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DISPERSION MODELING OF ODOURS EMITTED FROM PIG FARMS: WINTER-SPRING MEASUREMENTS

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ABSTRACT

One of the main environmental impacts of pig farms are the swine odours emitted from the various stages of the process. The main cause of odour emissions from pig farms are the anaerobic processes in manure. Numerous factors affect odour emissions such as diet, manure management and manure age. The majority of the odorous compounds emitted from pig farms are sulfurous organic compounds, hydrogen sulfide, phenols and indoles, ammonia, volatile amines and volatile fatty acids (VFA's) whose presence in the atmosphere causes annoyance at relatively low concentrations. However, the detection and quantification of these compounds at a daily basis is difficult because of their chemical instability and the fact that they can be tracked only using techniques of gas chromatography. For the needs of the present study many instantaneous measurements performed during the day in order to estimate the daily variation of their emissions. This is the reason why the compounds studied were hydrogen sulfide and ammonia. Both compounds have low odour threshold (0.47 ppb for hydrogen sulfide and 130 ppb for ammonia). In the present study, the results of odour concentration measurements sampled from a pig production unit placed close to the city of Rethymno (Crete, Greece) are presented. These measurements are used to estimate the emissions of hydrogen sulfide and ammonia from the various chambers of the pig farm. The emission data were used as input data for the dispersion model AERMOD for an area of 10 km^2 surrounding the odour source in order to determine the maximum allowed emissions in order not to cause complaints from nearby residents. Modifications were performed in the model based on the "peak to mean" ratio in order to predict the maximum odour concentrations with few seconds time-scale. Also, relations between odour annoyance and odour exposure concentrations have been used in order to express the odour impacts in terms of probability of detection, probability of discrimination and degree of annoyance. These parameters were embedded into the AERMOD model in order to be able to use this program as an odour dispersion model. The results are provided as probability of detection and probability of annoyance instead of hourly mean concentrations. Several scenarios were examined using the modified AERMOD program taking into account the complex terrain around the pig farm. Finally, the effect of raising the height of the stacks to the concentrations around the facility was examined as a possible solution to the situation.

KEYWORDS: odour dispersion modeling, odour measurements, hydrogen sulfide, ammonia, AERMOD.

1. INTRODUCTION

Odours emitted from piggeries are becoming a significant source of environmental annoyance. Odour-related complaints from communities surrounding these facilities have been constantly increasing during the last decade. The odour generated from piggeries is a result of the decomposition of manure and waste food. Odour from freshly excreted manure is generally less offensive than odour released from anaerobically decomposing manure. The odour composition depends on several factors such as the type of operations and the stage of animal growth. The main odorous compounds emitted are sulphur or nitrogen containing compounds (hydrogen sulphide, methyl mercaptan, dimethyl disulfide, carbon sulfide, ammonia, amines, indole and skatole). The resulting odour is a mixture of these compounds, however the most significant odorous compounds are hydrogen sulfide and ammonia

The main impact from the existence of H_2S and NH_3 in the atmosphere is the annoyance caused to humans. The detection and perception of odours by humans is an extremely complex process. The main factors determining whether an odour causes annoyance are the concentration of the odorous compound in the air, the “odour quality”, the odour appearance frequency and the odour duration (US EPA, 2006).

Atmospheric dispersion modeling has been applied for the assessment of odour impacts in several cases using mainly Gaussian models such as the Industrial Source Complex (ISC) model. Dispersion modeling can effectively be used in two different ways: firstly to assess the dispersion of odours and to correlate with complaints and secondly, in a reverse mode, to estimate the maximum odour emissions which can be permitted from a site in order to prevent odour complaints occurring (McIntyre, 2000). In this case, the model outputs are hourly concentrations which is a non representative time-scale, because only a few seconds are enough to cause human annoyance. For this reason, a “peak to mean” ratio is used to predict the maximum odour concentrations (Piringer *et al.,* 2007; Smith, 1973). Also, recent studies provide relations between odour annoyance and odour exposure concentrations in order to express the odour impacts in terms of probability of detection and degree of annoyance (Henshaw *et al.,* 2006; Nicell, 2003). The methodology presented in the current study indicates the need to use these dose-response relationships in conjunction with dispersion modeling. The utter goal is to estimate the probability of response and degree of annoyance of the communities surrounding piggeries instead of the hourly mean concentrations.

