ODOUR NUISANCE AND DISPERSION MODELLING: AN OBJECTIVE APPROACH TO A VERY SUBJECTIVE PROBLEM

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ABSTRACT

The three main components of a study into the behaviour of material emitted into the atmosphere, i.e. emissions, dispersion and impacts, are discussed in the context of predicting odour nuisance. In particular, the importance of the effects of buildings on dispersion, and the significance of short averaging times are considered. Finally, an approach is suggested for modelling odour nuisance that takes account of the current understanding of atmospheric processes.

KEYWORDS

Odour, Dispersion, Modelling, ADMS

INTRODUCTION

The treatment of sewage has always resulted in unpleasant odours. However, for a range of reasons, explained in the CIWEM Monograph on Odour Control (CIWEM, 1997), the treatment of sewage now gives rise to an ever increasing incidence of odour nuisance and corresponding abatement problems. Since the abatement of odour nuisance can be very costly it is important to have the best possible understanding of the extent of an odour nuisance and of the benefits of the available abatement strategies. One tool in achieving this is to be able to simulate the extent of any odour impacts arising from the use of the different abatement strategies available. This should ideally be for a range of operating conditions and comparisons should be made between the impacts of various plant options and, for existing plants, those of the existing situation. However, the modelling of odours and the prediction of odour nuisance involves a number of complications and needs to be undertaken with some care.

The reasons for this are discussed here, followed by a description of the traditional approaches to the modelling of odours and the limitations of these approaches. Finally, suggestions are presented of how the modelling of odours could be tackled using an up-to-date understanding of the behaviour of the lower atmosphere. This approach makes use of the Atmospheric Dispersion Modelling System (ADMS) developed by Cambridge Environmental Research Consultants (CERC) with sponsorship from the UK Environment Agency, the Health and Safety Executive, the National Radiological Protection Board, the major UK power companies and others. The objective of ADMS is to make the developments in our understanding of the lower atmosphere available in a usable and practical form.

ODOUR NUISANCE MODELLING AND THE PRACTICAL DIFFICULTIES

There are three key components to any study of the behaviour of material emitted into the atmosphere. These are:

- The emissions; consideration of what is emitted, in what form, from where and how the emission occurs.
- Dispersion; determination of where the emitted material goes under the influence of the motions within the atmosphere.

- Impacts and interpretation; the predictions made need to take account of the form of the potential impact, for example whether short or long-term in nature and the statistical form of any appropriate air quality criteria.

While dispersion modelling obviously focuses on the second item, to be of use a study needs to take account of all three. Consequently we will consider first emissions and impacts before discussing dispersion, which has the function of forming a credible link between them.

Emissions

For many industrial emissions the maximum quantity and form of the emissions, in terms of velocity and some stack considerations, are prescribed in guidance notes and plant authorisations. Modelling then just needs to take account of the permitted worst case. However, for odours this is often not the case. Typically an odorous emission will be a mixture of components, in varying quantities and with different odour detection thresholds, and often arising from fugitive or passive sources, for example filter beds rather than definite stack locations. Dynamic olfactometry is then very useful in providing an emission quantity in odour units (CEN, 1995), which can be used directly in a modelling study. However, it is important to note that for many sources of odour the emissions can vary significantly through the seasons, during the diurnal cycle and even under apparently similar operating conditions. Therefore it is important to have sufficient emission measurements to fully characterise a source if its impacts are to be successfully modelled.

For proposed developments there is the additional complication that emissions will not normally be known. Modelling can be carried out using performance information for odour abatement products such as scrubbers or filters, but this information is often only available for limited components of the emission, for example only for hydrogen sulphide, and allowance has to be made for the other odorous components.

Impacts

For many pollutants there are air quality standards, expressed typically in terms of maximum permitted mean, worst hour or 98th percentile concentrations, and so on. Modelling then needs only to provide predicted concentrations in the form of these statistics for comparisons to be made. This approach is not so appropriate for odour nuisance, as it is a subjective concept. However, a number of suitable criteria have been proposed.

