공학 연구논문집 제24권 제1호 pp. 227~235, 울산대학교
Journal of Engineering Research Vol. 24, No. 1, pp. 227~235, 1993,
University of Ulsan.

Modeling Methodology for Determining Odor Dilutions to Community Odor Threshold Values of Odor Causing Compounds at Sanitary Landfills

Duk-Man Song
Dept. of Chemical Engineering

Abstract

This study is to provide reasonable guidance for evaluating acceptable community odor threshold, and to develop a method for evaluating odor dilutions to community odor thresholds associated with appropriate horizontal isolation distances. The one odor unit strategy incorporated into modeling and analysis provides reasonable criteria for evaluating alternative horizontal isolation distances at sanitary landfills. For effective odor reduction, this study suggests that horizontal isolation distance must provide at least 10^3 dilutions from the original concentration to render odorous compounds odorless.

INTRODUCTION

In a study of gas emissions from sanitary landfills in Great Britain [1,2], 100 organic compounds were analyzed, however, only 15 of these were found to have a high odor intensity. Odor causing compounds can be divided into two groups [2-6]. The first group is dominated by esters and organosulfurs. Of these, methyl mercaptan is a chief constituent with a high odor intensity. It smells similar to hydrogen sulfide (rotten eggs), and is often confused with that chemical, but has a much greater odor intensity. At some sites, gases at the landfill surface containing methyl mercaptan required as much as 10^6 dilutions to render them odorless [2]. The second group of odor causing compounds is alkyl benzenes and limonene. Gases containing these compounds at sanitary landfills required 10^3 to 10^4 dilutions to render them odorless [1].

Contrary to popular belief, hydrogen sulfide is rarely the cause of odors associated with household refuse at landfills [2]. However, this compound has been a major source of odors where gypsum, either as wall board or as quarrying waste, has been disposed of in large quantities [2]. This gas can require as much as 10^8 dilutions to render it odorless [2], and therefore a significant odor source.

Studies in West Germany [7] and Great Britain [8] indicated that CH_4 is an effective tracer gas for odorous constituents when diluting and mixing with air occur. Results from a pilot study in Great Britain [2] indicated that the number of dilutions necessary to reach odor threshold were always proportional to the CH_4 concentration in the gas samples. Further experiments [1] were conducted using CH_4 concentration as an odor intensity indicator in ambient air around older landfills. These experiments also indicated that odor intensity in ambient air could be predicted by measuring CH_4 concentration. Even though the total concentration of odor causing compounds is proportional to CH_4 concentration, odor intensity is dependent on the combination of specific odor causing compounds gathered from the source. Odor intensity is therefore not necessarily proportional to the total concentration of odor causing compounds or CH_4 concentration [5,9].

For this study, CH_4 was chosen as a tracer gas [2, 3, 5, 6, 9] because it is present in detectable concentrations at all sanitary landfills and in all but the earliest phases of waste biological decompositions. In addition, it is generated in proportion to the majority of odor causing compounds at sanitary landfills. Finally, inexpensive real-time monitoring equipment is readily available.

LANDFILL EVALUATIONS

The Applied Science and Technology, Inc. (ASTI) measured gas concentrations and flux rates from landfill surfaces using an isolation flux chamber [5, 9, 11, 12], which was designed and operated according to USEPA guidelines [10]. For all sampling locations, CH_4 was chosen as a tracer gas for measuring total hydrocarbons concentration [5, 9, 11, 12].

The Wayne County Air Pollution Control Division (WCAPCD) collected discrete gas samples at selected locations and analyzed according to the principles of the American Society for Testing and Materials (ASTM) method D-1391 [5, 9, 11, 12]. The response of an odor panel, using a forced choice dilution syringe method, was employed to estimate dilutions to community odor thresholds. These dilutions define the odor intensity, in odor units, for each monitored source.

Based on site sampling data to determine source odor intensities, dispersion modeling predicts community odor thresholds at selected receptors for each modeling scenario, and subsequently determines dilutions to community odor thresholds of odorous compounds at sanitary landfills.

DISPERSION MODELING METHODOLOGY

1. One Odor Unit Strategy

The fundamental problem in odor quantification would be how to define odors as objectionable. One way to quantify odors is through the use of the "odor threshold". The odor threshold is the number of dilutions of an objectionable gas necessary to dilute it to the point where the odor is barely discernible.

