The Canadian society for engineering in agricultural, food, and biological systems

CSAE SCGR

La société canadienne de génie agroalimentaire et biologique

Paper No. 05-026

Evaluation of Air Dispersion Models for Livestock Odour Application

X. J. Zhou, Graduate Student
Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB
Q. Zhang, Professor
Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB
H. Guo, Assistant Professor
Agricultural and Bioresource Engineering, University of Saskatchewan
Y.X. Li, Research Associate
Agricultural and Bioresource Engineering, University of Saskatchewan

Written for presentation at the
CSAE/SCGR 2005 Meeting
Winnipeg, Manitoba
June 26 - 29, 2005

Abstract Instantaneous downwind malodours from two swine farrowing facilities were assessed in the field by 15 trained human sniffers. A total of 34 1-hour field monitoring sessions were carried out on the two farms between June and October in 2003 and 2004. Odour emissions from the farm were measured and weather conditions were monitored simultaneously. Four air dispersion models, ISCST3, AUSPLUME, IN-PUFF 2, and WindTrax were applied to simulate odour dispersion around the two farms by using on-site measured source emission rates and meteorological data. Correlation between odour concentration and 8-point odour intensity for swine odour was developed to convert model simulated downwind odour concentration into odour intensity so that model predictions could be evaluated against field measurements. The comparison between model predictions and field measured data indicated that in general, all four models predicted downwind odour well at distances of 500 m and 1000 m. In particular, the agreement between model predictions and field measurements was almost 100% at 1000 m for all four models. However, at downwind distance of 100m, all models predicted field odour with relatively low agreement. Since long-distance (>1000 m) predictions are of more practical value, all models are considered to be adequate in predicting odours downwind from swine operations.

Keywords: swine operation, odour, dispersion

INTRODUCTION

One of the most effective ways to control livestock odour is to maintain adequate separate distance between the facility and the neighbors to increase the dilution of odour in the atmosphere, thus avoiding odour nuisance near the facility. Air dispersion models are commonly used to determine the setback distance scientifically. Air dispersion models are mathematical models based on the diffusion theory of pollutants in the atmosphere for predicting pollutant concentrations at any distances downwind from the emission sources. Commonly used dispersion models are either based on Gaussian plume or Lagrangian particle trajectory theory. Gaussian plume models can be further subdivided to steady–state models and puff models. Gaussian plume dispersion models are relatively easy to use, and have simple and a small number of input requirements. These features make them widely used and well understood in terms of their applications and limitations. Lagrangian particle models are generally capable of simulating more complex atmospheric dispersion by incorporating time-dependent, three-dimensional atmospheric behaviour.

The applicability of Gaussian plume dispersion models to ground level odour emission from agricultural sources has been studied by some researchers. Janni (1982) simply evaluated the effects of various meteorological parameters and emission heights on downwind odour concentrations from agricultural sources using an EPA Gaussian air pollution model PTDIS. He concluded that wind speed and stability class, downwind distance, and source emission rate were determinant factors affecting the odour dispersion process and downwind odour concentration. Carney and Dodd (1989) compared measured downwind odour concentrations with predictions by a Gaussian plume model. The experiment was carried out for a point source (manure tank), a linear source (linear land manure spread), an area source (land spreading of manure), and a swine building. They collected downwind odour samples and quantified odour concentration by using an olfactometer. In their model calculation, downwind odour concentration fluctuation was taken into account by taking five times the 3-minute average as the 5 s peak concentration. They concluded that the Gaussian plume model was a good indicator of odour dispersion from a point source and a linear source. But for area sources, good agreement was found only if an equivalent width of 10 m is used. Mejor and Krause (1985, cited from Gassman (1993)) performed tracer gas field experiments for a point source in which odour was simulated with propane gas to facilitate high measurement accuracy, and then compared the model simulation results with the field measured concentrations. They concluded that the Gaussian model generally agree with the experimental results with reasonable accuracy.

