEN 2 model for identical input conditions to show the differences in the results to give an idea of the concept of peak concentration.

There is a set of limited chemicals for which the odor threshold is available. Of the 63 pollutants listed in the software, extensive behavioral study was conducted on Acetone and a selected test runs were conducted on Benzene and Petrol (light). Model test runs are made under varying wind velocity and stability conditions. The different wind velocity values considered to test the model are 2 m/s, 3 m/s and 5 m/s for the specific stability classes. The wind velocities chosen are within acceptable limits as used by the USEPA in SCREEN model. For instance, the maximum wind velocity for stability class B is 5 m/s. A higher value than 5 m/s is not valid. Hence, care has been taken to input the acceptable values only. This does not limit the applicability of the software.

The parameters taken into consideration for source data are stack height and exit velocity. The different stack heights considered to test the model are 10 m, 76 m and 100 m. The exit velocities considered were 6 m/s, 4 m/s, 3 m/s and 2 m/s.

The odor model computes the peak odor concentration, $\sigma_z$, $\sigma_y$, and original concentration for 10 iterative distances. The DO and PLSA values can be calculated for a particular odor concentration.

Analysis of Peak Odor Concentration

The input parameters for the odor model include meteorological data, source characteristics and sampling time, which affect the calculation of peak odor concentration. The study of the effect of variation of these parameters on the peak concentration helps in understanding the underlying phenomena in an odor concentration model and also helps predicting the peak values under different conditions. The meteorological conditions (e.g.: stability class and wind speed), land use, sampling time, and source characteristics such as stack height, stack exit velocity, etc., affect the
concentration values to varying degrees. The influence of some of the above parameters on the behavior of the peak concentration has been analyzed.

One of the important input parameters in the odor model is the sampling time \( t_s \). To study the effect of sampling time on the peak concentration, the model is executed for various values of sampling time. The values of sampling time used for the analysis are 5 min., 15 min., 30 min. and 1 hr. The peak odor concentrations for the various sampling times for the different stability classes are given in Figure 2. The peak odor concentration increases with sampling time for a given downwind distance. The variation of peak odor concentrations with atmospheric stability for a given sampling time is shown in Figure 3. The changes in peak odor concentration with stability are similar in nature for different sampling times. A comparison of peak odor concentration and the SCREEN2 concentration for stability class A is given in Figure 4. Note that the output of SCREEN2 model is not affected by sampling time. Figure 4 shows that the peak concentration is approximately 6 times more than the SCREEN2 concentration for stability class A and sampling time of 1 hr.

The land use and wind speed \( u \) are also useful parameters in analyzing the behavior of peak concentration. This is shown in Figure 5 as a function of atmospheric stability. Urban peak concentrations are generally lower than the corresponding rural peak concentrations because of much more dilution due to atmospheric turbulence.

Another parameter, which is affected due to the change in wind speed, is the \( n_{\text{cut}} \) value or the cut off frequency. This is an important parameter in calculating \( C_{\text{peak}} \) value. Figure 6 clearly shows the increase in \( n_{\text{cut}} \) value as the wind speed increases. From Figures 7 one could determine the percentage increase in the peak odor concentration relative to corresponding values of SCREEN 2 model for increasing values of wind speed. Using Figures 6 and 7 one could conclude that the percentage increase in the peak odor concentration relative to corresponding values of SCREEN 2 model grows with the increasing \( n_{\text{cut}} \) values.

Another important source characteristic that should be taken into consideration while calculating the peak odor concentration is the stack height. The effects of change in peak concentration due to varying exit velocities for three different stack heights are shown in Figure 8. The qualitative behavior in the change of peak concentration with downwind distance for these two parameters (stack height and exit velocity) is similar to the output of a Gaussian model.

Acetone was studied extensively and the above runs were conducted on it. But for comparison with the other chemicals, Benzene and Petrol (light) were selected. The different stability classes considered for test runs are A, B, and D. The variations in peak concentration for the three chemicals due to varying stability classes are shown in Figure 9. The difference in the profile can be attributed to the difference in the threshold value for the three chemicals.

**SUMMARY AND CONCLUSIONS**

The results presented in the above section indicate that the peak odor concentrations differ significantly from the SCREEN2 concentrations under different wind velocities and stability. The behavior is very prominent as the sampling time is varied. The results
discussed in the earlier section help in arriving at varied conclusions regarding the qualitative behavior of the model. The conclusions, which are drawn from this study, are:

1. The analysis of model behavior for varying sampling time indicated an increase in the peak odor concentration for a given downwind distance. The increase in peak concentration is a function of sampling time and downwind distance.
2. The factor, which gets affected due to the increase in wind speed, is the $n_{\text{cut}}$ value. This is an important parameter in calculating the $C_{\text{peak}}$ value. Results show that the percentage increase in the peak odor concentration relative to corresponding values of SCREEN2 model grows with the increasing $n_{\text{cut}}$ values.
3. As predicted, the stack exit height has considerable effect on both the peak concentration and SCREEN2 concentration. This is due to the fact that the model behavior is directly dependent on the effective stack height value. Therefore, the smaller the stack height, the odor problems are more evident. The graphs clearly show the increase in peak concentration due to reduction in the height of stack. The exposure to such high concentrations can prove to be fatal, at times.
4. The three chemicals studied for the comparison show that Acetone is more likely to cause odor problems than Benzene or Petrol. If Benzene crosses the threshold level it can cause serious problems to the surrounding community.
5. As predicted, the stack exit height has considerable effect on both the peak concentration and SCREEN2 concentration. This is due to the fact that the model behavior is directly dependent on the effective stack height value. Therefore, the smaller the stack height, the odor problems are more evident. The graphs clearly show the increase in peak concentration due to reduction in the height of stack. The exposure to such high concentrations can prove to be fatal, at times.
6. The OCM developed concentrations are compared with the USEPA's SCREEN 2 model and the results clearly indicate several fold increases in the peak concentration values. Hence, it is very clear that when the SCREEN2 concentration values are used in hazard assessment models, we are bound to ignore the effect of peak values of fluctuating concentrations. Also in many odor problems it is difficult to explain the continuing complaints of residents using SCREEN2 type approach.

Some of the conclusions are also helpful in planning future work needed to improve the model or even in determining the shortcomings of the model predictions.

REFERENCES:

5. Air Pollution Control Association Semi-Technical Seminar; *Odors: Their Detection, Measurement and Control*; Rutgers University, New Jersey, 1970.


Figure 1. Diagrammatic Representation of the Odor Concentration Model.

Figure 2. Influence of sampling time on Odor Concentration vs. Downwind Distance for various stability classes.
Figure 3. Comparison of odor concentration for varying stability class under various sampling times.
Figure 4. Odor concentration vs. SCREEN2 concentration for stability class A under various sampling times.
Figure 5. Urban vs. Rural values for wind velocities 2m/s, 3m/s for different stability classes.

Figure 6. Wind Speed vs. Cut Off Frequency.
Figure 7. Odor concentration vs. original concentration for different wind speed.
Figure 8. Effect of effective stack height on odor concentration for varying stack exit velocities.
Figure 9. Comparison of concentrations of Acetone, Benzene and Petrol (light) for different stability classes.