When evaluating landfill odors, total gas generation must be considered in conjunction with odor intensity. Odor intensities are obtaind from field sampling and can be reported in odor units. The odor unit, used to quantify odor intensity, is a relative measure of the dilution factor necessary to render the original odorous compounds odorless. It is a common procedure in sensory analysis to express community odor thresholds in terms of dilution factors instead of concentrations [5, 9]. Therefore, the number of odor units is generally defined as the number of dilutions to community odor threshold values.

Thus, determining the number of odor units in odorous compounds provides crucial information about how much odor emissions must be diluted to reach the minimal level of detection. If the odor unit strategy is to be used as the criterion for model evaluation, the issue is one of determining that number of units that should be considered acceptable.

To provide an additional measure of conservatism, we adopted one odor unit as the community odor threshold values for this study. One odor unit is generally defined as the quantity of a mixture of odorous compounds (odorants) in 1 m^3 of air just detectable by 50% of the population [9, 11, 12].

This value was chosen [5, 9, 11, 12] because research indicates that odor panels have difficulty in detecting levels of odor below 25 odor units. In addition, although we cannot define the level of odor which consititutes a nuisance, we can assume that an emission that results in off-site concentrations below the level of detection level will not be a nuisance. A zero odor unit of detection is also impossible to predict.

2. Dispersion Modeling and Model Scenario

2-1. Dispersion Modeling

We cannot establish a precise relationship between odor units in odorous compounds and the occurrence of a nuisance. However, we can incorporate conservative assumptions into the modeling and analysis to provide reasonable guidance for evaluating acceptable community odor threshold values and for determining appropriate horizontal isolation distances [5, 9, 11, 12]. If the source strength of a particular odor causing compound is input to ISCST Dispersion Model, concentrations of that compound at the receptor, could be compared to odor threshold information. Community odor threshold values can vary significantly depending on the procedures and the instruments used to measure them.

Given a quantified source strength, dispersion modeling will allow a quantitative prediction of receptor concentration. For odor dispersion modeling purposes, the source strength (Q) could be quantified as follws:

$$Q = v \cdot A \cdot C \quad (1)$$

The dispersion model predicts a concentration (χ) which is proportional to the source strength (Q).

The dilution factor (D) is defined to be:

$$D = C/\chi \quad (2)$$

The dilution factor is independent of the actual source strength. Thus, any consistent set of units can be used for the input concentration. Using Turner's simplified equations [13] for ground-level downwind plume centerline concentration with no effective plume rise ($\triangle H$), we obtain the predicted concentration as follows:

$$\chi = Q/(\pi\sigma_y\sigma_z u)=(vAC)/(\pi\sigma_y\sigma_z u) \quad (3)$$

Then,

$$D = C/\chi=(C\pi\sigma_y\sigma_z u)/(vAC) \quad (4)$$

$$D = (\pi\sigma_y\sigma_z u)/(vA) \quad (5)$$

Thus, the quantity χ (=C/D) directly represents the predicted ambient concentrations in odor units comparable to those determined by the odor panel. The odor unit, a relative measure of the dilution factor, can be used to quantify odor intensity obtained from the field sampling. Consequently, we can express community odor thresholds in terms of dilution factors instead of concentrations [5, 9, 11, 12].

2-2. Model Scenario

This dispersion modeling was performed in two parts [5, 9, 12]. First a hypothetical modeling includes single source and multiple source scenarios with various hypothetical landfill configurations. This modeling scenario involved a simple circular geometry to surround a square landfill zone. Second Ann Arbor case modeling includes actual complicated geometry and source functions for 3 different configurations based on historical operational and design changes. This modeling scenario used the actual locations of five odor sources in the sanitary landfill as input functions into the ISC Terrain Model.

Modeling was conducted using the Industrial Source Complex (ISC) Dispersion Model with standard preprocessed meteorological data from the Detroit and Flint Bishop Airport for January or October of 1976, and using one hour averages for odor intensities. Worst case conditions were used to compute the concentration profiles as a distance for each of 16 radial spokes of a polar grid.

RESULTS AND DISCUSSIONS

An absolute flux of 0.001 $g/m^2/sec$ of tracer gas was hypothetically used for this study [5, 9, 12]. If we assume that this source was either from the open tipping face or the final cover, then the average velocity of tracer gas through flux measurements was estimated to be 2.54×10^{-5}m/sec [5, 9]. Thus, the effective tracer concentration at the surface is C=Q/v=39.4g/m^3 (=39.4×10^6 $\mu g/m^3$). As the density of dry air at 0℃ and 760 mmHg is $1.29 \times 10^3 g/m^3$, this could be a 3% ([39.4g/m^3]/[$1.29 \times 10^3 g/m^3$]=0.03) of tracer concentration in ambient air.

