A dispersion modelling approach to determining the odour impact of intensive pig production units in Ireland

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Abstract

It is becoming more common now to use atmospheric dispersion models to predict where odour nuisance is likely to occur near pig units. An odour threshold concentration of 1 $\text{Ou} \times \text{m}^{-3}$ is the level at which an odour is detectable by 50% of screened panellists. A new odour annoyance criterion ($C_{98,1-h} \leq 4.3 \text{ Ou} \times \text{m}^{-3}$) was developed in this study and compared to the Environmental Protection Agency (EPA) (Ireland) recommendation ($C_{98,1-h} \leq 6 \text{ Ou} \times \text{m}^{-3}$) using the ISCST3 model with data from three meteorological stations. Abatement techniques such as exhaust vent modification, feed manipulation, and biofiltration were assessed. Based on current limits ($C_{98,1-h} \leq 6 \text{ Ou} \times \text{m}^{-3}$) for existing facilities, predicted setback distances can be up to 780 m for a 1000-sow unit, depending on which meteorological dataset is used. However, if using the suggested odour impact criterion in this research ($C_{98,1-h} \leq 4.3 \text{ Ou} \times \text{m}^{-3}$), setback distances could reach a maximum of 1000 m. Biofilters on second stage weaning and finishing pig buildings offer the greatest single reduction (up to 650 m) in odour impact. When combined with feed manipulation and increased exhaust air velocity, the figure can be as high as 920 m. Due to the critical requirement for local meteorological data, it is recommended that a meteorological station be installed on large pig units to facilitate more accurate predictions. Site measurements of odour emissions should be made in each case because emissions are influenced by a range of local factors including feed, manure management, building design and operation.

Keywords: Atmospheric dispersion model; Pig odour; Emissions; Setback distance; Abatement

1. Introduction

A number of approaches can be taken in order to avoid odour nuisance near pig production units. Setback distances are often specified as part of local legislation or guidelines, i.e. pig units must be located at a minimum distance from odour sensitive locations such as residential housing (Curran et al., 2002). These requirements are not always easy to achieve, particularly where there are existing pig units. Another strategy is to assess the odour impact using field measurements by trained panellists (van Langenhove and van Broeck, 2001). This method is time consuming and expensive and cannot be implemented easily to account for a wide variety of local meteorological conditions.

It is becoming more common now to use atmospheric dispersion models to predict where odour nuisance is likely to occur near animal production facilities. This approach has many advantages in that emissions can be modelled for different scenarios. There are several models (e.g. ISC3, ADMS3, AUSPLUME) that are commercially available and often, particular models are favoured in different parts of the world. A problem has been the lack of peer-reviewed data on model validation, particularly regarding odour (Curran et al., 2002). Differences in model outputs can be critical especially if the result is used to determine setback distances and abatement techniques as part of a regulatory framework.

Any material discharged into the atmosphere is carried along by the wind and diluted by the turbulence, which is always present in the atmosphere. This dispersion process has the effect of producing a plume of polluted air that is roughly cone shaped with the apex towards the source and can be mathematically described by the Gaussian equation (Carney and Dodd, 1989; Smith, 1995). Atmospheric dispersion modelling has been applied to the assessment and control of odours for

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many years, originally using a Gaussian form model ISC (Industrial Source Complex) (Keddie, 1980) and more recently utilising advanced boundary-layer physics models such as Atmospheric Dispersion Modelling Software (ADMS) and AERMOD (Hall et al., 1999). Once the odour emission rate from the source is known, Ouₘ s⁻¹, the impact on the vicinity can be estimated.

Models can be applied to pig units in four different ways:

1. to assess the dispersion of odours and to correlate them with complaints;
2. to estimate which source is causing greatest impact;
3. to site a pig production unit appropriately;
4. in a “reverse” mode, to estimate the maximum odour emissions which can be permitted from a site in order to prevent odour complaints occurring (Zannetti, 1990; McIntyre, 2000).

In this latter mode, models can be employed for imposing emission limits on pig production units and to predetermine the amount of abatement required to prevent odour complaints, and thereby reduce capital investment required in abatement technologies.