In the current study the focus is on the specification of the main parameters that we have to take into account when modeling odours. These parameters are embedded in the Gaussian dispersion model AERMOD in order to be able to estimate the odour impacts from an existing wastewater treatment plant. Section 2 presents the materials and methods used, Section 3 presents the results of the hydrogen sulfide and ammonia measurements and the results of the model applied and Section 4 presents our conclusions.

2. MATERIALS AND METHODS

2.1 Site description

The study area is a piggery facility located 15 km east of the city of Rethymno (Crete, Greece). Piggery facility of Creta Farm Co. consists of approximately 72 feeding compartments. The facility is located at a coastal area with a rather complex terrain with sea to the north and hills to the south. This fact has an important influence to the dispersion of odorous compounds emitted from the various compartments of the facility. In the present section the input parameters for the application of the dispersion model AERMOD are described. Also the necessary modifications to the model for the study of odours instead of regular pollutants are presented.

2.2 Meteorological data

The main meteorological parameters that affect the dispersion of air pollutants are air temperature, relative humidity, wind direction, wind velocity and atmospheric stability. The data used in the present study were collected from a meteorological station (Galltec Mess- und Regeltechnik GmbH, MELA Sensortechnik GmbH, Germany) located close to the sources of the odours (at height of 10 m above the main building). The meteorological observations were recorded at a 30-second temporal resolution between 04 November 2008 and 30 March 2009. The mean period temperature was 13.5 ^{o}C and the mean relative humidity 66.5%. The prevailing wind direction was North and the wind speed ranged mainly from 3 to 9 m s^{-1} but in several cases exceeded 18 m s^{-1}. These conditions are typical for a coastal area in northern Crete and are affected by the landscape of the area with the sea to the north and hills south of the site. Mean daily values are presented in Figure 1.