McPhail (1991) and Gassman (1993) indicated that odour moves in the form of a series of puffs rather than a continuous stream, therefore puff models might predict higher odour concentrations and be more appropriate for agricultural odour dispersion. A Gaussian puff model (INPUFF-2) was evaluated for predicting downwind odours from animal production facilities by several researchers. Zhu et al. (1999) conducted field odour measurements on 28 farm sites in Minnesota with 7 trained human sniffers. Model predictions were compared with the field measurements and the results showed that INPUFF-2 model could well predict downwind odour concentration from single or multiple animal production sites at distances less than 400 m. However, a source dependent scaling factor for modification of source emission input was proposed to adjust the odour dispersion. A scaling factor of 35 and 10 was used for animal building and manure storage respectively in their research. Following Zhu et al. (1999) work, Guo et al. (2002) calibrated the same model for long-distance odour estimation up to 4 km. They concluded that the model was capable of predicting downwind odour at low intensity (level 1, faint odour) under stable to slightly unstable weather conditions. However, the model underestimated higher odour intensities of 2 and 3.

A Lagrangian particle model - AUSTAL2000G has been developed in Germany as the regulatory dispersion model to handle odour dispersion problems specifically (VDI 2000). However, there is little information on evaluation of these models by field measurements.

Although various dispersion models have been studied to predict odour concentration from agricultural sources, limited field data exist to evaluate their applicability in agricultural odour dispersion. The major problem in field odour measurement is that it is difficult to evaluate the instantaneous downwind odour by the commonly used olfactometery technique. When collecting downwind sample into a Tedlar bag, it usually takes 3 – 5 minutes, therefore the sample is a composite sample over the sampling period, not the representative of the odour that people would experience at downwind locations under instantaneous changes in wind direction and wind speed. Human sniffers have been shown to be effective in quantifying the instantaneous odour intensity. The detailed procedures are described in German guideline for determining field odour plumes by human sniffers (VDI 1993).

The objective of this study was to using human sniffers to quantify downwind odour from swine farrowing operations; to study the influence of weather conditions on the dispersion of swine odour; and to evaluate the performance of some existing air dispersion models for livestock odour application.

MATERIALS AND METHOD

Field Odour Measurement

Human sniffers were recruited primarily from the students at the University of Manitoba. A preliminary screening test was performed for each participant. The standard 8-point referencing n-butanol solutions were used for the screening test (Table 1). This Odour Intensity Reference Scale with n-butanol (in water) was based on the ASTM standards (ASTM 1999). The selected sniffers went through a series of six (6) training sessions (Zhang et al. 2005). The sniffers "calibrated" their noses using the standard reference n-butanol samples before leaving for the field.

For each field sniffing session, a portable weather station (WatchDog Model 550, Spectrum Technologies, Inc., Plainfield, IL) was set up first to determine the wind direction. The weather station was placed 2 m above the ground level to collect on-site weather information during the entire field sniffing session. Solar radiation, temperature, relative humidity, and wind speed and direction were recorded every minute.

A base point was then selected at the edge of the farm and its position was marked by the longitude and latitude readings from the GPS. Based on the measured wind direction, 15 sniffers were placed in a three-row grid (fig. 1) downwind from the odour sources (farm) with the assistance of GPS positioning systems. Upon reaching the predetermined grid point, each sniffer was asked to record his or her exact position based on the longitude and latitude readings from the GPS.

Every sniffer was carrying a two-way radio system to allow them to receive instructions from a central coordinator. Sniffing was timed by the coordinator, i.e., the coordinator informed all sniffers when to start and then broadcast every 10 second to remind the sniffers to conduct sniffing. The duration of a single measurement session was 10 minutes. To prevent nose from being "saturated", the sniffers wore the carbon filtered masks. They only removed the masks briefly every 10-second to sniff odour. For every sniffing, the sniffer recorded the odour intensity and odour description on a field data recording sheet. At the end of each 10-minute duration, 60 observations were recorded by every sniffer. A total of 3 measurement sessions were carried out within one hour, with a 10-minute break between sessions.