This paper illustrates a dispersion modelling approach to determining the odour impact of intensive pig production units. Odour impact criteria, model selection, input parameters, and the effect of various abatement strategies on odour impact from a 1000-sow integrated pig unit are discussed.

2. Methods

2.1. Odour annoyance criteria

Odour is considered to be an annoyance when exposure to a particular concentration for a period of time is perceived by a person to be unwanted and causes him/her to complain. Five factors known as the FIDOR factors have been identified in relation to odour impact (Sheridan, 2002). These are:

- frequency (refers to the number of times the odour is detected in a given time period);
- intensity (refers to the strength of the odour);
- duration (length of exposure);
- offensiveness (hedonic tone);
- receptor (physiological aspects of the person perceiving the odour).

The development of an odour annoyance criterion is complex and requires a significant length of time (6–12 months) (VDI, 1993b; GIRL, 1994). It usually requires that an odour impact exists around a facility and therefore can cause bias in results and careful consideration of results is required. Many different techniques exist including questionnaires and telephone surveys. VDI guideline 3883 (1993a) describes a methodology for estimation of a person’s response. In conjunction with odour intensity relationship and dispersion modelling, an odour annoyance criterion can be established.

An odour threshold concentration of 1 Ouₘ m⁻³ is the level at which an odour is detectable by 50% of screened panelists. The odour recognition threshold is approximately 3–5 times this concentration (i.e. 3–5 Ouₘ m⁻³) and is liable to cause offence. Simms et al. (1999) reported a proposed odour annoyance criterion of 5 or 10 odour units as a 98th percentile. In other words, this is a level of 5 or 10 Ouₘ m⁻³ which can be exceeded for no more than 2% of the time. For example, a limit of 5 Ouₘ m⁻³ is implemented in the UK for wastewater treatment works (Northumberland Planning Board, 1993).

EPA (Ireland) (2001) reported extensive dose–effect studies carried out in the Netherlands in 1999 involving more than 2500 people living in the vicinity of pig production units. From this study, it was concluded that the percentage of the population annoyed by odour exposure should be less than 10% of the residential population in the vicinity of pig production units. For existing pig units in Ireland, 1 h odour concentrations should be below 6 Ouₘ m⁻³ as a 98%-ile in order to prevent complaints arising. This criterion has been utilised for the operation of pig production units in The Netherlands and has been found to be acceptable to regulatory bodies and the public, where allowance is made for residents living in an agricultural zone (EPA, 2001).

2.1.1. Development of dose–effect relationship using odour intensity measurement

Odour concentration alone is inadequate to assess a person’s response to an environmental odour. Odour intensity is a dimension used to describe the relative magnitude of odour sensation experienced by a person. By using odour intensity, the odour threshold concentration at which a person will perceive an odour as a nuisance can be determined (Misselbrook et al., 1993). It has been reported that an odour nuisance occurs when the perceived intensity reaches a value of 3 (Jacobson et al., 2000) and this is known as the distinct odour concentration. Stevens (1957) proposed that the perceived psychological intensity is a function of the odourant concentration (Eq. (1)).

\[ I = k(C - C₀)^n \]  

where \( I \) is the perceived psychological intensity; \( k \), the constant dependent on the choice of units of \( C \); \( C \) and odourant; \( C₀ \), the physical intensity expressed as concentration of odour compound (Ouₘ m⁻³); \( C₀ \), an esti-
mate of the odour detection threshold \((O_u g \, m^{-3})\); \(n\) is the constant dependent on odourant (Callan, 1993).

Intensity for pig odour in this study was determined in accordance with the procedure specified in VDI 3882 guidelines (1992). Eighteen air samples were collected over a 2 year period at finishing pig houses at the University Research Farm, Dublin and at a 1000-sow integrated commercial pig unit. Eight pre-screened panellists were used for the determination of odour intensity on an ECOMA T07 olfactometer. When the first four panel members finished the test sequence, the second four began. The panel members were presented with a sample of odorous gas from which they had 1 min to evaluate if the sample was in the range from “not perceptible (0)< very weak odour (1)< weak odour (2)< distinct odour (3)< strong odour (4)< very strong odour (5)< extremely strong odour (6)”. The samples were presented to the panellists in a random sequence of steps of concentration.