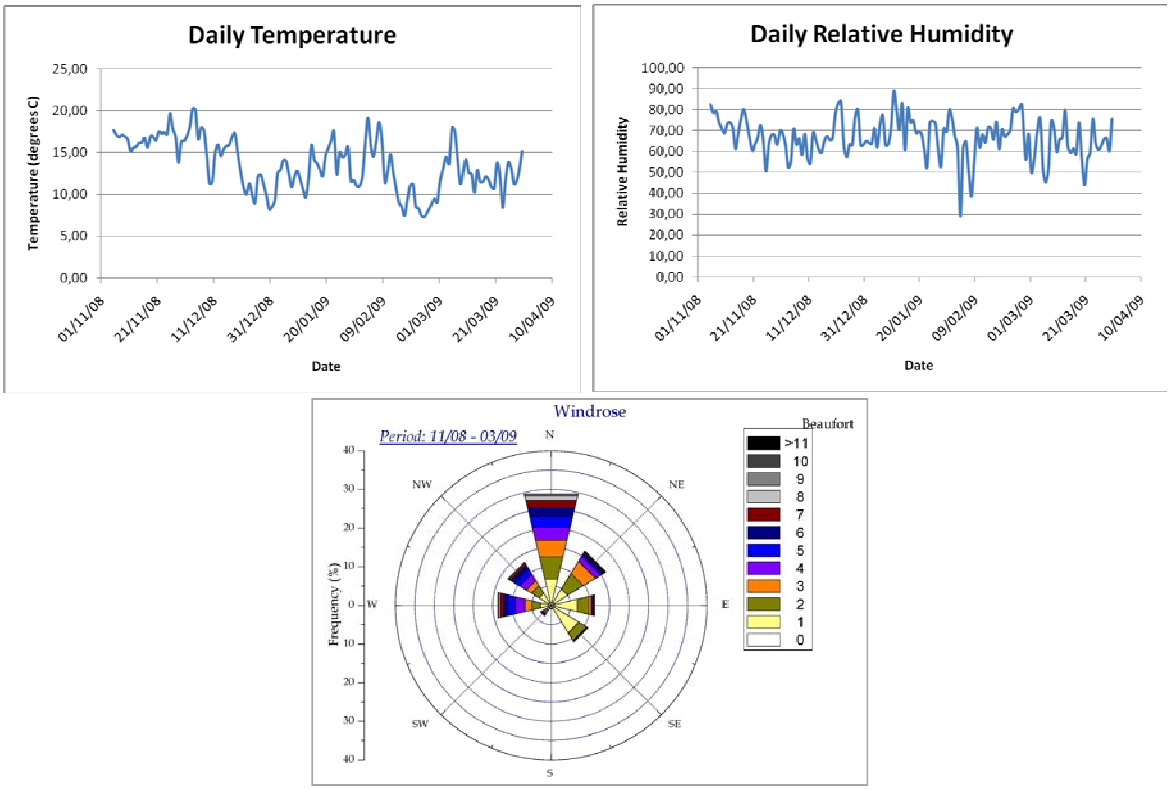

Figure 1. Meteorological parameters used in the present study (temperature, relative humidity, wind speed and wind direction)

2.3 Ammonia and hydrogen sulfide emissions

The most common sensory measurement is the threshold olfactometry which measures the odor concentration in terms of dilutions required to reduce an odorous compound until its threshold concentration. It has been shown that under carefully controlled conditions, the sensory measurement can provide meaningful and reliable information. Such kinds of measurements are useful only in terms of nuisance assessment but are limited for the examination of how odors are formed, how they are transferred and how they can be controlled. Furthermore, sensory measurements give little information on the chemical composition of an odorous mixture of gases. For this reason, analytical measurements are required, giving detailed information on the compounds responsible for an odor emission.

Analytical measurements have the advantage of objectivity, repeatability and accuracy and they can be used directly to theoretical models describing the mechanism of odor formation. Qualification and quantification of all odorants present in a sample is quite complex. In some cases odorants may be present in very low concentrations compared to non-odorous gases, which may interfere with the analysis. However, a single odorant may be dominant and therefore it can give a general indication of the overall odor concentration.

The compartments where the odour measurements took place were the fattening and battening compartments as well the biofilters because of their higher odour impact. Ammonia and hydrogen sulfide were measured during the months September and October 2008. The results are used in the present study in order to estimate the emissions of these compounds from each compartment. Hydrogen sulfide and ammonia were chosen to be studied because of their high odour impact to nearby residents.

The most common method for hydrogen sulfide measurement in the gas-phase is the use of a gold-film monitor. These instruments include a thin gold film, where in the presence of hydrogen sulfide, undergoes an increase in electrical resistance proportional to the mass of hydrogen sulfide contained in the sample taken. A common gold-film monitor, the Jerome 631-X H_2S analyzer (Arizona Instruments, USA) has a sensitivity of 3 ppb and can measure up to 50 ppm H_2S. Sample times vary depending on the H_2S concentration levels (Winegar and Schmidt, 1998). Ammonia was measured using GrayWolf's DirectSense TOX Multi-Gas Meter. Using the specific instrument, concentrations in the range 0-500 ppm can be measured.

2.4 Model description

The AERMOD model is a steady-state plume model. In the stable boundary layer (SBL), it assumes the concentration distribution to be Gaussian in both the vertical and horizontal. In the convective boundary layer (CBL), the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function. Using a relatively simple approach, AERMOD incorporates current concepts about flow and dispersion in complex terrain. Where appropriate the plume is modeled as either impacting and/or following the terrain. This approach has been designed to be physically realistic and simple to implement while avoiding the need to distinguish among simple, intermediate and complex terrain, as required by other regulatory models. As a result, AERMOD removes the need for defining complex terrain regimes (US EPA, 2004).

Odour perception by humans is proportional to the instantaneous peak concentration of the odorant rather than to mean values. AERMOD, similarly to other dispersion models, is set for calculation of at least half-hour mean concentrations. The sensation of odour, however, depends on the momentary (peak) odour concentration and not on a mean value. This is why it was essential for the model’s code to be modified in order to be able to calculate the peak values which might occur rather than the hourly mean values. Widely used peak-to-mean ratio approach has been selected as suitable solution of this task. The equation used to convert average concentrations to peak concentrations (equation 2) provides the ability to convert the 1-hour modeled concentrations to 1-minute peak concentrations.

$$C_p = C_m \left(\frac{t_p}{t_m} \right)^u \qquad (1)$$

where C_p stands for peak concentration calculated for a short period t_p and C_m stands for the mean concentration calculated from the dispersion model for a longer period t_m. The exponent u depends on the stability of the atmosphere and varies from 0.35 to 0.65.

