**Odour and Ammonia Emissions from Intensive Pig Units in Ireland**

E.T. Hayes[a], T.P. Curran[a]*, V.A. Dodd[a].

[a]Department of Biosystems Engineering, University College Dublin, Earlsfort Terrace, Dublin 2, Ireland.

*Corresponding Author. Fax: + 353 1 4752119. Email: tom.curran@ucd.ie (T. Curran)

**Abstract**

Odour and ammonia emissions were measured from dry sow, farrowing sow, 1st and 2nd stage weaner and finishing houses on four intensive pig units in Ireland. Odour samples were collected in Nalophan bags and analysed for odour concentration using an ECOMA Yes/No olfactometer. Ammonia concentrations in the exhaust ventilation air were measured using a portable iTX multi-gas biased sensor.

The geomean odour emission rates over the four pig units were 17.2, 44.4, 4.3, 9.9 and 16.8 $ou_E$ $s^{-1}$ $animal^{-1}$ for dry sows, farrowing sows, 1st stage weaners, 2nd stage weaners and finishers, respectively. The mean ammonia emission rates, measured at two of the units, were 12.1, 17.1, 1.4, 2.9 and 10.0 g $d^{-1}$ $animal^{-1}$ for dry sows, farrowing sows, 1st stage weaners, 2nd stage weaners and finishers, respectively.

In general, the odour and ammonia emission rates were comparable to those reported in literature, although some odour emission rate figures were noticeably lower for finishing pigs in this study. The variability in the data, both within and between

houses, may be related to the ventilation systems, building designs, manure storage systems, etc., and highlights the need for individual site assessment.

*Keywords:* Pig, Odour, Ammonia, Olfactometry, House design

## 1. Introduction

Due to increasing market demands, the development of genetic material and farming equipment and the availability of relatively cheap feed, farmers have been encouraged to specialise in intensive livestock production (European IPPC Bureau, 2002). This has resulted in a rationalisation of such enterprises into a smaller number of larger units across Europe. The increased public concern regarding sustainable agricultural development, combined with the growth in animal numbers and farm sizes, has led to the introduction of stringent environmental legislation throughout the European Union (EU).

Integrated Pollution Control Licensing (IPC) for pig and poultry production was introduced in Ireland in 1996 and the related guidance note was termed BATNEEC (Best Available Technology Not Entailing Excessive Cost) (EPA, 1996). BATNEEC sets out specific conditions to be implemented in order to comply with the environmental requirements of the Environmental Protection Agency (EPA). Minimisation of odour emissions and complaints is one of the requirements of the BATNEEC guidance note for intensive pig and poultry production units. In order to comply with this requirement, it is recommended that pig and poultry units should be sited at least 400 metres from any odour sensitive location (e.g. dwelling house, church, school). This distance is deemed sufficient to minimise malodourous problems from intensive production units.

EU Member States must now prepare and implement a Best Available Techniques (BAT) Note as required by the EU Council Directive (96/61/EC) on IPPC. It is expected that the BAT Note will be implemented fully for unlicensed and existing production units by 2007. At the present time, there are 73 pig farms licensed by the Irish EPA. The IPPC threshold of 2000 places for pigs over 30 kg live-weight would be reached in a integrated unit containing approximately 500 sows; this number or indeed the alternative of 750 sow places appears quite generous compared to the current Irish IPC threshold (Table 1).

The BAT Reference (BREF) document (European IPPC Bureau, 2002) was published to address the main issues in implementing the IPPC directive. BREF is concerned not only with odour but also with ammonia and other gases. Ammonia emissions in Europe originate mainly from agriculture, in particular from livestock farming. It is estimated that agricultural enterprises contribute 80-95% of ammonia emissions across Europe. Approximately 50% of ammonia emissions from pig production arise from pig buildings and the storage of manure (van der Peet-Schwering *et al.,* 1999). The monitoring and reduction of ammonia emissions from livestock farming is a legal requirement under the European Commission Acidification Strategy and the EU Directive 2001/81/CE on National Emission Ceilings (Commission of the European Communities, 1997) which has called for a limitation of ammonia emissions from each EU country. There are a number of on-farm sources of ammonia: animal housing, manure storage, field-applied manure and excreta deposited on the land by animals. The implications of both IPC, and more recently IPPC, are that all larger pig production units (> 300 sows) will have to conduct an evaluation of their emissions and demonstrate compliance with specified targets.