A common odour criterion is that no odour should be detectable at a plant boundary. This has two problems associated with it. Firstly, because of the highly variable nature of both odour generation and the behaviour of odours in the atmosphere, a regime designed to guarantee the achievement of this criterion may be significantly in excess of that required to prevent a nuisance occurring. Typically the greater part of the effort and cost will be in targeting the more infrequent odour occurrences, which may not be noticed or, if detected, may not be sufficiently frequent to constitute a nuisance. Secondly, for modern facilities malodorous emissions are often ducted to a stack and emitted well above the ground. This is designed to allow increased dispersion before reaching the ground, and could easily result in material passing above a boundary but giving rise to significant impacts beyond it.

Another proposed criterion is a limit of 5 or 10 odour units (ou) as a 98th percentile. In other words, this is a level of 5 or 10 ou which can be exceeded for no more than 2% of the time. The main problem with this is that it allows high levels of odour for anything up to 175 hours per year (2% of a year), which is sufficient to cause a significant nuisance. An emission that occurred for less than 2% of the year would give a zero 98th percentile value but could have a significant impact during the times when it did occur. Similarly an area which is downwind of a source for less than 2% of the time would have a zero 98th percentile value but could be experiencing high pollution concentrations whenever the wind comes directly from the source. An additional criterion of, say, 20 ou as a 99.9th percentile may resolve this, but these problems indicate that a percentile approach may be inappropriate.

Percentiles are difficult to explain to the general public and can be misinterpreted. A simpler approach is to consider directly the frequency of exceedence of levels of impact of, for example, 5, 10 or 20 ou. This is far easier to interpret and visualise in relation to perceived odour nuisance, which is often expressed in terms of the extent to which odours are detected.

Dispersion

The everyday experience of wind at the earth's surface is that, at any point in time, it has a general strength and direction but these typically include fluctuations, which can be large in magnitude. Material emitted into the atmosphere is moved bodily by the general or mean wind but it is the turbulent fluctuations that cause its dispersion and dilution away from a source. It is important to note that for a given wind speed and direction and a given emission the turbulence in the atmosphere can give rise to a vast range of possible downwind pollution distributions. However, a mean or typical pattern can be determined.

The level of turbulence in the atmosphere varies significantly with different atmospheric conditions. Hot summer days result in intense convective turbulence being generated by the heating of the lower atmosphere by the ground. Strong winds result in mechanical turbulence arising from interactions of the wind with the ground and obstructions such as trees and buildings. Minimal levels of turbulence occur on cold mornings with a low wind speed. Consequently these different conditions result in different behaviour of pollutants emitted into the atmosphere.

Modelling of the behaviour of material in the atmosphere takes account of the relevant processes by moving an emission according to the mean wind speed and direction defined for each hour of the study and allowing for its dispersion with a parameterisation of the meteorological situation. This parameterisation takes account of both variations in wind direction and atmospheric turbulence in each modelled hour.

A description of these processes and their application to the modelling of odours is given by Keddie (1980). This document also describes the effects that buildings can have on dispersion, which is shown schematically in Figure 1.