The main impact of hydrogen sulfide at relatively low concentrations is the annoyance caused to residents of this area. This is the reason why providing contour plots of the H_2S concentrations do not give the information of interest. Though, the sense of smell is subjective and people react in a different way when being exposed to an odorant. Recently, dose-response relations have been developed that correlate odour concentrations to the probability of detection of the specific odour or probability of annoyance. The probability of detection of an odorous compound can be estimated using equation 2 (Nicell, 2003).

$$P = \frac{100}{1 + \left(\frac{C_t}{C} \right)^{\frac{1-p}{p}}} \qquad (2)$$

where P (in %) stands for the probability of detection of an odour, C is the concentration of the odorous compound (in ppb), C_t is the threshold concentration of the specific odorous compound (in ppb) and p (dimensionless) is the “persistence of response” of the specific odour. The “persistence of response” varies from 0 to 1 depending on the compound. The value of p was set to 0.15 using observations about the percentage of people being able to identify the existence of hydrogen sulfide and at the same time measuring the concentration using the Jerome 631-X analyzer. The threshold concentration is the concentration at which 50% of people exposed to hydrogen sulfide can detect its presence and was set to 4.7 ppb. The corresponding value for NH_3 was set to 25 ppm (Leonards *et al.,* 1969). Figure 2 presents the sigmoid curve that correlates the probability of detection of hydrogen sulfide and its concentration.

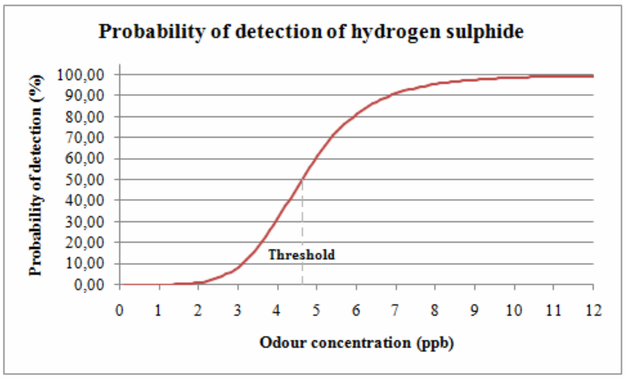

Figure 2. Probability of detection of hydrogen sulfide

A similar relation has been proposed to estimate the annoyance caused by odours (equation 3).

$$A = \frac{10}{1 + \left(\frac{C_{5AU}}{C} \right)^{\frac{1-\alpha}{\alpha}}} \tag{3}$$

where A (measured in annoyance units, AU) stands for the degree of annoyance of the population and ranges from 0 to 10, C is the concentration of the odorous compound (in ppm), C_{5AU} corresponds to the odorant concentration where the population annoyance has a value of 5 AU and the term a (dimensionless) is the “persistence of annoyance” of the specific odour. The “persistence of response” varies from 0 to 1 depending on the compound (Nicell, 2003). Using observations of the complaints recorded from people living near the WTP of Chania we made an estimation of the parameters C_{5AU} and a, to be 6 ppb and 0.3 respectively. Figure 3 presents the annoyance with respect to hydrogen sulfide concentrations.

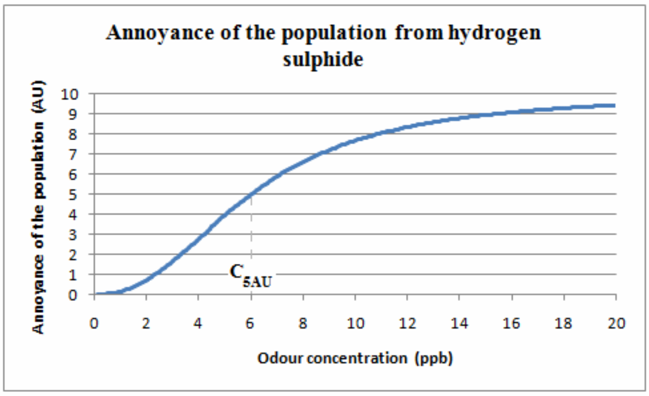

Figure 3. Annoyance of the population caused by H_2S.