Compliance with odour emission targets may be determined using dispersion models with standard odour emission factors based on international measurements. It is, however, well known that odour and ammonia emissions are variable and depend on a wide range of climatic, animal, building and management factors. To date there has been a lack of published data on emissions from Irish pig housing systems. This paper reports on odour and ammonia emissions from typical Irish pig production units and compares them with proposed standards. Further work will be published on odour and ammonia emission rates from poultry units.

## 2. Materials and methods

### *2.1. Description of the four pig units*

Odour and ammonia measurements were taken on four integrated pig units (P1, P2, P3 and P4) over a two-year period. The units selected were typical of those built in Europe in the 1990's and their design and operation predated the implementation of the BAT (EPA, 1996) and BREF documents (European IPPC Bureau, 2002). A detailed description of the four integrated pig units can be found in Tables 2a, 2b, 2c, and 2d.

On each production unit there were five animal housing systems for each of the following stages of production: dry sows, farrowing sows, 1$^{st}$ and 2$^{nd}$ stage weaners and finishers. Dry sows are gestating sows and gilts, weighing approximately 100 – 180kg; farrowing sows that suckle litters of piglets and weigh approximately 100 – 180 kg; 1$^{st}$ stage weaners are growing pigs weighing < 20kg; 2$^{nd}$ stage weaners are growing pigs weighing 20 – 35 kg; finishers are growing pigs weighing > 35kg.

*2.2. Measurement of ventilation rates*

The ventilation rate of each house type was measured simultaneously while the odour samples were being collected. Two methods were used to determine the airflow rates, namely a hot-wire probe and a carbon dioxide ($CO_2$) mass balance technique. The airflow through a representative number of exhaust vents in the mechanically ventilated buildings was measured at the time of sampling using a hot wire anemometer (Testo, UK). British Standard BS848 was used as a guideline for airflow measurement, thus minimising any influence of laminar flow at the measurement locations.

To determine the ventilation rates from naturally ventilated buildings, a series of equations were used which were based on animal activity, heat and carbon dioxide production (CIGR, 2002). During a short preliminary study on a single farrowing house at unit P2, which utilised mechanical ventilation rather than natural ventilation, both the hot-wire probe and the CIGR method (2002) were assessed. The calculated airflow rates for both methods were comparable, thus it was considered that the use of the $CO_2$ mass balance technique was appropriate for determining ventilation rates. The $CO_2$ concentration was measured using a two channel infrared absorption $CO_2$ probe (Testo, UK) both inside and outside each naturally ventilated building. The probe has a measurement range of 0-10,000 ppm at 1 ppm increments. It is accurate to ± 0.01%. The probe was placed at random locations within the house during the odour sampling period to determine the mean internal $CO_2$ level.

### *2.3. Olfactometry*

#### *2.3.1. Collection of odour samples*

Individual odour samples were taken from the exhaust vents in each house type on each of the four pig production units. The odour samples were collected from each house type (in the exhaust vent air stream in mechanically ventilated buildings and at a location close to the exhaust outlet in ACNV buildings) during eight random visits over a five week period. The odour samples were collected in 40 litre Nalophan bags using a battery-powered vacuum pump and a rigid container. The samples were collected using the lung principle whereby air was removed from the rigid sampling container using the vacuum pump at a rate of approximately 4 litres per minute (Rietschle Thomas, WI, USA). A critical orifice controlled the air evacuation rate from the rigid sampling container. This created a vacuum in the container and caused a 40 litre Nalophan bag fitted inside the container to fill through stainless steel tubing with odorous air extracted from the exhaust vents. The odour samples were sealed and stored in appropriate conditions (CEN, 2003). All the samples were analysed within 24 hours. Due to constraints in resources and time, no ambient samples were taken in the vicinity of the units. Furthermore, there were no other significant odour sources within 2 km of the measurement sites. It was therefore assumed that ambient concentrations of odour were zero. A preliminary one-day trial on the diurnal variations of odour and ammonia from the University College Dublin research finishing pig units determined that the optimum time to collect odour samples was between 11 am and 12 pm. This was the time of day at which the odour emission rate began to remain reasonably constant. This may be due to animal activity within the house, feeding regimes and diurnal temperature fluctuations both inside and outside the house (Hayes, 2004).