2.2. Model selection

In order to assess the odour impact of a pig production unit, a suitable atmospheric dispersion model must be employed to determine the odour isopleths on a map (EPA, 2001). Significant differences in predicted odour concentrations have been shown in comparisons between two widely used models ISCST3 and ADMS 3.1 (Curran et al., 2002; Sheridan, 2002). ISCST3 was selected as the most appropriate model to use in this study because of previous validation studies (Sheridan, 2002). It is a straight-line trajectory, Gaussian-based model. It assumes a Gaussian distribution of the concentration in the cross-wind vertical and horizontal directions, which is based on the 1960s description of boundary-layer physics. It is used with meteorological input data from the nearest source. The most important parameters needed in the meteorological data are wind speed and direction, ceiling heights, cloud cover, and Pasquill–Gifford stability class for each hour. ISCST3 is run with a sequence of hourly meteorological conditions to predict concentrations at receptors for averaging times of 1 h up to a year. It is necessary to use many years of hourly data to develop a better understanding of the statistics associated with calculated short-term hourly peaks or of longer time averages. The programme can function with a low meteorological input. However, this has disadvantages because an improved knowledge of the structure of the atmospheric boundary-layer and resulting estimations of turbulent dispersion processes cannot be obtained from the model (Hill, 2002).

For this study, the ISCST3 model was applied to a 1000-sow integrated pig unit to assess the influence of factors such as odour annoyance criteria, meteorological data and abatement techniques on odour impact distance.

2.3. Input data

Model inputs include source characteristics, topography of the area, meteorological data and odour emission rates.

Source characteristics include building heights, chimney heights and locations, efflux velocity, temperature and odour concentration of the waste air stream. The data may be collected using a combination of a global positioning system (GPS), airflow and temperature probes and olfactometry. It is suggested that the location of all odour sensitive receptors in the vicinity of a pig production unit be mapped using a GPS to improve accuracy.

Topography data will include the characteristics of the terrain roughness, heights of potential receptors in the vicinity of the pig production unit and valley/hill conditions. The surrounding terrain can have a significant effect on odour plume dispersion and predicted odour concentration at an odour receptor.

Meteorological data should be as representative as possible of the study location. Wind speed, direction, cloud cover and stability class will all significantly affect odour plume dispersion and plume rise from the pig production unit. In this study, the ISCST3 model was run according to the User’s Guide (US EPA, 1995) with meteorological data from Casement (1993–1997), Cork (1993–1997) and Claremorris (1993–1995), inclusive.

2.4. Odour emission factors for pig production units

The emission factors considered to be appropriate for use in the odour impact assessment of pig production units in Ireland are shown in Table 1. The emission factors for dry sows, farrowers, boars and gilts have recently been proposed by the Irish Environmental Protection Agency (EPA, 2001) to estimate odour impact from pig production units; these factors were determined during a Dutch study by Ognik and Klarenbeek (1997). The emission factors used for first stage weaners, second stage weaners and fatteners were determined by Hayes (2002) following sampling and measurement (CEN, 2001) of pig production units in Ireland; these figures vary significantly from those proposed by the Environmental Protection Agency (EPA) but are considered to be representative of conditions prevailing in Irish pig units. Clearly, there is a lack of unanimity in published odour emission rates for pig units. In these circumstances, site measurements should be made in each case because emissions are influenced by a range of local factors including feed, manure management, building design and operation.
2.5. Odour abatement techniques

Many different techniques are available for minimisation and abatement of odour emissions from pig production units; these include the following:

- exhaust vent modification;
- feed manipulation;
- biofiltration;
- combination of exhaust vent modification and feed manipulation;
- combination of exhaust vent modification, feed manipulation and biofiltration.

2.5.1. Exhaust vent modification

The efflux velocities of 0.01, 1, 4 and 7 m s\(^{-1}\) investigated during this study are typically encountered in pig production units. An efflux velocity of 0.01 m s\(^{-1}\) would represent sidewall ventilation with no upward momentum. Values of 1, 4 and 7 m s\(^{-1}\) would be typically encountered during winter, spring/autumn and summer ventilation rates. By optimising the chimney stack exit area, a minimum efflux velocity of 7 m s\(^{-1}\) could be attained. This will increase vertical plume rise and increase dilution. This should be effective in decreasing perceived odour concentration at short distances (e.g. 300 m) from pig production units.

