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Hudson, Neale A. and Ayoko, Godwin A. and Dunlop, Mark and Duperouzel, David and Burrell, D. and Bell, K. and Gallagher, Erin and Nicholas, P. and Heinrich, N. (2008) Comparison of odour emission rates measured from various sources using two sampling devices. *Bioresource Technology* In Press.

Comparison of odour emission rates measured from various sources using two sampling devices

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Abstract

Two commonly used sampling devices (a wind tunnel and the US EPA dynamic emission chamber), were used to collect paired samples of odorous air from a number of agricultural odour sources. The odour samples were assessed using triangular, forced-choice dynamic olfactometry. The odour concentration data was combined with the flushing rate data to calculate odour emission rates for both devices on all sources.

Odour concentrations were consistently higher in samples collected with a flux chamber (ratio ranging from 10:7 to 5:1, relative to wind tunnel samples), whereas odour emission rates were consistently larger when derived from wind tunnels (ratio ranging from 60:1 to 240:1, relative to flux chamber values). A complex relationship existed between emission rate estimates derived from each device, apparently influenced by the nature of the emitting surface.

These results have great significance for users of odour dispersion models, for which an odour emission rate is a key input parameter.

Keywords: odour; emission rate; sampling; device.

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1   Introduction

Numerous sources of odour exist at intensive livestock production facilities, including feedlot pads at feedlots, holding ponds containing stormwater runoff from feedlot facilities, compost windrows used to treat solid waste derived from feedlot pads or treatment ponds and anaerobic treatment ponds used to store and treat waste derived from piggeries. Inadequate management of any of these sources may create odour complaints. Measurement of rates at which odour is emitted from specific odour sources are important in at least two ways:

1. Excessive odour emissions and resulting odour complaints may trigger regulatory action, e.g. direction to cease odour emission or commence remedial action – objective measure of odour emission rates allows comparison over time and space;

2. Typical odour emission rates for specific sources may be used as inputs to dispersion models, from which buffer distances may be calculated.

The second point above may have significant consequences for a producer or industry. If the emission rate estimates input into the dispersion model are incorrect, the buffer distances may be inadequate, leading to an excessive number of odour complaints. Alternatively, if the buffer distances are too large, an unnecessarily large site may be required in order to obtain a licence to operate the facility. Either of these circumstances may result in direct financial and social consequences.

Recent reviews of the entire odour assessment process (Irish Environmental Protection Agency, 2001; Gostelow et al., 2003) identified a number of techniques that may be used to collect odour samples, including methods that do not require a sampling device, as well as methods utilising static and dynamic hoods and wind tunnels.

1   A 2003 report prepared by the National Research Council of the National

2   Academies reviewed processes used to assess odour emissions from intensive livestock

3   facilities in the USA (National Research Council of the National Academies, 2003).

4   Techniques for directly measuring odour emissions from odour emission rates from area

5   sources were summarised in a single paragraph. The existence of wind tunnel and

6   emission chambers was acknowledged, but no recommendation was made to guide in

7   the selection and operation of an appropriate device.

8   Recent investigations of odour emissions from area sources at intensive piggery

9   operations have made extensive use of the wind tunnel design originally developed by

10 the University of New South Wales (UNSW) (Jiang et al., 1995; Bliss et al., 1995;

11 Wang et al., 2001) for odour sampling and emission rate estimations. Typical odour

12 emission rate estimates derived from five of these studies are summarised in Table 1.

13 The results are representative, each study having considerable replication as well as

14 addressing factors that may influence emission rates, such as season. The olfactometric

15 assessments were also undertaken in compliance with recognised standards.

16 Considerable variation in odour emission rate is apparent, despite similarities in odour

17 source, sampling device and olfactometry practice.