While field sniffing was conducted, air samples were collected from building exhaust and manure storage to quantify odour emission rates. Air samples were collected in 10-L Tedlar bags using a vacuum chamber (AC'SCENT Vacuum chamber, St. Croix Sensory, Inc., Stillwater, MN). When taking samples from building exhaust, a bag was placed in the chamber and the inlet of the bag was connected to a Teflon probe which was placed in the mid stream of airflow from the exhaust fan. A floating flux hood was used to collect odour samples from the surface of manure storage. Fresh air was drawn through a carbon filter, and introduced into the sample collection hood through a 100 mm diameter PVC duct. Airflow rates were measured inside the duct using a hot wire anemometer and were adjusted if necessary to maintain an air velocity of 0.3 m/s inside the hood over the manure surface (Schmidt et al. 2002).

Collected samples (in Tedlar bags) were evaluated within 24 hours for odour concentrations. A single-port olfactometer (AC'SCENT, St. Croix Sensory, Inc., Stillwater, MN) with six trained assessors was used for odour concentration measurement. The triangular forced-choice method was used to present samples to the assessors, with a 3-s sniff time. Assessors were selected and re-evaluated periodically following the procedure of CEN (1999). For each olfactometry session, data were retrospectively screened by comparing assessors' individual threshold estimates with the panel average (CEN 1999).

Odour Dispersion Models

ISCST3 (Industrial Source Complex Short Term)

ISCST3 is a steady-state Gaussian plume dispersion model developed by the US EPA. It can be used to assess pollutant concentrations from wide variety of sources associated with industrial complex. This model is specially designed to support the US EPA's regulatory modeling programs, and is widely used in North America.

The input to ISCST3 includes locations of odour sources and receptors, odour source emission information (emission rate, source height, source area, emission temperature and velocity, etc.), and weather information (stability class, temperature, wind direction, wind speed, mixing height, etc.). For the model output, the model permits ground-level concentrations to be calculated for a range of averaging times, from at least one hour and to days, months, or over the full meteorological data period.

AUSPLUME

AUSPLUME was developed in 1986 by AEPA (Australian Environmental Protection authority), and it is an extension of the US EPA ISC (Industrial Source Complex) model. AUSPLUME currently serves as a regulatory plume dispersion model in Australia. AUSPLUME and ISCST3 share the similarities in many aspects, but there also exist differences in some details in parameter set up and modeling options. The model input includes source data (location, emission rate, physical stack height, stack gas exit velocity, stack inside diameter, and stack gas temperature), meteorological data (hourly surface weather data including stability class, wind direction, wind speed, temperature, and mixing height), and receptor data (coordinates and optional ground elevation for each receptor). For model output, AUSPLUME is more flexible than ISCST3. Although AUSPUME also uses one-hour meteorological data, but it allows the calculation of average concentrations to be less than an hour, with minimum averaging time of three minutes.

INPUFF-2 (INtegrated PUFF)

INPUFF-2 is based on the Gaussian puff theory and was also originally developed by the US EPA, but is now marketed by a commercial company (Bee-Line Software Co., Asheville, NC). INPUFF-2 predicts atmospheric dispersion of pollutants released over a short time period, or dispersion of a "puff" of the pollutant released into the atmosphere. The model can simulate the dispersion of airborne pollutants from semi-instantaneous or continuous point sources, and it can also handle multiple point sources and multiple receptors at the same time. Researchers suggested that puff models might provide better predictions of odour concentrations downwind from livestock operations (McPhail 1991, Gassman 1993). INPUFF-2 allows for different time intervals in dispersion simulations as determined by the user rather than the hourly interval as required by other air dispersion models (Petersen and Lavdas 1986).

WindTrax

WindTrax is a software tool developed by Thunderbeach Scientific (Nanaimo, BC, Canada) for assessment of turbulent transport on the micro-meteorological scale using Lagrangian stochastic particle models. It has an easy-to-use graphical interface and is designed to simulate short-range atmospheric dispersion (for horizontal distances within about 1 km of the source). The model uses 30 minutes average weather data and predicts 30 minutes average downwind concentrations. The program has a forward model to calculate downwind concentration and a backward model to evaluate the emission rate from emission source. The software has been used by some researchers to back-calculate the source emission using the backward model (Coates et al. 2004, Flesch et al. 2005).