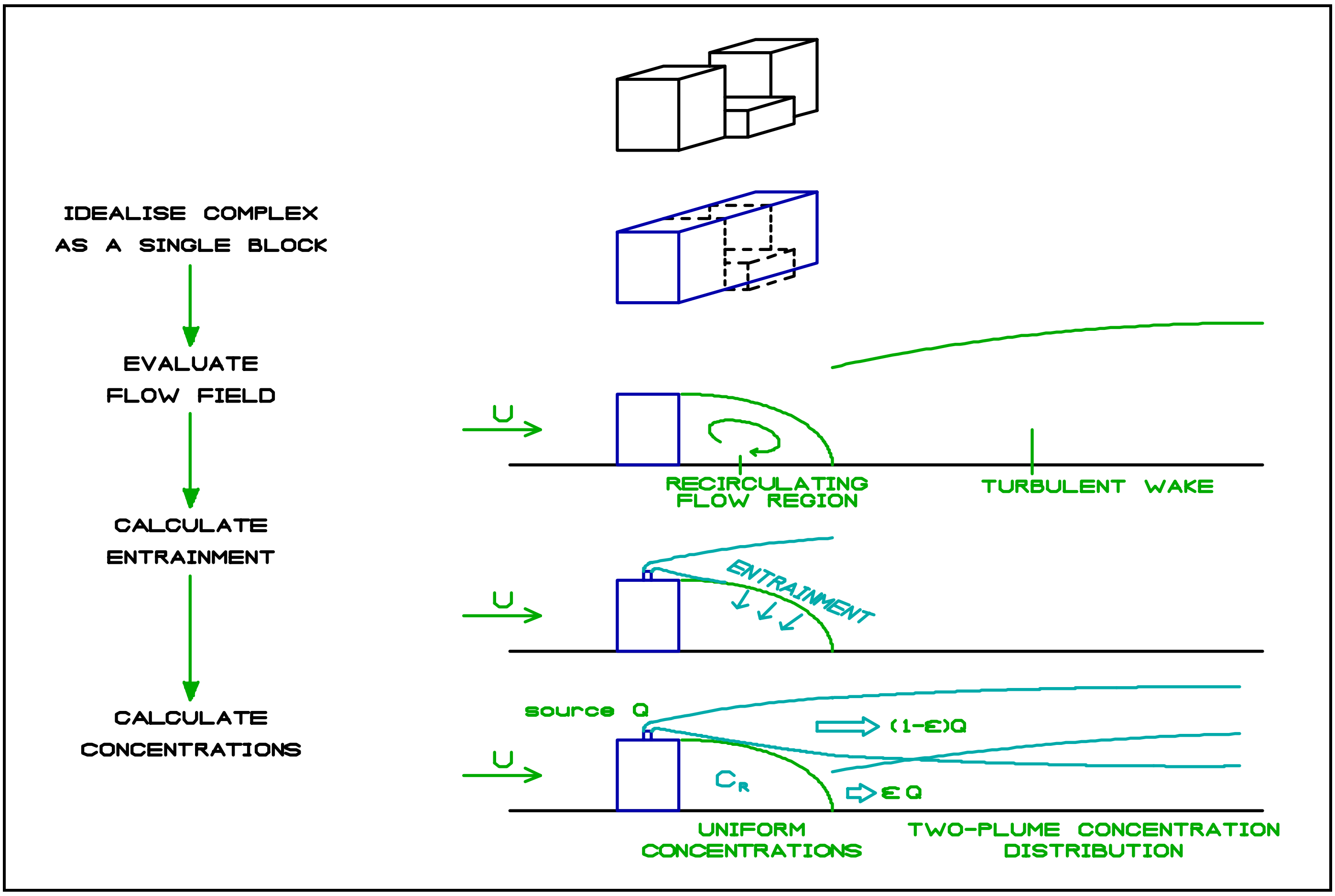

Figure 1. The effects of buildings on dispersion

There are three basic effects:

- The wind flow can be distorted by a building so that emitted material may be moved up or down, or displaced sideways, relative to its expected motion in the undeflected wind.
- Additional turbulence can be generated which will, in general, increase dispersion.
- Material can become entrained in the turbulent mixing cavity behind a building.

The third effect is by far the most important, particularly for releases near the height of a building, which is the case for many malodorous emissions, particularly those from waste-water treatment facilities. This effect is important because it can quickly bring significant amounts of emitted material down to ground level close to a building from where it can drift and impact on the surrounding areas. Figure 2 shows modelled ground-level concentrations using ADMS for a release from an 8 metre high stack both with and without an adjacent 6 metre high building of 10 by 6 metres. The increased impact with the building is clearly apparent.