Some investigations indicated that most odors associated with sanitary landfills are from trace concentrations that comprise less than 1 to 2% of total landfill gases [1, 2]. Of these constituents, most odors stem from volatile organic compounds (VOCs). Although this research program has little work done to quantify the effects of VOCs emissions, it was found that this result provides a reasonable tracer concentration for study sites.

Based on this tracer gas concentration, first we considered the hypothetical landfill dilutions calculation for a small square area with a diameter of 30.48m(100 feet). As shown in Figure 1(a), at a distance of 135m (442.9 feet) from the property line and 67.5° in wind direction, the predicted hourly averaged second highest concentration (χ) is equal to 5.5×10^3 $\mu g/m^3$. Thus, the minimum dilution factor at 135 m from the property line would be calculated as follows:

$$D = C/\chi = (39.4 \times 10^6\ \mu g/m^3)/(5.5 \times 10^3\ \mu g/m^3) = 7.2 \times 10^3$$

Intrapolating to the hourly averaged second highest concentration at 183 m (600 feet) from the property line and 45.0° in wind direction, the predicted hourly averaged second highest concentration (χ) would be 3.5×10^3 $\mu g/m^3$. Thus, the dilution factor at 183 m from the property line could be approximately:

$$D = C/\chi = (39.4 \times 10^6\ \mu g/m^3)/(3.5 \times 10^3\ \mu g/m^3) = 1.13 \times 10^4$$

Second, if the area size of hypothetical landfill were expanded to larger square area with a diameter of 1,000 m, then we could extrapolate to the hourly averaged second highest concentration at 200m (656 feet) from the property line and 45.0° in wind direction as shown in Figure 2(a). That predicted concentration value, χ would be 3.72×10^4 $\mu g/m^3$, which could represent a minimum dilution factor (D) of 1.06×10^3.

Great Britain research [1] found that some odorous gas samples at the surface of sanitary landfills required a 10^3 to 10^4 dilution to render them odorless. As a result, for effective odor reduction, this study suggests that horizontal isolation distance must provide at least 10^3 dilutions from the original concentration to render odorous compounds odorless [5, 9].

For a single source, this approach is exactly correct; the dispersion model simply determine the dilution and hence distance necessary to reduce the level below 1 odor unit of odor threshold [5, 9, 12]. When many sources are involved, the situation is potentially more complex. For odors from different sources and presumably different chemical species, we knew that this approach is not strictly correct; it is likely to be incorrect, but provides a generally conservative approach [5, 9, 12].

Therefore, incorporating conservative assumptions into the modeling and analysis, we can provide reasonable guidance for evaluating acceptable community odor threshold values [11]. Some conservative assumptions are provided in the previous research [5, 9, 11, 12].

Associated with the Weber-Fechner relationship of odors, approximations based on available information may be acceptable for conducting comparisons to the community odor thresholds. Neglecting any possible synergistic effects of odor causing compounds at sanitary landfills, the one odor unit strategy avoids the nonlinearity problem of the Weber-Fechner effect and protects the public interest [5, 9, 12]. The one odor unit level can be used as a measure of acceptability for reviewing landfill proposals including detectability, the relationship of one odor unit to a nuisance, and uncertainty in air quality modeling [5, 9, 12].

CONCLUSION

For effective odor reduction, this study suggests that horizontal isolation distance must provide at least 10^3 dilutions from the original concentration to render odorous compounds odorless. Although the number of dilutions per foot of horizontal isolation distances is dependent on meteorological conditions, local topography, and surface velocity, the Ann Arbor case study indicated that a 10^3 dilution can be achieved at as little as 600 feet under certain operating and site conditions. Consequently, this modeling approach offers a good procedure to evaluate odor dilutions to community odor thresholds for odor control at sanitary landfills.

ACKNOWLEDGEMENT

I greatly appreciate my advisor, Dr. Ralph H. Kummler, Chairman in Department of Chemical and Metallurgical Engineering, Wayne State University, for his valuable guidance, financial support and unfailing encouragement.

This cooperative research project was funded by the City of Ann Arbor and the State of Michigan through the Southeast Michigan Council of Governments (SEMCOG) and the Applied Science and Technology, Inc. (ASTI). I greatfully acknowledge their financial support, cooperation and assistance.