Meteorological data for dispersion modeling

Hourly weather data were prepared by taking the average of the one-minute readings from the on-site weather station (WatchDog Model 550, Spectrum Technologies Inc., Plainfield, IL) for ISCST3 and AUSPLUME. Atmospheric stability of each hour was classified using the Pasquill (1961) stability categories based on hourly average solar radiation and wind speed values. One-minute weather data measured by the on-site weather station was used directly in INPUFF-2. Thirty (30) minutes average weather data were used in WindTrax simulations.

RESULTS AND DISCUSSION

Relationship between Odour Concentration and Intensity

Dispersion models predict odour concentration in OU/m^3, whereas field measurements quantify odour intensity in the 0-8 scale. To compare dispersion models with the field data, it is necessary to convert the measured odour intensity to odour concentration. Several researchers have attempted to correlate the intensity to concentration for livestock odours (Bundy et al.1997, Nicolai et al. 2000, Guo et al. 2001). Nicolai et al. (2000) and Guo et al. (2001) showed that the Weber-Fechner logarithmic model provided the best mathematical description of odour from hog operations. The model has the form of:

$$I = k_1 + k_2 \ln(C) \quad (3)$$

Where: I = odour intensity
C = concentration of stimulus (OU/m^3)
k_1 and k_2 = constants

To evaluate two constants k_1 and k_2, odour samples collected in Tedlar bags were evaluated for odour intensity by trained sniffers after testing for odour concentration on the olfactometer. Then measured intensity and concentration were plotted in a semi-log scale to determine k_1 (intercept) and k_2 (slope) (Figure 2).

Sixteen odour samples were collected in Tedlar bags from the two farms. Two of the original source samples were diluted 5 to 200 times to make more diluted subsamples. The human panels used for evaluation of odour intensity and odour concentration were the same as that used for field sniffing. The results were plotted in Figure 2, and the constants were determined as: k_1 = 0.78 and k_2 = 1.43.

Effect of Atmospheric stability on Odour dispersion

One of the most important factors that influence odour dispersion is the meteorological condition in the area. To study the effect of weather conditions on the odour dispersion from livestock operations, hourly field odour data was grouped according to the stability class of the weather at time of the sniffing. The center line (direct downwind) odour intensities at 100, 500, and 1000 m for each session were used to develop percentage of downwind odour exceeding odour intensity 2 under various atmospheric stability class.

Figure 3 showed the percentage of downwind odour level above intensity 2 at distances of 100, 500, and 1000 m under different weather stability conditions. Unfortunately we did not have field data under strongly stable condition of class F. Under stability class E which is slightly stable condition, the percentages of downwind odour above intensity 2 were 100, 40, and 0 at distances 100m, 500m and 1000m, respectively. Under strongly unstable condition of class A, the percentages were 50, 0, and 0, respectively. The results showed that unstable conditions with strong horizontal and vertical mixing resulted in better dispersion of odour in the field. In contrast, stable conditions limited vertical mixing and odour dispersion, leading to occurrence of high downwind odour intensities. However, at downwind distance of 1000 m, there was no odour level exceeding intensity 2 under all weather conditions, implying that odour dissipates quickly after traveling 1000 m.