3. RESULTS AND DISCUSSION

3.1 Hydrogen Sulfide emissions

In the present section, the emissions of ammonia and hydrogen sulfide from the various compartments are presented.

The emissions of hydrogen sulfide were estimated using in situ measurements of its concentration and the fans flow rate. The emissions were found to be higher (in some cases exceeding 40 g h^{-1}) at the fattening compartments and ranged from 1 to 8 g h^{-1} at the battening compartments (Figure 4). The concentrations of H_2S at the biofilter were found to be below detection threshold during all the sampling period.

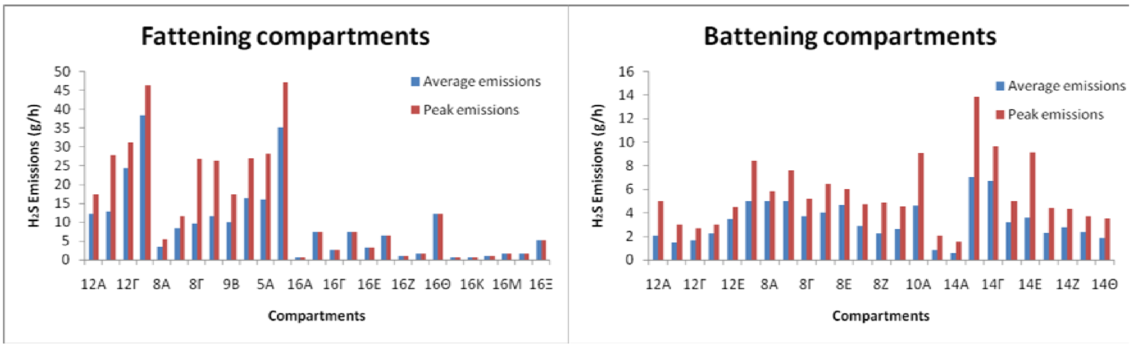

Figure 4. Hydrogen sulfide emissions estimations from various compartments

3.2 Ammonia emissions

The emissions of NH_3 were found to be highly depended on the type of the compartment. Emissions from fattening compartments were found to be about 10 times greater than those from battening compartments. Also high NH_3 emissions were observed at the biofilters. The results are presented in Figure 5.