NOMENCLATURE

A : Cross sectional area [m^2].
C : Concentration in odor units [o.u./m^3].
D : Dilution factor [-].
Q : Source strength [o.u./sec].
u : Wind velocity [m/sec].
v : Surafce velocity [m/sec].

Greek Letters

$\triangle H$: Effective plume rise [m].
σ_y : Horizontal dispersion coefficient [m].
σ_z : Vertical dispersion coefficient [m].
χ : Ground-level plume centerline concentration [o.u./m^3].

REFERENCES

1. Baker, J.M., Peters, C.J., Perry, R., and Knight, C.P.V.: "Odor Control in Solid Waste Management", Effluent and Water Treatment Journal, April (1983).
2. Young, P.J. and Parker, A.: "Origin and Control of Landfill Odours", Chemistry and Industry, May 7 (1988).
3. SEMCOG Landfill/Air Quality Committee: "Draft Project Report", March 30 (1989).
4. USEPA: "Air Emissions from Municipal Solid Waste Landfills-Background Information for Proposed Standards and Guidelines, Draft", Emission Standard Division, Office of Air and Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, NC., March 12 (1990).
5. Wackerman, T., Kandler, G., O' Brien, J.,

Kummler, R., Song, D., and Warner, P.: "Odor Prediction and Control Study-Ann Arbor Sanitary Landfill", Applied Science and Technology, Inc., Vol.I-III, March (1989).

6. EMCON Associates: "Methane Generation and Recovery from Landfills", Prepared for Consolidated Concrete Limited and Alberta Environment, Ann Arbor Science Publishers Inc., The Butterworth Group, Ann Arbor, Michigan (1982).
7. Bruckman, P. and Muelder, W.: "Der Gehalt an Organischen Spurenstoffen in Deponie-gasen", Schriftenreihe der Landessantalt immissionsshutz Landes Nordrhein, Westfalen Essen., Vol. 55, P. 21-28 (1982).
8. Young, P.J. and Parker, A.: "Vapors, Odors, and Toxic Gases from Landfills", Hazardous and Industrial Waste Management and Testing: Third Symposium, ASTM STP 851 (1984).
9. Song, D.M.: "Odor Modeling Methodology for Determining the Odor Buffer Distance for Sanitary Landfills", Ph.D. Dissertation, Wayne State University, Detroit, MI, May (1991).
10. Kienbusch, M.: "Measurement of Gaseous Emissions Rates from Land Surfaces Using an Isolation Flux Chamber", USEPA (1986).
11. Wackerman, T., Finley, D., Kummler, R., Song, D., and Hersey, C.: "A Characterization Model for Determining Horizontal Isolation Distances for Odor Control at Sanitary Landfills", The Environmental Management Conference & Exposition-Air, Water, & Waste Technologies, Air and Waste Management Association (AWMA), Nov. (1991).
12. Kummler, R., Song, D., Wackerman, T., Kandler, G. Warner, P., and Hersey, C.: "Methodology for Determining the Odor Buffer Distance for Sanitary Landfills", in Recent Developments and Current Practices in Odor Regulations, Controls and Technology, Transactions of the Air and Waste Management Association (AWMA), Derenzo, D.R. and Gnyp A., ed., Pittsburgh, Pennsylvania, P. 104-111 (1991).
13. Turner, T.B.; "Workbook of Atmospheric Dispersion Estimates", Office of Air Programs Publication No. AP-26, USEPA, Research Triangle Park, North Carolina (1970).