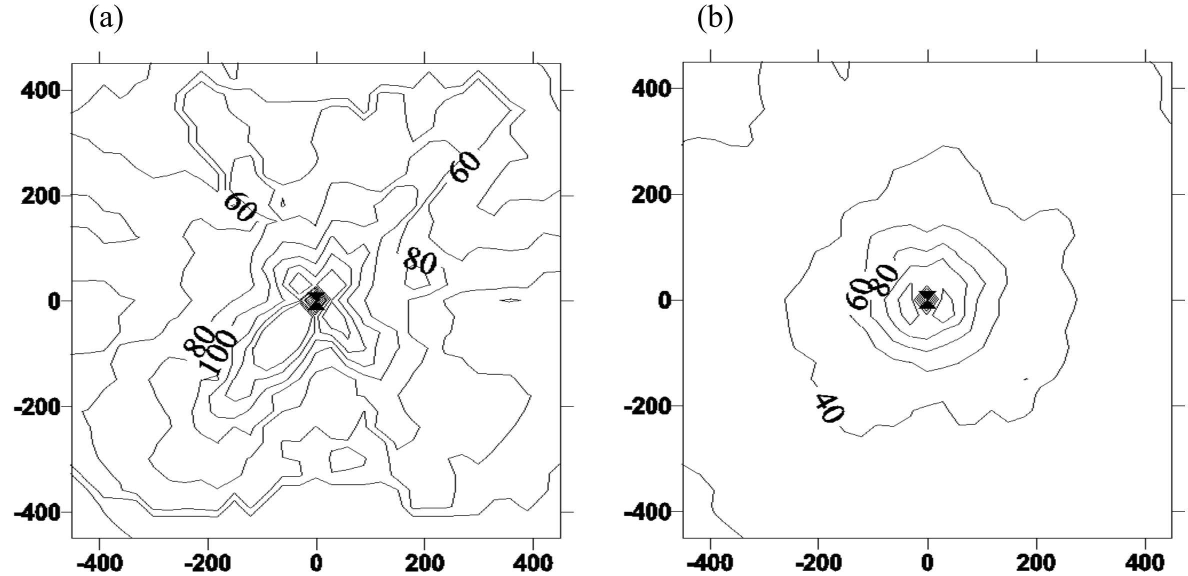

Figure 2. ADMS modelled ground level concentrations (ppb) (a) with and (b) without building

It should be noted that dispersion models created in the 1970s and 80s often only take account of the first two effects of buildings on dispersion. This is because they have typically been developed for power plant applications, using data measured in the vicinity of this type of facility, where the heights of the chimneys make entrainment less of a concern. This type of model can be significantly misleading in situations where building entrainment is fundamental to dispersion processes. Extensive studies carried out in recent years (CERC, 1999), particularly in wind tunnels, have now demonstrated the true extent of building entrainment. Unfortunately modelling experience based on the older models often gives a misleading impression of this issue.

Complex terrain can also deflect wind flow and increased turbulence. However, the effects are usually less marked than those from buildings so, while they should be taken into account in a study of emissions in or near complex terrain, they are not considered further here.

Odour detection duration is an important issue considered here. It is clear that the nose can detect elevated concentrations of an odorous material lasting only a second or so. What is not so clear is the point at which intermittent detection should be considered a nuisance. Figure 3, taken from Hall and Kukadia (1994), shows a continuous ground-level measurement of concentration of an elevated point-source emissions. It clearly shows the effect of the turbulent structure and that a detection threshold of a few times the mean concentration would result in intermittent detection of an odour. In the past, because most available models have been limited to predicting mean concentrations for periods of typically one hour, adjustment factors have been employed to attempt to take account of the intermittence of short-period concentrations. A typical value of 10 has been used for this so-called peak-to-mean ratio. Hall and Kukadia (1994) give a clear explanation, based on the random nature of the peak concentration experienced, of why this approach is not appropriate. This is a consequence of the unpredictable nature of turbulence in the atmosphere.