18   Emission rate data has been published for area sources associated with beef cattle

19 feedlots (Smith and Watts, 1994a; Watts et al., 1994; Smith and Watts, 1994b; Lunney

20 and Smith, 1995; Smith, 1995; 2003; 2001). Comparison of these data are complicated

21 by factors such as differences in olfactometry practice, differences in feedlot

22 management, differences in diet between feedlots, as well as climatic and geographic

23 differences. Measurements made at Australian feedlots during the 1980's and 1990's

24 identified another factor that could complicate comparison of emission rate values –

3

1   differences induced by the actual sample collection device. Using a wind tunnel, typical

2   rates of odour emission of feedlot pads reported by Smith et al. (1994a) ranged from 14

3   to 800 OU/m^2 s , whereas previous measurements made in Australia had provided very

4   different values - about 0.11 OU/m^2 s (Ormerod, 1991) and 0.5 to 2.0 OU/m^2 s (Carson

5   and Round, 1990). The latter two sets of results [cited in (Smith and Watts, 1994a)]

6   were derived from low flushing rate, cylindrical flux chambers, described as "flux

7   hoods". Smith and Watts (1994a) applied back-calculation procedures to these data to

8   estimate device-independent values. They concluded that *"....for the direct*

9   *determination of point emission rates from extensive surfaces, the flux hood appears to*

10   *be inappropriate. The preferred method of direct measurement is the wind tunnel*

11   *operated at a wind speed equivalent to ambient conditions".*

12   To our knowledge, no additional research has been undertaken to resolve or

13   explain the observed differences in odour emission rate obtained following the use of

14   different sampling devices since the work of Smith and Watts (1994a). Our research

15   summarises emission rate measurements that have been undertaken from a number of

16   sources at typical intensive livestock facilities. Samples of odorous air were collected

17   from these sources using both wind tunnel and US EPA dynamic emission chambers

18   and analysed using dynamic olfactometry. This publication is the first direct

19   comparison of experimental results obtained using these two devices. It confirms that

20   the devices provide very different estimates of emission rate. It also demonstrates that a

21   relationship between the emission rates provided by each device may be identified,

22   apparently influenced by the nature of the emitting surface.

2 Methods

2.1 Sources of odorous air

Samples of odorous air were collected from various representative area sources:

1. Sawdust compost windrows, used for the disposal of animal carcases at many intensive livestock facilities;

2. The open liquor surface of anaerobic ponds treating piggery wastes;

3. The surfaces of permeable covers installed on the liquor surface of anaerobic ponds treating piggery wastes;

4. The open liquor surface of detention basins constructed at all feedlots to store runoff from the facility;

5. The manure pad surface within a series of pens at two feedlots.

The emphasis of these investigations was on determining the relationship (if any) between odour emission rates derived from the two devices used to collect the samples of odorous air. Accordingly, limited information was collected to describe the various sources except for the feedlot manure pads. Care was taken when selecting specific locations for the collection of odour samples from the feedlot pad. Obviously wet areas or patches were avoided. Preference was given to areas that were reasonably flat. This was not always possible, particularly following rainfall events, which softened the pad and allowed animal hooves to roughen the pad surface.

2.2 Characterisation of manure pad

Samples were collected from the surface of the feedlot pads enclosed by the sampling devices immediately following collection of the samples of odorous air.

1   Replicate samples collected from the surface and base of the manure pad were dried to

2   determine the moisture content of the manure pad. Sample material was dried to

3   constant weight in a drying oven at about 105 °C over a 24-hour period.

4   In all cases, the apparent moisture status of the manure pad was also categorised

5   into two broad classes according to visual appearance – dry (where the surface material

6   was friable and crumbly, forming dust on disturbance), or wet (where dust was absent,

7   and where the manure surface had a dark appearance).

8   *2.3   Odour sample collection devices*

9   *2.3.1   UNSW-style wind tunnel ("wind tunnel")*

10   The wind tunnel system employed for collection of odour samples was based on

11   the University of New South Wales design (Wang et al., 2001). Both the wind tunnel

12   and typical use was described in detail by Hudson et al. (2006). Essentially the device

13   is a rectangular, open-bottomed box constructed from stainless steel, with dimensions

14   800 mm long x 400 mm wide x 250 mm high. During use it was flushed with carbon-

15   filtered air to create a stable internal velocity of about 0.3 m/s.