*2.3.2. Measurement of odour threshold concentration*

The odour measurements were carried out according to the European Standard EN13725 (CEN, 2003) in the olfactometry laboratory in the Department of Biosystems Engineering, University College Dublin. An ECOMA TO7 dynamic olfactometer (ECOMA, Honigsee, Germany) was used to measure the odour threshold concentration of the ventilated air from the five house types on each of the four pig production units. The odour threshold concentration is defined as the dilution factor at which 50% of the panellists can just detect an odour. The panellists were previously selected by screening using the certified reference gas n-butanol (CAS 71-36-3). Only panellists who adhered to the code of behaviour for olfactometry were selected. The odour threshold concentration was calculated according to the response of four panel members and was displayed in $ou_E\ m^{-3}$. This refers to the physiological response from the panel equivalent to that elicited by 40 ppbv *n*-butanol evaporated in 1 $m^3$ of neutral gas (CEN, 2003). Odour units were considered a dimensionless unit, but pseudo-dimensions of $ou_E\ m^{-3}$ have been commonly used for odour dispersion modelling in place of $g\ m^{-3}$ (McGinley *et al*., 2000).

*2.4. Measurement of ammonia concentration*

Ammonia concentration measurements (ppm) were taken using an iTX Multi-gas monitor fitted with a biased sensor (iTX Multi-gas Monitor, ISC, PA, USA). The biased sensor has a measurement range of 0-999 ppm, in 1 ppm increments. The sensor was set to take readings every five minutes over the duration of its placement within each house type; these data were logged. The ammonia measurements were taken at random locations within the house close to the exhaust outlets of the ventilation system or from within the exhaust stacks. The iTX provided a simple and easy way of measuring ammonia concentration. As with odour samples, due to constraints in resources and time, no ambient ammonia measurements were taken in the vicinity of the units. It was therefore assumed that ambient concentrations of ammonia were zero.

*2.5 Statistical analysis*

Statistical analysis was carried out according to Wheater and Cook (2000). All statistical values were calculated using the software package Microsoft Excel™.

## 3. Results and discussion

### *3.1. Odour results*

Odour emission rates per animal ($ou_E$ $s^{-1}$ $animal^{-1}$) were calculated to allow standardisation and comparison between the four pig production units and published results. The results are reported as odour emission rates per animal rather than per livestock unit, as precise animal numbers were established in each house on the days when samples were collected. The same could not be done for the livestock unit as only rough estimations could be made of the mean animal weight within the house, thus making odour units per animal a more appropriate unit to use. The geomean odour concentrations, ventilation rates and odour emission rates per animal are reported in Table 3. The geomean odour emission rates over the four pig units were 17.2, 44.4, 4.3, 9.9 and 16.8 $ou_E$ $s^{-1}$ $animal^{-1}$ for dry sows, farrowing sows, 1$^{st}$ stage weaners, 2$^{nd}$ stage weaners and finishers, respectively.

Variations in odour emission rates were observed during the study for all animal house types, both between farms and temporal variations within the house type. The coefficients of variation (standard deviation as a percentage of the mean) were quite high in some cases; this is not unusual for sensorial analysis (van Langenhove and De Bruyn, 2001).

The odour measurements were made from P1 during winter conditions, from P2 and P4 during the spring and from P3 during summer conditions. Mean ambient temperatures during the collection of the data for P1, P2, P3 and P4 were 4, 14, 23 and 10°C respectively. The standard deviations of the ventilation rates were quite high in some cases (Table 3). The variability in the weather conditions and its influence on ventilation rates in each house type may have contributed to this result.

The odour emission rates per animal from the farrowing houses were generally higher than those from the other house types. This may be due to the high ventilation rates per animal for these houses which all used automatically controlled natural ventilation systems. The odour emission rates for the 1st stage and 2nd stage weaners were consistent across the four pig production units. The odour emission rates for the finishing pigs showed some variability across the four units. The highest result of 28.2 $ou_E$ $s^{-1}$ $animal^{-1}$ was observed for the finishing unit that utilised the porous ceiling ventilation system. This ventilation system allows for a better quality of air inside the animal house by moving air uniformly through the building. However, the air is then drawn by a mechanical fan below the slatted floor and across the manure surface before being exhausted from the building via a vertical shaft. Thus, the odour concentration in the exhaust air may be higher due to the airflow passing close to the manure surface resulting in increased volatilization of gases.