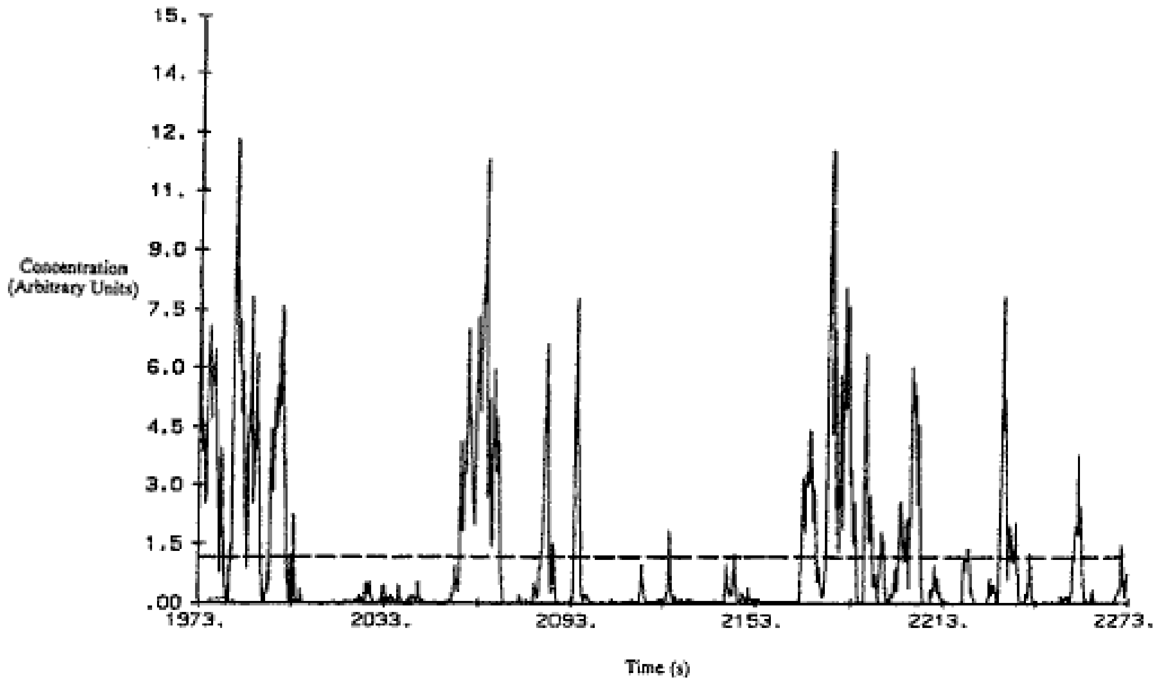

Figure 3. Short term concentrations measured in a plume; data taken from centre of a ground-based plume 10m from the source (— — — mean concentration)

Table 1 further demonstrates the limitations of the peak-to-mean ratio approach by presenting ratios between the one-hour mean concentration and predicted maximum peak concentration, calculated using ADMS. Values for a single point source emission are shown for a range of averaging times, extending from fifteen minutes down to one second, and a range of meteorological conditions and locations.

The ratio values exhibit wide variation with values significantly greater than ten occurring for the shorter averaging times and under stable conditions, particularly close to the source. Clearly using a fixed value of ten or similar for this ratio could underestimate short-term impacts in many situations. It should also be noted that these values will also vary for different emissions scenarios and those in the table should only be taken as indicative of the likely range of variation.

Table 1. Peak-to-mean ratios

Atmospheric condition	Distance from source (m)	15 minutes	3 minutes	10 seconds	1 second
Unstable	10	6.8	13.5	40	59.4
	20	5.7	10.5	33	47.4
	50	5.6	11.5	37	46.7
	100	5.6	12.1	32	37.7
	500	4.7	8.1	12	11.9
Neutral	10	3.3	13.3	159	326
	20	2.1	4.3	20	40.6
	50	1.3	2.1	6.9	13.4
	100	1.4	2.2	7.2	12.4
	500	1.6	2.8	8.4	11.6
Stable	10	86.1	1937	6263	7497
	20	15.0	199	1043	1489
	50	3.6	12.9	64	103
	100	2.0	4.2	14.8	21
	500	1.2	2.3	4.0	4.2