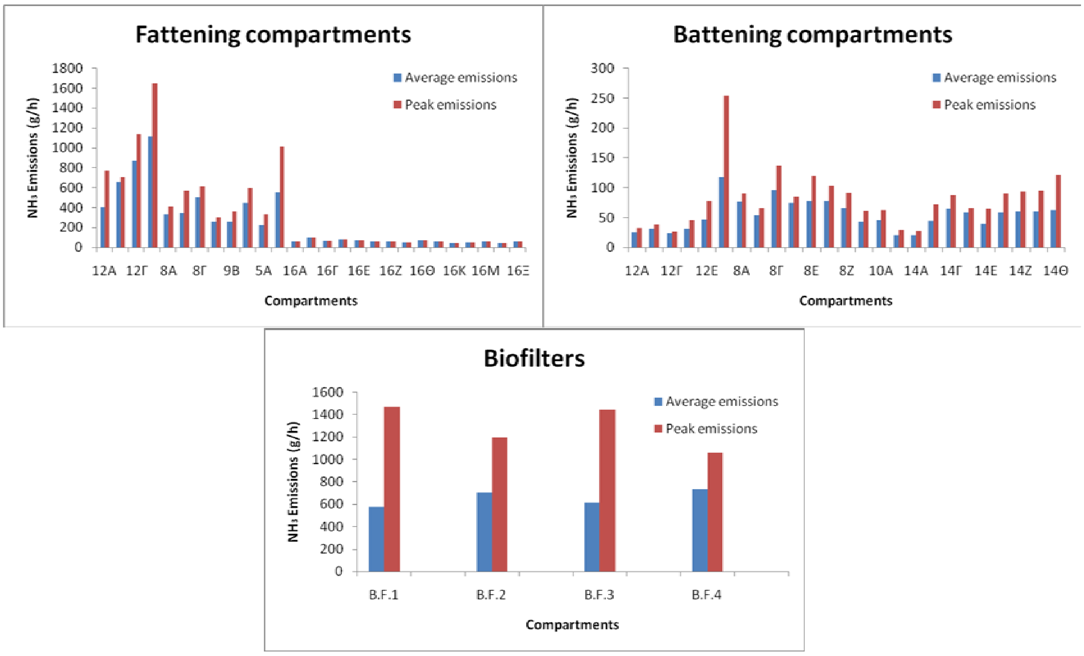

Figure 5. Ammonia emissions estimations from various compartments and the biofilters

3.3 Model results

The model AERMOD was applied to study the impact of ammonia and hydrogen sulfide to the area surrounding the piggery facility. At first, the model was applied to estimate the annual, monthly and daily average values for the concentration of hydrogen sulfide and ammonia close to the facility studied. The values calculated were lower than the detection threshold in each case, even in the facility. This fact is obviously untrue because the characteristic odour of H_2S and NH_3 has been identified several times from the nearby residents and the employees of the facility.

Using the modified AEROMOD model the results showed that the annoyance caused within the area of the facility and at a range of 2 km around it can be important. The methodology described for hydrogen sulfide is applicable for ammonia also by altering the coefficients used according to the detection/recognition threshold of ammonia. Also the probabilities of detection (PD) of H_2S and NH_3 and the degree of annoyance (AU) were estimated using several scenarios. The results of the simulations are presented in tables 1 and 2 for hydrogen sulfide and ammonia respectively.

The short-time step used in the present study for the estimation of the peak concentrations of the odorants was 5 sec in order to approach the duration of a single breath. The choice of the time scale is very important to estimate the impact of odours in the atmosphere. Sensitivity analysis was also performed to study the results of the model application using different short-time scales in the peak-to mean ratio. Using a time step of 10s (100% greater than the “base-value of 5 sec) the mean decrease of the probability of detection was about 5%. Using 30s and 60s as a short time scale (600% and 1200% increased values according to the “base value” of 5s correspondingly) the mean decrease of the probability of detection of H_2S was 12% and 16% correspondingly. We can also notice that the effect of choosing different short-time scales is less significant at greater distances. This happens because peak-to-mean ratio is reduced as the distance from the source increases due to turbulent mixing.

Scenario 1 was the application of the modified model using the worst case inputs (peak emissions observed). As we can notice the probability of detection of the odorous compounds is rather high inside the facility (75% for H_2S and 94% for NH_3) with high degrees of annoyance (4.8 for H_2S and 5.3 for NH_3).

Scenario 2 was the application of the modified model using emission inputs raised by 50%. Elevated values for the probabilities of detection (PD) and degree of annoyance (AU) were calculated as expected. The PD was raised for H_2S NH_3 and 2 km from the fence line from 9.1 % and 28% correspondingly (Scenario 1) to 21% and 57% (Scenario 2).

Scenario 3 was the application of the modified model using the same worst-case inputs as in scenario 1, but assuming that the stacks were 8 meter high instead of 6m. The results indicate that both the probability of detection and the degree of annoyance have significantly smaller values. Scenario 4 is about keeping the stacks to their current height but reducing the NH_3 and H_2S emissions by 50%. We notice that the concentrations near the facility are higher than those that were calculated using scenario 3 but are significantly lower than those were found using scenario 1.

Table 1. Hydrogen sulfide Probability of Detection (PD) and Degree of Annoyance (DA) using several input scenarios

	Maximum values							
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	PD (%)	**DA (AU)**	**PD (%)**	**DA (AU)**	**PD (%)**	**DA (AU)**	**PD (%)**	**DA (AU)**
Inside the facility	75.1	4.8	80.7	5.4	51.3	3.2	63.0	4.0
100m from fenceline	66.3	4.2	74.1	4.8	46.2	3.0	55.0	3.5
200 m from fenceline	59.4	3.8	68.3	4.3	42.0	2.8	46.7	3.0
300 m from fenceline	44.0	3.0	58.0	3.7	39.1	2.7	33.2	2.3
500 m from fenceline	35.4	2.3	46.7	3.0	33.1	2.3	22.0	1.8
1 km from fenceline	21.3	1.7	40.9	2.7	20.1	1.7	17.5	1.6
2 km from fenceline	9.1	0.7	21.0	1.7	8.6	0.7	6.3	0.5