16   When sampling from the surface of polypropylene and shade cloth permeable pond

17   covers, the wind tunnel was suspended from a cableway that spanned the anaerobic

18   pond. The vertical height of the wind tunnel was adjusted using a remote controlled

19   winch system. This system was described by Hudson et al. (2008).

20   When sampling from the surface of the feedlot pens, a leak-tight seal was achieved

21   between the wind tunnel base and the pad surface by applying clean, coarse sand around

22   the outside of the wind tunnel base. No attempt was made to flatten the manure pad

23   from which the samples were collected. Although this left quite large depressions and

1   mounds in the area covered by the wind tunnel, it was felt that this was better than

2   exposing lower layers of the pad as a result of flattening the pad surface.

3   *2.3.2   US EPA dynamic emission chamber ("flux chamber")*

4   A flux chamber constructed according to the specifications of Klenbusch (1986)

5   was used. Essentially the device is an open-bottomed stainless steel cylinder (406 mm

6   id x 178 mm height) capped with an acrylic dome. The surface area covered by the

7   device was 0.13 m^2, while the internal volume was about 0.03 m^3.

8   When used to collect odour samples from liquid surfaces, the flux chamber was

9   either suspended from the gantry adjacent to the wind tunnel, or from a hoist mounted

10   on the tray of a light truck. In the latter circumstance, the height of the flux chamber

11   was adjusted using a hand operated winch.

12   The chamber was continuously flushed with instrument grade air (BOC P/L) at 5

13   L/min. This flow was measured using a TSI model 4140 mass flow meter. Sample air

14   was withdrawn from the outlet port using a vacuum pump, regulated to between about 2

15   L/min and 4 L/min using a second TSI model 4140 flow meter.

16   *2.4   Odour sample collection*

17   *2.4.1   Typical sampling protocol*

18   In most cases duplicate samples were collected from each surface using each

19   device (four samples per surface per sample event). Some surfaces were sampled a

20   number of times over a period of time, others were one-off sets of samples. The

21   following sequence was followed on all occasions:

22   1. Specific sample locations were identified;

2. Sampling equipment was assembled and the devices were deployed on the surface to be sampled according to standard procedures;

3. A flow of flushing air was initiated through both devices, which were allowed to stabilise (three to five minutes for the wind tunnel, 20 to 30 minutes for the flux chamber);

4. While conditions within the sampling devices were stabilising, the odour sample bags were primed with odorous air. This was achieved by part-filling the sample bags with odorous air from the appropriate device, and allowed them to stand in this state until the device had stabilised for the required period of time. The air used to prime the sample bag was then expelled, and the bag was now ready to be filled with the sample.

5. The sample bags were filled with odorous air, capped and stored on site. Wind tunnel samples took about six to ten minutes to fill, whereas flux chamber samples required 40 to 60 minutes for completion. Care was taken to avoid exposure of the sample drums to direct sunlight before, during and after sample collection to minimise excessive heating of the samples.

6. Samples were transported to the laboratory for assessment.

All odour samples were stored in Melinex® bags inside 120 L polyethylene drums for transport to the Department of Primary Industries & Fisheries (DPI&F) olfactometer facility in Toowoomba. Most samples were analysed by olfactometry within five hours of collection. All samples were analysed within 24 hours of collection. Only stainless steel, Teflon® or Melinex® made contact with the odour sample during collection and storage.

2.5 Determination of odour concentrations and emission rates

2.5.1 Odour assessment by dynamic olfactometry

Odour concentrations were determined using the eight panellist, triangular, forced-choice dynamic olfactometer developed by the DPI&F, described previously (Zeller et al., 2002; Nicholas et al., 1999). This olfactometer was constructed to comply with the Australian/New Zealand Standard for Dynamic Olfactometry (AS4323.3) (2001). The odour assessment also occurred in compliance with this Standard. The processes followed during olfactometric assessment were previously described in detail (Hudson et al., 2007).