While more work is clearly required into the relationship between odour nuisance and the detection of odour over short time-scales, it would seem unlikely that a highly intermittently detectable odour with a mean concentration well below the detection threshold would cause a nuisance. Consequently the effects of very short-term fluctuations (over a matter of seconds) can probably be adequately modelled by considering an averaging period of three minutes or similar. It is reasonable to suggest that where the results of such an investigation did not exceed a detection threshold it would be unlikely that shorter-period peak concentrations would be detectable to the extent required to cause a nuisance. This is based on the experience that odour does not become a concern until it is detectable for significant periods of time, well in excess of three minutes.

A final point to note is that concentration fluctuations will be significantly modified when material becomes incorporated within a building wake region. This is because the additional mixing involved will tend to reduce the peak concentrations, giving a more uniform, less intermittent structure to the concentrations.

TRADITIONAL STUDIES

Studies of odour impact, particularly those from waste-water treatment plants, have generally been of one of two types: odour mapping and dispersion modelling studies. The former involves taking readings of the concentrations of, usually, hydrogen sulphide at various locations on or near to a waste-water treatment site and contouring the results. Figure 4 shows an example taken from the CIWEN Odour Control Monograph (CIWEM, 1997). The main limitation with this approach is that it has no predictive capability and can only identify significant ground-level, or near ground-level sources. Walking around a site determining odour on a zero to five scale would probably be as effective an approach.