Comparison of these emission rates with other previously published odour emission rates is difficult, due to the numerous variables that affect the odour concentration such as ventilation system, manure management system, house design, animal diet, etc. However, the values recorded in this study fall within the ranges published for similar housing systems across Europe with the exception of farrowing houses. Previous published odour emission rates are compared with those from this study in Table 4.

The odour emission rates recommended by the Irish EPA for odour impact assessment studies of intensive pig units are based on data from three major European studies carried out in The Netherlands (Ogink and Groot Koerkamp, 2001), Belgium (van Langenhove and De Bruyn, 2001) and the United Kingdom (Peirson and Nicholson, 1995) and from two case studies carried out in Ireland. The results in this study for the dry sows, 1st stage weaners and 2nd stage weaners are similar to those reported across Europe and to the recommended emission factors used by the Irish EPA. This is probably due to the uniformity in housing systems for these animal types across Europe in the early 1990's. The odour emission rates per animal from the farrowing houses in this study varied widely and were notably higher than any other reported figures. As noted earlier, this may be due to the system of ventilation used i.e. ACNV. The odour emission rates per animal from the finishing units showed some variation. Apart from the mean odour emission rate of 28.2 $ou_E$ $s^{-1}$ $animal^{-1}$ for P2(B), the other finishing houses showed levels either equal to or 30-50% lower than those previously reported. Seasonal variations, ventilation systems, floor type and feed compositions could all be factors in these lower emissions.

As finishing pigs are the dominant source of odour emissions on intensive units, accounting for up to 72% of the total (EPA, 2001), the utilisation of accurate odour emission rates in atmospheric dispersion models is important for predicting the odour impact of a facility. For example, consider a 500 sow unit. The total odour emission rate from the animal buildings could vary from 65,000 $ou_E$ $s^{-1}$ using the Irish EPA recommended odour emission rates to 40,000 $ou_E$ $s^{-1}$ using the lowest site specific emission rates from this study. This suggests that using standard odour emission factors for Irish finishing houses could in many cases over-estimate the extent of the odour impact created on the vicinity surrounding a pig production facility. Pig production unit managers may therefore consider it worthwhile to determine site specific odour emission rates in situations of marginal compliance with the odour impact criterion set out by the EPA. As the provisions of BAT and BREF are implemented particularly in relation to minimisation techniques such as feed manipulation, rapid removal of the manure and redesigned ventilation systems, one could anticipate significantly lower levels of odour emissions.

*3.2. Ammonia results*

The mean ammonia concentration (ppm) and mean ammonia emission rates (g $d^{-1}animal^{-1}$) are reported in Table 5. Results are only available from the P2 and P3 pig production units (the ammonia sensor was unavailable when odour measurements were made at P1 and P4). The mean ammonia emission rates were 12.1, 17.1, 1.4, 2.9 and 10.0 g $d^{-1}$ $animal^{-1}$ for dry sows, farrowing sows, $1^{st}$ stage weaners, $2^{nd}$ stage weaners and finishers, respectively. The figures in Table 5 allow standardisation and comparison between the different pig production units and published results. The values reported in this study may be regarded as mean emission values for mean conditions of animal growth and manure handling.

The results reported are similar to the higher values reported in the BREF document (European IPPC Bureau, 2002). BREF reported high values of 11.5, 24.6, 2.2 and 8.2 g $d^{-1}$ $animal^{-1}$ for dry sows, farrowing sows, weaners <30kg and finishers >30 kg respectively. Extensive research on ammonia concentrations and emission rates in pig units has been reported by Groot Koerkamp *et al.* (1998); the ammonia concentration results ranged from 8.7 - 17.8, 4.5 - 7.8 and 12.1 - 18.2 ppm and the ammonia emission rates ranged from 7.8 - 17.5, 0.5 - 1.1 and 4.4 - 9.2 g $d^{-1}$ $animal^{-1}$ for sows, weaners and finishers respectively. These results are similar to those measured and reported in this study (Table 5). The manure handling system used in the dry sow and farrowing houses in the pig production units in this research may have had a beneficial impact in that it facilitates lower ammonia emissions due to the partially slatted floor and the reduced surface area of the manure beneath the slat owing to the design of a narrow manure pit. By utilising this manure system, the emitting surface of the manure stored in the manure pit is lower; 20-40% reduction in ammonia emissions can be achieved in this way (European IPPC Bureau, 2002).