Comparisons between Model Predictions and Field Measurements

Both Ausplume and ISCST3 predict one-hour odour concentrations. Field odour intensity was measured in sessions of ten-minutes, with three sessions per hour. The measured odour intensity for every three ten-minute sessions within one hour was averaged as the one-hour average for comparison with AUSPLUME and ISCST3. INPUFF-2 predicted ten-minute average odour concentrations. Therefore, the predicted values were directly compared with the ten-minute odour intensity values measured in the field. Thirty minutes field data were prepared for WindTrax using the average of two ten-minute sessions within the half hour. When comparing model predictions with field data, if a model predicted value (converted from concentration to intensity with equation 16) was within the 95% CI (confidence interval) (Figure 2) of the measured average intensity value, this prediction was considered to ***agree*** with the measurement. The percentage of agreement between the predicted and measured intensity values was calculated for each farm at three downwind distances respectively (Table 2). At distances of 500 m and 1000m, all three models predicted field odour well, In particular, the agreement between model predictions and field measurements was almost 100% for four models at 1000 m. However, at downwind distance of 100m, all models predicted field odour with relatively low agreement. It seems that all models under-predicted high odour concentrations occurred at close distance of 100 m. Since long-distance (>1000 m) predictions are of more practical value in assessing the odour impact, all four models are considered to be adequate in predicting odour impact.

In overall, the percentage of agreement between the model predictions and the field data was higher for Farm B than for farm A, possibly due to the fact that the manure storage on farm A was covered, which facilitated accurate emission measurement from the storage. While on farm B, the emission rate from the open storage surface was measured using a wind tunnel under controlled surface wind velocity of 0.3 m/s. As odour emission rate from area source increases with the wind velocity on the emission surface (Smith and Watts 1994, Heber and Ni 1999), and our measurements of wind velocity close to storage surface at farm B indicated that the actual surface wind velocity varied from 0 to 2.08 m/s during the study, actual wind speed at the manure surface needs to be considered when conducting emission measurement from area sources using wind tunnels.

CONCLUSIONS

Field odour measurement using human sniffers confirmed that under stable weather conditions odour was less diluted in the atmosphere, which led to high occurrence of strong odour in the area compared to unstable conditions. At distance of 1000 m, no odours were detected above intensity 2 under all weather conditions.

ISCST3, AUSPLUME, IN-PUFF 2, and WindTrax dispersion models can predict downwind odour concentrations with good agreement for distances of 500 m and 1000 m. The percentage of agreement between model predictions and field measurements was relatively low for 100 m. Since the long-distance (>1000 m) predictions are of more practical value, all models are considered to be adequate in predicting odours downwind from the hog operations.

ACKNOWLEDGEMENTS

We wish to acknowledge the financial support provided by the Manitoba Livestock Manure Management (MLMMI). We appreciate Dr. R.York at the Canadian Food Inspection Agency for her dedicate input to our panel training. We wish to thank S. Alston and J. Alston for their technical assistance, and Mr. G. Plohman for assisting us in selecting the study sites. We also wish to express our gratitude to two farmers for their collaborations, and to all who participated in odour sniffing.

REFERENCES

ASTM. 1999. E544-75: Standard practices for referencing suprathreshold odour intensity. Annual Book of ASTM Standards. Philadephia, Pa.: American Society of Testing and Materials.

Bundy, D.S., Y.C. Chen., S.J. Hoff and J.Zhu. 1997. Modeling odour intensity for swine units. *In Proceedings of the International Symposium on Ammonia and Odour Control from Animal Production Facilities,* 83 – 91. Vinkeloord, The Netherlands: Dutch Society of Agricultural Engineering.

Carney, P.G. and V.A. Dodd. 1989. A comparison between predicted and measured values for the dispersion of malodours from slurry. Journal of Agricultural Engineering Research. 44(1): 67 – 76.

CEN 1999. Air quality – Determination of Odour Concentration By Dynamic Olfactomery. Draft European Standard PrEN 13725 , Brussels, Belguim

Gassman, P.W. Simulation of odour transport: A Review. ASAE paper No.92 – 4517. St. Joseph. Mich.: ASAE.

Guo, H., L.D. Jacobson, D.R. Schmidt and R.E. Nicolai. 2001. Calibrating INPUFF-2 Model by resident-panelists for long-distance odour dispersion from animal production sites. Applied Enginnering in Agriculture. Vol.17(6):859-868.

Guo, H., L.D. Jacobson, D.R. Schmidt and R.E. Nicolai. 2003. Evaluation of the influence of atmospheric conditions on odour dispersion from animal production sites. Transaction of the ASAE. Vol.46(2):461 – 466.