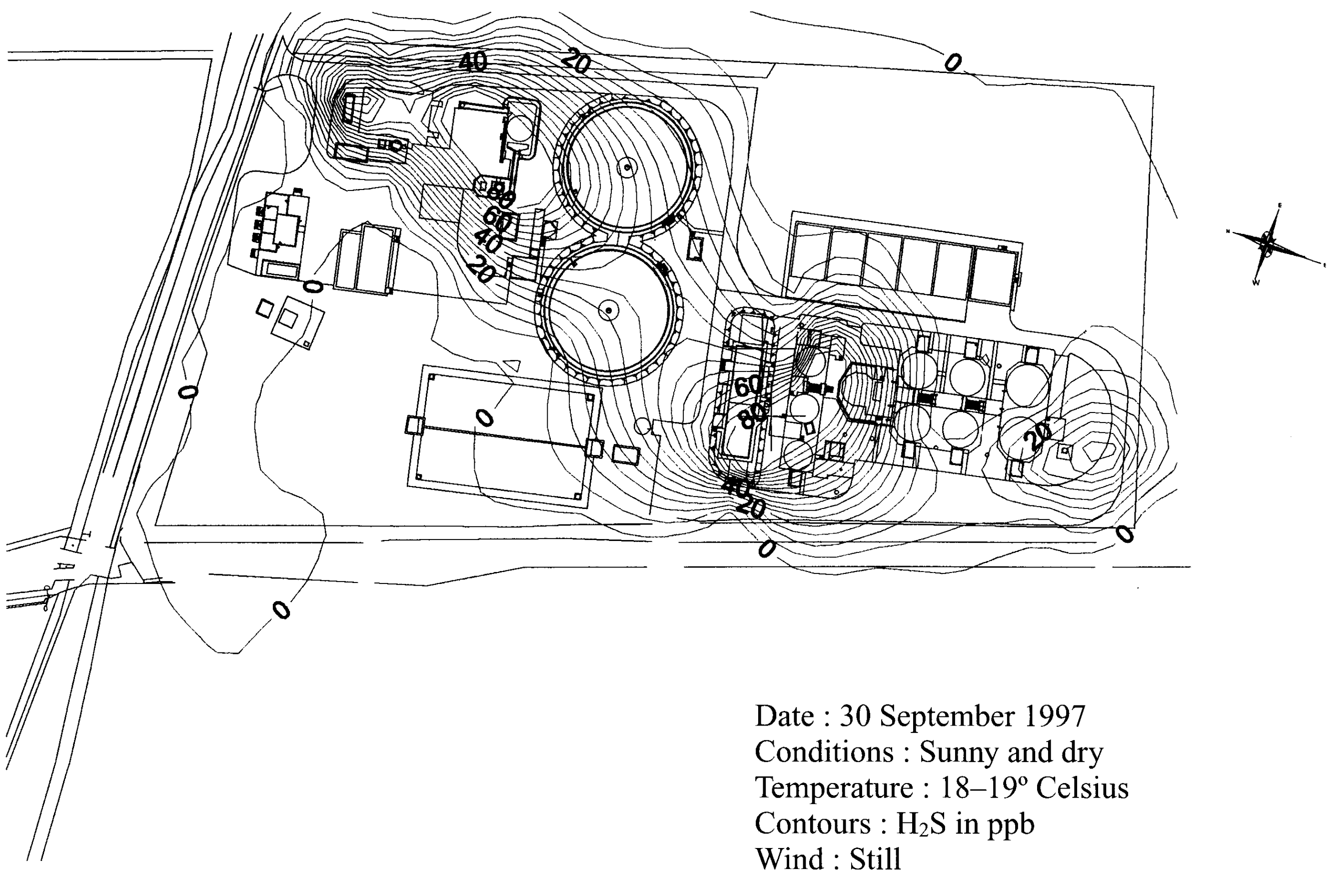

Figure 4. Example of odour map (values as ppb H_2S)

Most dispersion modelling studies have made use of models such as the Industrial Source Complex Model (ISC) provided by the US Environmental Protection Agency. These models invariably only provide one-hour average results, so the results predicted are usually required to be multiplied by a factor of, typically, ten to give a pseudo short-term peak concentration result.

The ISC model, in common with most models of its generation, does not take account of the cavity region adjacent to a building, so is clearly inappropriate for predicting concentrations in this region. This is expressed in the user manual for the ISC model (EPA, 1995) which states that '*The air flow in the building cavity region is both highly turbulent and generally recirculating. The ISC models are not appropriate for estimating concentrations within such region.*' (paragraph 1.1.5.3.1). In addition, if a model does not take account of the cavity region it will also neglect the contribution of material escaping from this region which will make a contribution to the ground level concentrations further downwind.

In general, the use of a factor of ten to estimate the short-term peak concentration probably makes this type of modelling very conservative, and so plants designed or modified based on these studies are unlikely to result in odour problems. However, the limits on emissions based on this modelling may be more restrictive, and therefore more expensive, than actually required. This cannot be guaranteed to be true in all cases, particularly where material becomes incorporated into a building cavity region close to an area of potential or actual complaint. In these situations there is the possibility of impacts being underestimated.

PROPOSED APPROACH TO ODOUR STUDIES

Based on experience gained from carrying out a wide range of studies, CERC have developed an approach to modelling odour nuisance which takes account of the current level of understanding of the atmospheric boundary layer. In addition, it minimises the risks associated with the areas where our understanding is not yet complete. Specifically, these are the behaviour of concentration fluctuations within and downstream of building cavity regions, and the effects of multiple buildings.

This approach is based around the use of the ADMS model (CERC, 1999). This model allows the turbulent fluctuations of concentration to be modelled directly, so that peak-to-mean adjustments are not required. It also takes account of the material incorporated into the mixing cavity regions adjacent to a building and the subsequent increases in ground-level concentrations downwind of the building.

The components of the approach are to:

- Provide predictions of the frequencies with which threshold levels are exceeded;
- Use three minute fluctuations predictions for locations beyond the immediate influence of buildings;
- Model separately all buildings, or groups of buildings, which could have a significant impact on dispersion;
- Use a safety factor to take account of the effects of fluctuations in the vicinity of buildings; and
- Use a comparative study wherever possible.

The threshold levels normally considered are 5, 10, 20 and 50 ou. 5 ou is considered to be the minimum level for detection in the open environment, where inhabitants are subject to a wide range of natural odours, and consequently this level corresponds to a worst-case situation. 10 and 20 ou are levels that, if occurring frequently enough, may be sufficiently detectable to constitute a nuisance. Finally, investigation of a 50 ou threshold gives information about the extent of high levels of impact.