The variation observed between P2(A) and P2(B) for the odour emission rates from the finishing houses was also observed for the ammonia emission rates (Table 5). This may have been due to the orientation of the fans in relation to the manure surface in the P2(B) room. There was no significant difference between the ventilation rates of the two systems ($P > 0.05$); however, the high air velocity beneath the slatted floor near the manure surface due to the location of the fans in P2(B) could enhance the volatilisation potential of gases. Aarnink and Elzing (1998) reported that a change in ventilation rate of 0.01 $m^3$ $s^{-1}$ $m^{-2}$ floor area can result in a 21% change in the ammonia emissions and that air velocity above the manure in the pit had a substantial effect on ammonia emission. Sheridan *et al.* (2002) and Hayes *et al.* (2003) also noted the influence of fan orientation within an experimental finishing pig building on the volatilisation of ammonia from the pen floor and manure surface.

The large range in published ammonia emissions from pig houses may be attributed to differences in animal size, house design and operational systems (Demmers *et al*., 1999). The production and release of ammonia within the animal building depends on a range of parameters such as temperature, pH, moisture and nitrogen content of the manure, and the influence of house design (Seedorf and Hartung, 1999).

Hyde *et al.* (2003) estimated that Ireland will not achieve its commitment with regard to ammonia emission reductions in a “business as usual” scenario by 2010. In order to achieve these targets, there may be a requirement on pig production units to reduce their current emission levels. Strategies to reduce ammonia emissions from pig housing systems include dietary manipulation (Hayes *et al*., 2003; Canh *et al*., 1998), changes in manure management and storage systems (Portejoie and Martinez, 2002; European IPPC Bureau, 2002) and practices within the buildings.

## 4. Conclusions

Odour and ammonia emissions from four typical Irish pig units were measured from dry sow, farrowing sow, 1st stage weaner, 2nd stage weaner and finishing houses.

The odour emission rates measured for the dry sow, 1st stage weaner, and 2nd stage weaner houses were within the range reported around Europe. However, the measured odour emissions from the farrowing houses were higher than previously published values. This may reflect the high ventilation rates per animal and low animal numbers in the individual farrowing houses.

With only one exception, the odour emissions measured from the finishing houses were either equal to or only 30-50% of published values. This suggests that using standard emission factors for Irish finishing houses could over-estimate the extent of the odour impact on the vicinity surrounding a pig production facility. Pig production unit managers may therefore consider it worthwhile to determine site specific odour emission rates in cases of marginal compliance with the odour impact criterion set out by the Irish EPA.

The ammonia emission rates generated were similar to those published around Europe. Manure handling systems and fan orientation can have a significant effect on the ammonia emission. To achieve national emissions targets, Ireland will need to implement specific ammonia minimisation practices such as modification of manure management systems and dietary manipulation.

## 5. Acknowledgements

The authors would like to acknowledge the financial assistance provided by Teagasc, the Irish Agricultural and Food Development Authority, under the Walsh Fellowship programme. They would also like to thank the members of the olfactometry panels, the owners, management and staff at each of the four pig units, Dr. Enda Cummins for his statistical assistance, Dr Owen Carton for his advice and especially Dr. Brian Sheridan and Mr. John Casey from UCD for their assistance in monitoring the units.

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**LIST OF TABLES.**

| Glossary of Abbreviations | |
|---|---|
| ACNV | Automatically controlled natural ventilation |
| BAT | Best available technique |
| BATNEEC | Best available technology not entailing excessive cost |
| BREF | BAT reference document |
| CEN | Comité Européen de Normalisation – European Committee for Standardization |
| CIGR | Commission Internationale du Génie Rural – International Commission of Agricultural Engineering |
| CP | Crude protein level in animal diet |
| CV | Coefficient of variation – standard deviation as a percentage of the mean |
| EPA | Environmental Protection Agency |
| EU | European Union |
| IPC | Integrated Pollution Control |
| IPPC | Integrated Pollution and Prevention Control – referring to the European Directive 96/61/EC |
| MAFF | Ministry of Agriculture Fisheries and Food (Now managed by the Department of Environmental, Food and Rural Affairs, DEFRA, UK) |
| s.d. | Standard deviation |
| s.e. | Standard error |