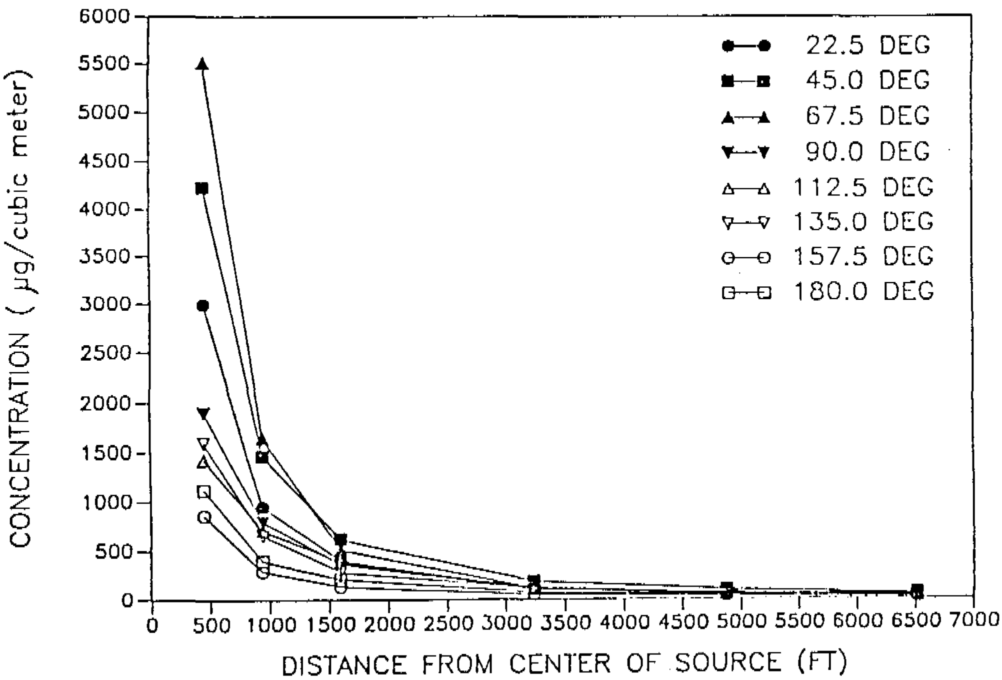

Fig. 1(a). The odor level at distances from center of source (ft) with 100 ft (30.48 m) diameter of a single area source for 31 day period of Jan. 1976 METDATA [CASE STUDY A].

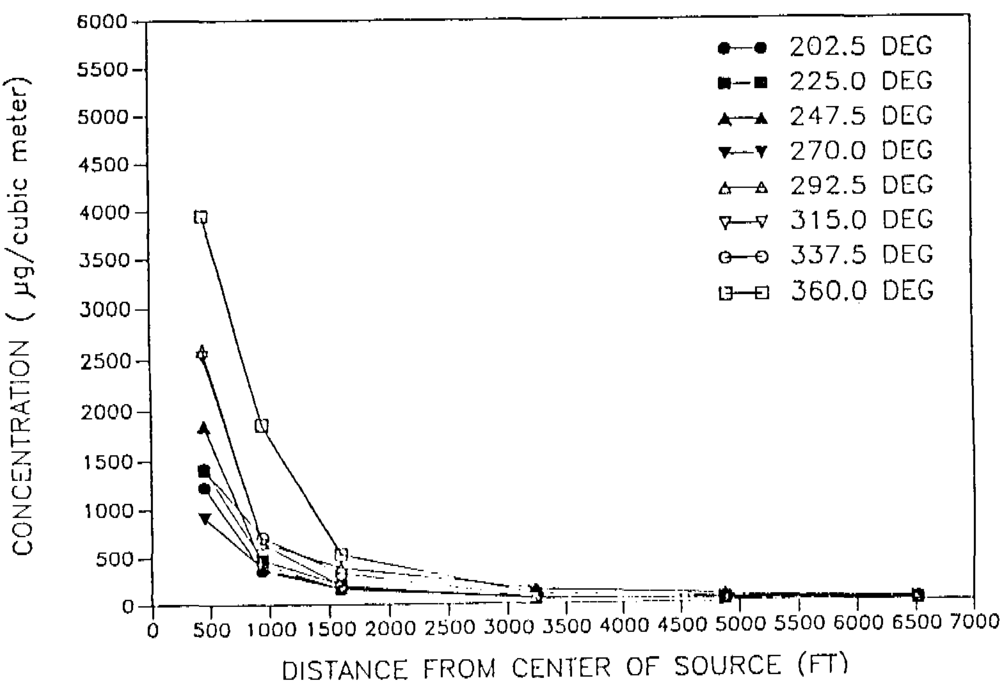

Fig. 1(b). The odor level at distances from center of source (ft) with 100 ft (30.48 m) diameter of a single area source for 31 day period of Jan. 1976 METDATA [CASE STUDY A].