Hartung, E. and T. Jungbluth. 1997. Determination of the odour plume boundaries from animal houses. In Proc. Of the 5th Intl. Symp. of Livestock Environment. St. Joseph. Mich.: ASAE.

Laubach, J., and F.M. Kelliher. 2005. Measuring methane emission rates of a dairy cow herd (II): results from a backward-Lagrangian stochastic model. J. Agricultural and Forest Meteor. 129:137-150.

Li, J., D.S.Bundy, S.J.Hoff, and Q. Liu. 1994. Field odour measurement and applications of Gaussian plume model. ASAE Paper No. 94-4054. St. Joseph. Mich.: ASAE.

McPhail, s. 1991. Modeling the dispersion of agricultural odours. Proceedings of a workshop on agricultural odours, Toowoomba, Queensland, Australia, AMLRDC Report No. DAQ 64/7. Toowoomba, Queensland, Australia: Feedlot Services Group, Queensland Department of Primary Industries.

Nicolai, R.E., C.J. Clanton and H.Guo. 2000. Modeling the relationship between detection threshold and intensity of swine odours. In *Proceedings of the Second International Conference: Air Pollution from Agricultural Operations*, 296 – 304. St. Joseph. Mich.: ASAE.

Pasquill. F. 1961. The estimation of the dispersion of windborne material. Meerol. Mag. 90(1063):33-49.

Petersen, B.W. and L.G. Lavdas. 1986. Inpuff2.0 – A multiple source Gaussian puff dispersion algorithm – User's guide. Research Triangle Park, N.C.: Atmospheric Sciences Research Laboratory, Office of Research and Development, USEPA.

Schmidt, D.R., J.R. Bicudo, 2002. Using a wind tunnel to determine odour and gas flux from manure surface. ASAE Paper No. 02-4083. St. Joseph. Mich.: ASAE

Sommer, S.G., S.M. McGinn, and T.K. Flesch. 2005. Simple use of the backwards Lagrangian stochastic dispersion technique for measuring emissions from small field plots. European J. of Agronomy.

VDI 1993. VDI 3940. Determination of Odourants in Ambient Air by Field Inspections. Beuth Verlag, Berlin

VDI, 2000. Environmental Meteorology Atmospheric Dispersion Models, Particle Model. Verein Deutscher Ingenieure, Berlin, Germany.

Williams, M.L. and N. Thompson. 1986. The effects of weather on odour dispersion from livestock buildings and from fields. In *Odour prevention and control of organic sludge and livestock farming*. Eds. Nielsen, J.H. Voorburg and P. L'Hermite.London. Elsevier Applied Science Publishers. 227-233.

Zhu, J., L.D. Jacobson, D.R. Schmidt, and R. Nicolai. 2000. Evaluation of INPUFF-2 model for predicting downwind odours from animal production facilities. Applied Engineering in Agriculture 16(2): 159 – 164.

Zhang, Q., X.J. Zhou, H. Guo, Y.X. Li, and N. Cicek. 2005. Odour and Greenhouse Gas Emissions From Hog Operations. Report submitted to Manitoba Livestock Manure Management Initiative Inc., Winnipeg, MB.

Table 1. Eight-point odour intensity referencing scale (ASTM 1999)

Intensity level	n-butanol in water (ppm)	Annoyance
0	0	no odour
1	120	not annoying
2	240	a little annoying
3	480	a little annoying
4	960	annoying
5	1940	annoying
6	3880	very annoying
7	7750	very annoying
8	15500	extremely

Table 2. Percentage of agreement between model predictions and field measurements

Downwind distance	% agreement							
	AUSPLUME		ISCST3		INPUFF-2		WindTrax	
	Farm A	Farm B	Farm A	Farm B	Farm A	Farm B	Farm A	Farm B
100 m	68%	69%	64%	63%	61%	47%	52%	55%
500 m	99%	89%	99%	88%	98%	90%	100%	88%
1000 m	100%	98%	100%	97%	100%	98%	100%	99%
Overall	**89%**	**85%**	**88%**	**83%**	**86%**	**78%**	**84%**	**80.7**