2.5.2. Feed manipulation

A 30% reduction in odour emissions can be achieved using low crude protein diets (EPA, 2001; Hayes et al., in press). Currently, feed manipulation is only viable for finishers due to the sensitivity of younger pigs (e.g. first and second stage weaners) to crude protein levels. It is assumed in this paper that a 30% reduction in odour emissions can be maintained on a continuous basis for finishing pig houses.

2.5.3. Biofiltration

According to Sheridan et al. (2002), a removal efficiency of 90% can be assumed for the biofiltration of exhaust ventilation air from second stage weaners and finishers. The biofiltration of odorous exhaust ventilation air from these buildings was chosen for the dispersion modelling study as they represent approximately 60–70% of odour emissions from integrated pig production buildings.

2.5.4. Combined abatement methods

It may be necessary to employ a combination of odour minimisation and treatment strategies to reduce the odour impact from a pig production unit. Two combinations were assessed in this paper:

1. combination of exhaust vent modification and feed manipulation;
2. combination of exhaust vent modification, feed manipulation and biofiltration.

These methods can effectively reduce odour impact around a pig production facility by reducing odour emissions and increasing odour dispersion.

3. Results and discussion

3.1. Odour annoyance criteria

The odour intensity relationship was calculated using linear regression analysis (Fig. 1). When average odour

![Fig. 1. Odour intensity relationship for pig odour.](image-url)
intensity is plotted against Log₁₀ [Odour concentration], the following relationship can be formed.

\[ I = 2.19(\log_{10}[\text{Odour concentration}]) + 0.736 \]  

(2)

This allows for the determination of the distinct odour concentration \((I=3)\), which would be perceived as an odour nuisance. The distinct odour concentration is calculated to be 4.3 OuEm⁻³, so residents located within the odour impact area of 4.3 OuEm⁻³ at the 98%-ile, 1-h average, may perceive the odour as a nuisance; this is similar to the value of 4.8 OuEm⁻³ determined by Carney and Dodd (1989) and the figure of 6 OuEm⁻³ suggested by the EPA (2001).

3.2. Emission rates

Table 2 contains animal numbers and odour emission rates for a 1000-sow integrated pig production unit. Second stage weaners and finishers make up 67% of the total emissions. The overall odour emission rate per sow place is 94 OuEs⁻¹ s⁻¹ sow⁻¹.

3.3. Effect of meteorological data

Table 3 illustrates the influence of meteorological data on odour impact distances. Fig. 2 shows how the minimum and maximum distances were determined using the Cork meteorological data. Using the EPA limit of 6.0 OuEm⁻³, the Cork and Casement data indicate that receptors will consider the odour to be a nuisance up to 780 m away from the pig unit. However, a distance of 1000 m using the Casement data is the worst-case scenario for the 4.3 OuEm⁻³ limit. Obviously, a lower odour annoyance criterion will produce a greater impact distance. This assessment demonstrates that the use of local meteorological data is critical to output results; thus, an on-site meteorological station would be useful for more accurate predictions, especially if the nearest meteorological station is a considerable distance from the pig unit. It is also important to highlight the fact that a standard setback distance is not appropriate in all directions from pig units as can be seen from both Table 3 and Fig. 2.

Although arbitrary and based on practical experience and common sense, the recommended setback distances used in many current regulatory guidelines such as the