Table 1. Irish IPC and IPPC thresholds for pig units

| Irish IPC threshold | IPPC threshold |
|---|---|
| 1,000 units on gley soils or 3,000 units on other soils, where 1 pig = 1 unit 1 sow = 10 units | 2000 places for production pigs (over 30 kg liveweight), or 750 places for sows |

Table 2a. Pig production unit (P1) with 300 sows and progeny from birth to slaughter.

| Stage of production | Ventilation type | Floor type and manure storage | Diet[a] | Animal numbers |
|---|---|---|---|---|
| Dry sows | Negative mechanical ventilation, 0.6 m diameter roof ridge fans x 3 | Partially slatted floor, reduced manure pit[c], 222 individual crates | Commercial diet *ad lib* | 222 sows |
| Farrowers | ACNV[b] – single roof ridge exhaust vent with two side inlet vents running the length of the house | 78 individual crates on a partially slatted floor | Commercial diet *ad lib* | 78 sows |
| 1st stage | Negative mechanical ventilation, 0.45 m diameter roof ridge fans x 1 | 150 animals per house on fully slatted flat deck floors; manure stored beneath | Commercial diet *ad lib* | 600 weaners |
| 2nd stage | Negative mechanical ventilation, 0.6 m diameter roof ridge fans x 2 | 150 animals per house on fully slatted floors; manure stored beneath | Commercial diet *ad lib* | 600 weaners |
| Finishers | Negative mechanical ventilation, 0.6 m diameter roof ridge fans x 4 | 200 animals per house on fully slatted floors; manure stored beneath | Commercial diet *ad lib* | 1200 finishers |

a: details on diets unavailable;

b: Automatically Controlled Natural Ventilation (ACNV) is a form of natural ventilation by which the airflow through the building is regulated by adjusting the inlet and outlet vents to maintain a preset internal temperature

c: Reduced manure pit - the surface area of the manure stored beneath the slat is reduced by having a smaller slatted area within the house.

Table 2b. Pig production unit (P2) with 568 sows and progeny from birth to slaughter.

| Stage of production | Ventilation type | Floor type and manure storage | Diet | Animal numbers |
|---|---|---|---|---|
| Dry sows | Negative mechanical ventilation, 0.6 m diameter roof ridge fans x 6 | Partially slatted floor, reduced manure pit[b], 440 individual crates, manure removed to external tank | 15% CP diet *ad lib* | 440 sows |
| Farrowers | ACNV[a] – single roof ridge exhaust vent with two side inlet vents per house | 8 individual crates per house on a partially slatted floor, manure removed to external tank | 18% CP diet *ad lib* | 128 sows |
| 1st stage | Negative mechanical ventilation, 0.45 m diameter roof ridge fans x 1 | 125 animals per house on fully slatted flat deck floors; manure stored beneath | 21% CP diet *ad lib* | 1260 weaners |
| 2nd stage | Negative mechanical ventilation, 0.6 m diameter roof ridge fans x 2 | 125 animals per house on fully slatted floors; manure stored beneath | 20.5% CP diet *ad lib* | 1260 weaners |
| Finishers (A) | Negative mechanical ventilation, porous ceiling ventilation system, exhaust air emitted via a 2 vertical shafts fitted with a 0.6 m fan | 200 animals per house on fully slatted floors; manure stored beneath | 17% CP diet *ad lib* | 1450 finishers |
| Finishers (B) | Negative mechanical ventilation, 0.6 m diameter roof ridge fans x 2 | 300 finishers on fully slatted floors; manure stored beneath | 17% CP diet *ad lib* | 300 finishers |

a: Automatically Controlled Natural Ventilation (ACNV) is a form of natural ventilation by which the airflow through the building is regulated by adjusting the inlet and outlet vents to maintain a preset internal temperature

b: Reduced manure pit - the surface area of the manure stored beneath the slat is reduced by having a smaller slatted area within the house.