Table 2. Ammonia Probability of Detection (PD) and Degree of Annoyance (DA) using several input scenarios

	Maximum values							
	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**	
	PD (%)	**DA (AU)**	**PD (%)**	**DA (AU)**	**PD (%)**	**DA (AU)**	**PD (%)**	**DA (AU)**
Inside the facility	94.0	5.3	98.2	5.9	60	4.1	64.0	4.1
100m from fenceline	89.0	4.9	97.0	5.7	48	3.8	50.0	3.9
200 m from fenceline	80.0	4.6	93.6	5.3	37	3.6	31.0	3.5
300 m from fenceline	74.0	4.4	91.2	5.1	29	3.4	24.4	3.3
500 m from fenceline	62.0	4.1	86.5	4.8	26	3.3	16.5	3.1
1 km from fenceline	51.0	3.9	77.6	4.5	24	3.3	10.0	2.8
2 km from fenceline	28.0	3.4	57.4	4.0	15	3.0	5.2	2.5

4. CONCLUSIONS

Measurements of hydrogen sulfide and ammonia have been conducted in the various compartments of a piggery facility. These measurements indicate that high concentrations may be observed in the facility but these values decrease rapidly only a few meters away from the sources. The measurements conducted outside from the fence line of the facility showed that the concentrations of H_2S and NH_3 were always below the threshold concentration. Application of dispersion models showed that the hourly mean concentrations were also below the threshold during the same period. This fact indicates that the application of a standard dispersion model underestimates the impacts of odorous pollutants because these impacts depend on peak concentrations rather than mean hourly values.

In order to estimate the impacts of the highly odorous compound H_2S to the surrounding community several changes were performed to the model's AERMOD code. The modified AERMOD predicts peak concentrations of odorous compounds and estimates the probability of detection of a specific pollutant and the degree of annoyance of the surrounding community. This is the first application in the scientific literature of the modified AERMOD model using the "peak to mean" ratio. The results of the simulations indicate that the annoyance caused by the presence of NH_3 and H_2S in the atmosphere close to the facility can be important during worst-case emissions-meteorological conditions. Several possible solutions were studied as increasing the height of the stacks or decreasing the emissions. Both scenarios presented reduce the probability of detection and the degree of annoyance significantly. The choice of the best solution however demands further study for a longer period in order to study summer conditions where the odours impacts are greater.

REFERENCES

1. Henshaw P., Nicell J.A., Sikdar A. (2006) Parameters for the Assessment of Odor Impacts on Communities, *Atmospheric Environment*, **40**, 1016-1029.
2. Leonards G., Kendall D. and Barnard N. (1969) Odor threshold determination of 53 odorant chemicals, *JAPCA*, **19**(2), 91–95.
3. McIntyre A. (2000) Application of dispersion modeling to odour assessment: a practical tool or a complex trap?, *Water Science and Technology*, **41**(6), 81-88.
4. Nicell J. (2003) Expressions to Relate Population Responses to Odor Concentration, *Atmospheric Environment*, **37**, 4955-4964.
5. Piringer M., Petz E., Groehn I., Schauberger G. (2007) A sensitivity study of separation distances calculated with the Austrian Odour Dispersion Model (AODM), *Atmospheric Environment*, **41**, 725-1735.
6. Smith M.E. (1973) Recommended Guide for the Prediction of the Dispersion of Airborne Effluents, ASME, N.Y.
7. U.S. Environmental Protection Agency (2004) AERMOD: Description of the model formulation, EPA-454/R-03-004, U.S. Environmental Protection Agency, RTP, NC.
8. U.S. Environmental Protection Agency EPA (2006) Assessment and Management of Odour from Stationary Sources in NSW, NSW Environment Protection Authority, Sydney.
9. Winegar E.D. and Schmidt C.C. (1998) Jerome 631-X portable hydrogen sulfide sensor: laboratory and field evaluation, Report to Arizona Instrument Corporation, 15p.