Three-minute fluctuations are calculated because, from the discussion above, a period of three minutes is considered a suitable length of time to take account of the short-term detection capabilities of the nose as well as the need for an odour to be detectable over a period of time long enough to constitute a nuisance.

ADMS, in common with similar models, can only model single buildings, or a group of buildings represented as a single building, so it is important to model sufficient building combinations to obtain a complete picture of the dispersion. In addition, a safety factor is applied to building results to take account of the effects of concentration fluctuations within the vicinity of buildings. This is determined by consideration of the difference between exceedences over one-hour and three-minute periods for the same emissions configuration but in the absence of buildings. Since the effect of buildings is to reduce concentration fluctuations, this approach is suitably conservative.

Finally, for existing plants it is preferable to model a current situation and ensure that it is consistent with the perceived level of odour nuisance in the vicinity. This can then be used as a basis against which to compare the relative benefits of different odour reduction strategies.

Figure 5 shows results from a modelling study showing the frequency, in hours per year, during which a level of 20ou is predicted to be exceeded in the region surrounding an odour source.

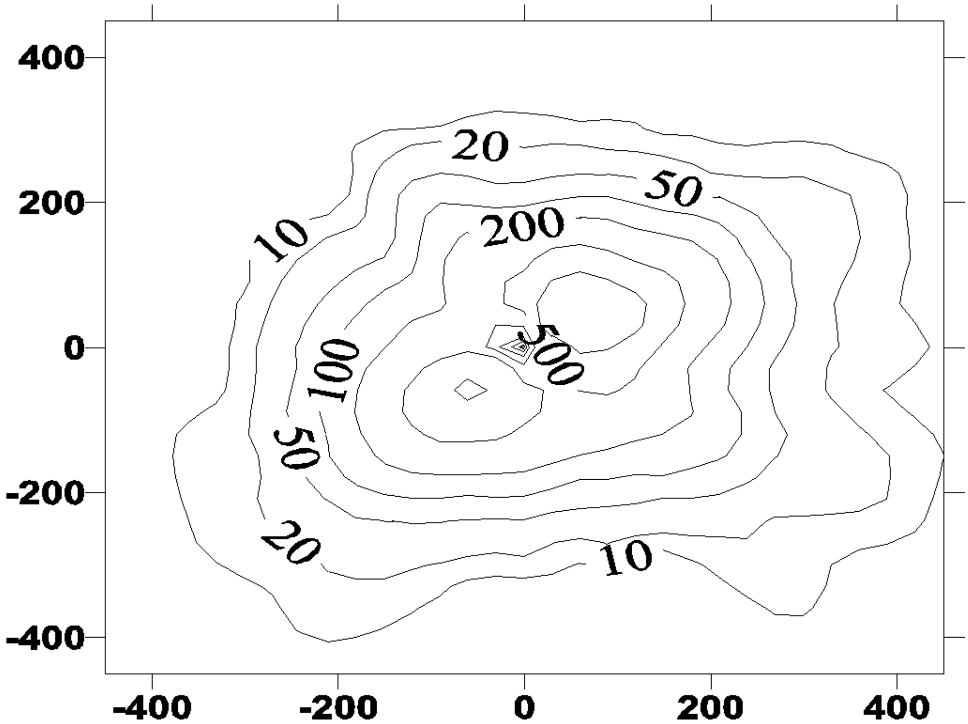

Figure 5. ADMS modelled frequency of exceedence of 20 ou threshold (hours per year)

SUMMARY

Increasing levels of odour complaint, particularly in relation to waste-water treatment facilities, and the need to provide cost-effective solutions mean that it is important to understand the link between malodorous emissions and their impacts. The limitations and potential risks of the more traditional study approaches have been explained. Finally, an approach has been suggested for determining odour nuisance based on our current understanding of atmospheric dispersion and taking account of the uncertainties inherent in this type of study.

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