Table 2c. Pig production unit (P3) with 550 sows and progeny from birth to slaughter.

| Stage of production | Ventilation type | Floor type and manure storage | Diet[a] | Animal numbers |
|---|---|---|---|---|
| Dry sows | ACNV[a] – single roof ridge exhaust vent with two side inlet vents per house | Partially slatted floor, reduced manure pit[b], 420 individual crates, manure stored beneath | 15% CP diet *ad lib* | 420 sows |
| Farrowers | ACNV[a] – single roof ridge exhaust vent with two side inlet vents per house | 10 individual crates per house on a partially slatted floor, manure stored beneath | 18% CP diet *ad lib* | 130 sows |
| 1st stage | Negative mechanical ventilation, 0.45 m diameter roof ridge fans x 1 | 100 animals per house on fully slatted floors; manure stored beneath | 21% CP diet *ad lib* | 1400 weaners |
| 2nd stage | ACNV[a] – single roof ridge exhaust vent with two side inlet vents per house | 200 animals per house on fully slatted floors; manure stored beneath | 20.5% CP diet *ad lib* | 1400 weaners |
| Finishers | ACNV[a] – single roof ridge exhaust vent with two side inlet vents per house | 200 animals per house on fully slatted floors; manure stored beneath | 17% CP diet *ad lib* | 2000 finishers |

a: Automatically Controlled Natural Ventilation (ACNV) is a form of natural ventilation by which the airflow through the building is regulated by adjusting the inlet and outlet vents to maintain a preset internal temperature

b: Reduced manure pit - the surface area of the manure stored beneath the slat is reduced by having a smaller slatted area within the house.

Table 2d. Pig production unit (P4) with 1300 sows and progeny from birth to slaughter.

| Stage of production | Ventilation type | Floor type and manure storage | Diet[a] | Animal numbers |
|---|---|---|---|---|
| Dry sows | Negative mechanical ventilation, 0.6 m diameter roof ridge fans x 2 | Partially slatted floor, reduced manure pit[b], 200 individual crates per house | 15% CP diet *ad lib* | 1000 sows |
| Farrowers | ACNV[a] – single roof ridge exhaust vent with two side inlet vents running the length of the house | 8 individual crates per house on a partially slatted floor | 18% CP diet *ad lib* | 300 sows |
| 1st stage | Negative mechanical ventilation, 0.45 m diameter roof ridge fans x 1 | 160 animal per house on fully slatted flat deck floors; manure stored beneath | 21% CP diet *ad lib* | 3250 weaners |
| 2nd stage | Negative mechanical ventilation, 0.6 m diameter roof ridge fans x 2 | 160 animals per house on fully slatted floors; manure stored beneath | 20.5% CP diet *ad lib* | 3250 weaners |
| Finishers | Negative mechanical ventilation, 0.6 m diameter roof ridge fans x 4 | 380 animals per house on fully slatted floors; manure stored beneath | 17% CP diet *ad lib* | 3480 finishers |

a: Automatically Controlled Natural Ventilation (ACNV) is a form of natural ventilation by which the airflow through the building is regulated by adjusting the inlet and outlet vents to maintain a preset internal temperature

b: Reduced manure pit - the surface area of the manure stored beneath the slat is reduced by having a smaller slatted area within the house.

Table 3. Geomean odour concentrations, ventilation rates and odour emission rates per animal for each pig production stage