<table>
<thead>
<tr>
<th>Process description</th>
<th>Number of animals</th>
<th>Emission rate (OuEs⁻¹ animal⁻¹)</th>
<th>Emission rate per process (OuEs⁻¹)</th>
<th>Percent of total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry sows</td>
<td>800</td>
<td>19</td>
<td>15,200</td>
<td>16.2</td>
</tr>
<tr>
<td>Farrowing</td>
<td>200</td>
<td>18</td>
<td>3600</td>
<td>3.8</td>
</tr>
<tr>
<td>First stage weaners</td>
<td>2000</td>
<td>4.16</td>
<td>8320</td>
<td>8.8</td>
</tr>
<tr>
<td>Second stage weaners</td>
<td>1600</td>
<td>9.97</td>
<td>15,952</td>
<td>16.9</td>
</tr>
<tr>
<td>Finishers</td>
<td>4000</td>
<td>11.7</td>
<td>46,800</td>
<td>49.8</td>
</tr>
<tr>
<td>Gilts</td>
<td>200</td>
<td>19</td>
<td>3800</td>
<td>4.0</td>
</tr>
<tr>
<td>Boars</td>
<td>25</td>
<td>19</td>
<td>475</td>
<td>0.5</td>
</tr>
<tr>
<td>Total</td>
<td>8825</td>
<td></td>
<td>94,147</td>
<td>100</td>
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<tbody>
<tr>
<td></td>
<td>Minimum (m)</td>
<td>Maximum (m)</td>
<td>Minimum (m)</td>
</tr>
<tr>
<td>6.0 OuEm⁻³</td>
<td>140</td>
<td>780</td>
<td>320</td>
</tr>
<tr>
<td>4.3 OuEm⁻³</td>
<td>190</td>
<td>1000</td>
<td>345</td>
</tr>
</tbody>
</table>
Irish BATNEEC guidance note for pig production (EPA, 1996) and the New Zealand code of practice (Watts, 1999) are within the range of results from this study.

3.4. Influence of odour minimisation and abatement strategies on odour impact

Table 4 illustrates the emissions reduction that can be achieved using abatement strategies for a 1000-sow integrated pig production unit. An increase in exhaust air velocity will not have any effect on the odour emission rate. Feed manipulation for finishers offers a 14% reduction while biofiltration can achieve a 60% decrease; however, when combining all three techniques, a 61% reduction at source is possible.

Table 5 shows the range of reductions in impact distance that can be achieved by using various abatement techniques; the figures in Table 5 can be applied to the impact distances in Table 3. It is important to note that significant odour dispersion can be attained by increasing the exhaust air velocity. In this assessment, it was assumed that the increased air velocity does not lead to any increase in odour emission rate. Improvements using feed manipulation are relatively small. Biofilters offer the greatest single reduction (up to 650 m) in odour impact. When combined with feed manipulation and increased exhaust air velocity, the figure can be as high as 920 m.

Accordingly, it is concluded that biofiltration can play a significant role in odour impact reduction, particularly for existing pig units sited close to odour sensitive locations. The use of this technology would also dramatically increase the number of potential sites available on which to construct new units.

Significant differences exist between current atmospheric dispersion models (Curran et al., 2002). Further research is required in comparing models and validating results. The difficulties associated with the measurement of odour emissions at source and downwind means that further work is required in the area of odour nuisance prediction.

4. Conclusions

The main conclusions from this study of odour dispersion modelling for pig units are:

- There is a lack of unanimity in published odour emission rates for pig units. Site measurements should be made in each case because emissions are influenced by a range of local factors including feed, manure management, building design and operation.
- ISCST3 was selected as the most appropriate model to use for a detailed analysis because it has been validated for odour dispersion elsewhere and significant differences exist between it and other models in predicted odour concentrations.
- This assessment demonstrates that the use of local meteorological data is critical to output results; thus, it can be suggested that an on-site meteorological station would be useful for more accurate predictions.
Although arbitrary and based on practical experience and common sense, the recommended setback distances used in many current regulatory guidelines are within the range of results from this study.

- Based on current EPA limits ($C _ {98,1-h} \leq 6$ $OU_e$ $m^{-3}$) for existing facilities, calculated required setback distances in this study were up to 780 m for a 1000-sow unit. However, if using the suggested odour impact criterion in this research ($C _ {98,1-h} \leq 4.3$ $OU_e$ $m^{-3}$), setback distances could reach a maximum of 1000 m.

- Biofilters on second stage weaning and finishing pig buildings offer the greatest single reduction (up to 650 m) in odour impact. When combined with feed manipulation and increased exhaust air velocity, the figure can be as high as 920 m.

- Accordingly, it is concluded that biofiltration can play a significant role in odour impact reduction, particularly for existing pig units sited close to odour sensitive locations. The use of this technology would also dramatically increase the number of potential sites available on which to construct new units.

- Further research is required in comparing existing atmospheric dispersion models and validating results.

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