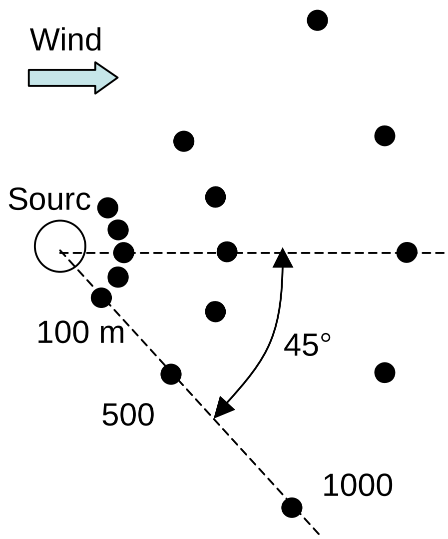

Figure 1. Field grid (locations) for downwind odour sniffing

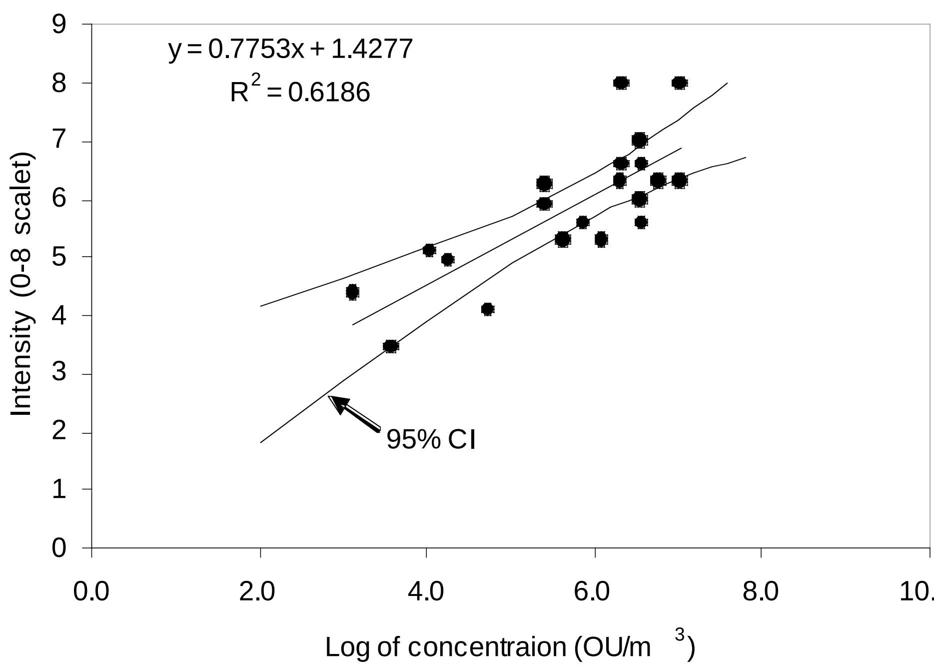

Figure. 2. Relationship between odour intensity and odour concentration.

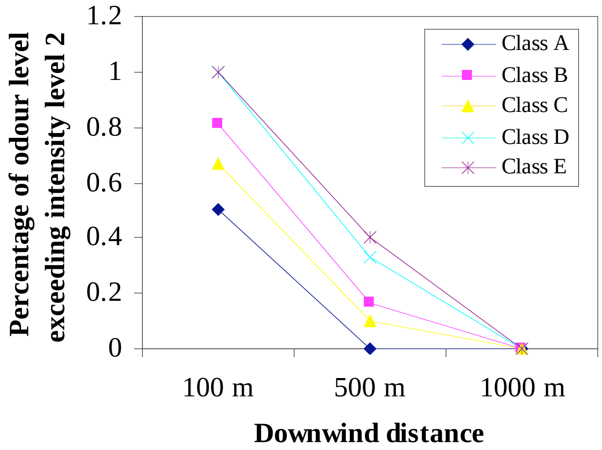

Figure 3. Effect of atmospheric stability class on odour dispersion