| Unit | Production stage | No of samples | Odour Concentration | | Ventilation Rate | | Odour emission rate per animal | |
|---|---|---|---|---|---|---|---|---|
| | | | $ou_E$ $m^{-3}$ | CV % | $m^3$ $s^{-1}$ | CV% | $ou_E$ $s^{-1}$ $animal^{-1}$ | CV% |
| P1 | Dry sows | 6 | 1609 | 30.2 | 0.8 | 25.0 | 16.4 | 14.7 |
| | Farrowers | 4 | 1074 | 10.2 | 0.3 | 0.0 | 35.7 | 10.3 |
| | 1st stage weaners | 6 | 1115 | 73.2 | 0.3 | 66.7 | 3.7 | 14.2 |
| | 2nd stage weaners | 8 | 1971 | 25.7 | 0.5 | 20.0 | 9.3 | 14.5 |
| | Finishers | 8 | 2016 | 11.3 | 2.9 | 6.9 | 12.1 | 11.8 |
| P2 | Dry sows | 12 | 1265 | 42.4 | 3.9 | 23.1 | 20.4 | 39.1 |
| | Farrowers | 8 | 115 | 12.3 | 0.3 | 33.3 | 37.5 | 25.9 |
| | 1st stage weaners | 16 | 1450 | 23.1 | 0.4 | 50.0 | 4.3 | 34.7 |
| | 2nd stage weaners | 16 | 2111 | 27.0 | 0.5 | 20.0 | 9.4 | 44.8 |
| | Finishers (A) | 6 | 1943 | 30.1 | 2.4 | 29.2 | 16.3 | 6.9 |
| | Finishers (B) | 14 | 2172 | 16.4 | 2.7 | 11.1 | 28.2 | 11.8 |
| P3 | Dry sows | 8 | 1119 | 11.2 | 9.1 | 1.1 | 24.1 | 10.8 |
| | Farrowers | 12 | 1078 | 12.1 | 0.2 | 0.0 | 33.2 | 18.0 |
| | 1st stage weaners | 8 | 812 | 35.6 | 1.4 | 35.7 | 4.6 | 1.7 |
| | 2nd stage weaners | 16 | 1285 | 22.4 | 2.0 | 10.0 | 10.5 | 16.2 |
| | Finishers | 16 | 1355 | 38.4 | 4.0 | 47.5 | 22.8 | 11.9 |
| P4 | Dry sows | 6 | 683 | 86.8 | 1.7 | 0.0 | 10.9 | 83.2 |
| | Farrowers | 8 | 1008 | 23.5 | 0.8 | 12.5 | 66.4 | 23.0 |
| | 1st stage weaners | 8 | 1681 | 36.2 | 0.5 | 40.0 | 4.6 | 38.9 |
| | 2nd stage weaners | 12 | 1565 | 32.5 | 1.7 | 11.8 | 10.5 | 33.7 |
| | Finishers | 14 | 2157 | 47.4 | 1.0 | 120.0 | 10.7 | 92.3 |

Table 4. Comparison with published odour emission rates

| | Dry sows $ou_E\ s^{-1}\ animal^{-1}$ | Farrowers $ou_E\ s^{-1}\ animal^{-1}$ | $1^{st}$ stage weaners $ou_E\ s^{-1}\ animal^{-1}$ | $2^{nd}$ stage weaners $ou_E\ s^{-1}\ animal^{-1}$ | Finishers $ou_E\ s^{-1}\ animal^{-1}$ |
|---|---|---|---|---|---|
| This study | 10.9 - 24.1 | 33.2 - 66.4 | 3.7 - 4.6 | 9.3 – 10.5 | 10.7 - 28.2 |
| Irish EPA [1] | 19.0 | 18.0 | 6.0 | 6.0 | 22.5 |
| Netherlands [2] | 19.0 | 17.8 | 5.0 – 16.3 | 5.0 – 16.3 | 22.4 |
| Belgium [3] | 44.6 | 17.2 | 3.3 | 3.3 | 25.4 |
| United Kingdom[4] | n/a | n/a | n/a | n/a | 18.7 – 36.1 |

Source: 1 EPA (2001); 2 Ogink and Groot Koerkamp (2001); 3 van Langenhove and De Bruyn (2001); 4 Peirson and Nicholson (1995)

Table 5. Mean ammonia concentrations and emission rates for units P2 and P3

| Animal type | Unit | No. of samples | Ammonia concentration | | Ammonia emission rate | |
|---|---|---|---|---|---|---|
| | | | ppm | s.e. | $g\ d^{-1} animal^{-1}$ | s.e. |
| Dry sows | P2 | 602 | 13.6 | 0.10 | 13.5 | 0.11 |
| | P3 | 552 | 10.7 | 0.09 | 10.6 | 0.09 |
| Farrowers | P2 | 524 | 8.8 | 0.07 | 17.8 | 0.13 |
| | P3 | 552 | 8.9 | 0.08 | 16.3 | 0.14 |
| 1st stage weaners | P2 | 965 | 5.8 | 0.02 | 1.1 | 0.004 |
| | P3 | 1073 | 4.7 | 0.03 | 1.7 | 0.01 |
| 2nd stage weaners | P2 | 977 | 10.8 | 0.06 | 3.0 | 0.02 |
| | P3 | 1073 | 5.5 | 0.03 | 2.7 | 0.01 |
| Finishers | P2(A) | 1610 | 13.7 | 0.07 | 6.9 | 0.04 |
| | P2(B) | 1860 | 15.2 | 0.09 | 11.9 | 0.07 |
| | P3 | 1977 | 10.2 | 0.06 | 11.3 | 0.06 |