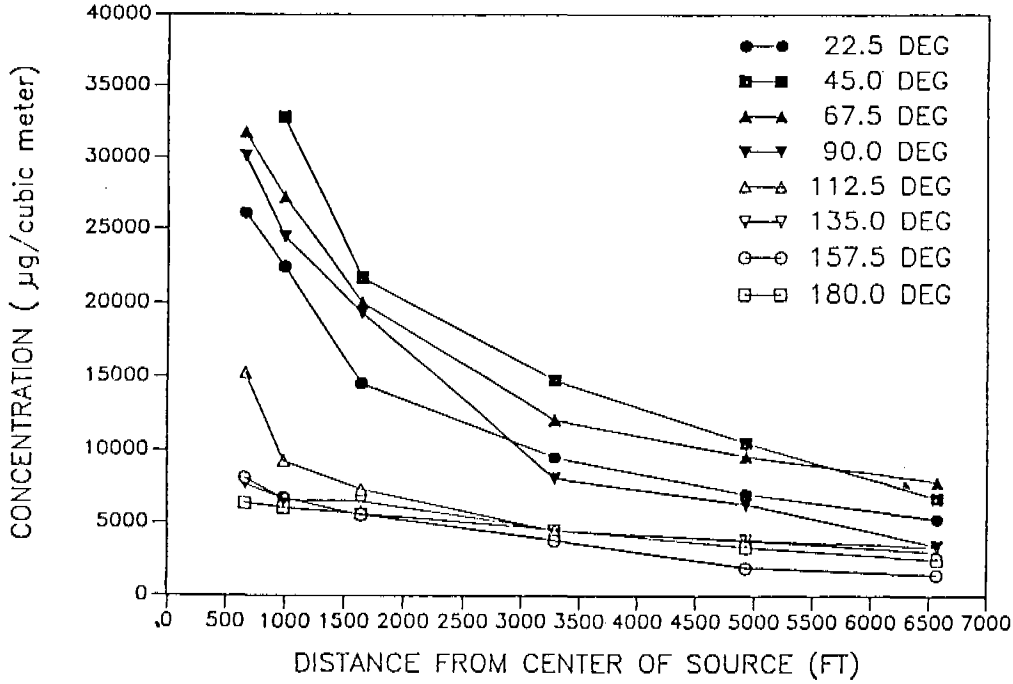

Fig. 2(a). The odor level at distances from center of source (ft) with 1000 m diameter of a single area source for 31 day period of Jan. 1976 METDATA [CASE STUDY B].

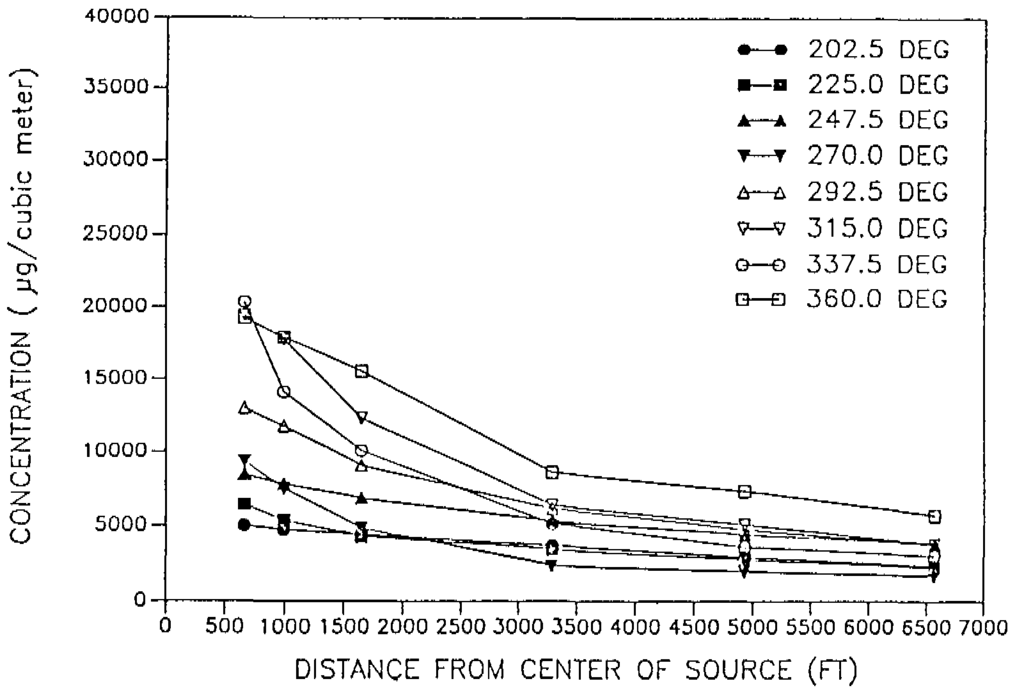

Fig. 2(b). The odor level at distances from center of source (ft) with 1000 m diameter of a single area source for 31 day period of Jan. 1976 METDATA [CASE STUDY B].