2.5.2 Calculation of odour emission rates

The odour emission rate, commonly defined as OER or E was calculated for the wind tunnel using Eq. (1) and expressed in OU/m^2 s:

$$E = CV_t \frac{A_t}{A_s}$$

(1)

where C is the odour concentration of the sample of air in the bag, derived from the olfactometric assessment (OU/m^3), V_t is the wind speed inside the tunnel (m/s), A_t is the cross sectional area of the tunnel (m^2), and A_s is the surface area covered by the tunnel (m^2).

OER or E was calculated for the flux chamber using Eq. (2):

$$E = C \frac{f}{A}$$

(2)

1   where C is the odour concentration of the sample of air in the bag, derived from

2   the olfactometric assessment (OU/m^3), f is the sweep air flow rate (m^3/s) and A is the

3   surface area covered by the flux chamber (m^2).

4   Eq. (1) and Eq. (2) assume that there is no background odour in the air introduced

5   into the wind tunnel or flux chamber by the sweep air, and there is complete mixing

6   between the emissions and the airflow in the tunnel (Smith and Kelly, 1996).

7   The OER calculated for the wind tunnel was then scaled to a standard tunnel wind

8   velocity of 1 m/s according to the method of Smith and Watts (1994a). Following

9   determination of emission rates of feedlot pads using two, differently-sized wind

10   tunnels, they concluded that the emission rate E_v at a particular tunnel wind speed V_t

11   could be related to the emission rate E_1 at a tunnel wind speed of 1 m/s according to the

12   relationship in Eq. (3):

$$\frac{E_v}{E_1} = V_t^{0.63}$$
(3)

13   The exponent of 0.63 was derived as a factor for wind tunnels operated on solid

14   surfaces at feedlots (Smith and Watts, 1994a). A value of 0.5 derived from work by

15   Pollock (1997) and Jiang et al. (1995), was used for samples derived from liquid

16   surfaces. These exponent values were used to standardise all odour emission rates

17   calculated using Eq. (3).

18   *2.6   Statistical and graphical analysis*

19   Following assessment of the entire dataset for outliers, graphical and regression

20   procedures in the statistical software package Genstat (Lawes Agricultural Trust, 2005)

21   were used. The significance level was set at 5% for all tests.

1   *3   Results and discussion*

2   *3.1   Initial assessment of impact of feedlot characteristics on emission rate*

3   Samples collected from feedlot sources were part of a much larger research project

4   (Nicholas et al., 2004). An initial assessment was undertaken to determine the impact

5   of a number of variables on measured emission rate. These included: feedlot from

6   which samples were derived; feedlot pen identity; pen management (stocking density

7   and manure pad thickness); season; time of day of sample collection; diurnal variation

8   in emission rate; delay between sample collection and assessment; sample collection

9   device; pad surface moisture; pad base moisture; manure pad temperature; air

10   temperature and solar radiation. Experimental design allowed the influence of most of

11   these factors to be eliminated or minimised. Feedlot pad moisture remained a variable

12   likely to influence emission rates.

13   *3.2   Odour concentration and emission rate characteristics*

14   Measured concentrations of odour samples collected using the two sampling devices

15   from a range of sample sources are summarised in Table 2. If either the wind tunnel or

16   flux chamber values are considered, average or median odour concentrations vary quite

17   widely according to odour source. If average or median results for wind tunnel and flux

18   chamber are considered for each source, there is a marked difference according to

19   sampling device. The measured odour concentrations are always higher for the flux

20   chamber relative to the wind tunnel. The ratio of mean or median values shown at the

21   foot of Table 2 indicates a ratio of between 1:3 and 1:5 (wind tunnel concentration to

22   flux chamber concentration) for most sources. Results for wet feedlot pad sources

1 appear to be different, with a ratio of about 7:10 (wind tunnel concentration to flux

2 chamber concentration).

3 The emission rates derived from these concentration data are summarised in Table 3.

4 The average or median emission rates derived from the wind tunnel were consistently

5 larger than those provided by samples collected with a flux chamber. The range of

6 average emission rate values generated using the flux chamber varied from 0.023

7 OU/m^2 s to about 3.92 OU/m^2 s. In contrast, average emission rate values generated

8 using the wind tunnel ranged from 3.2 OU/m^2 s to 650 OU/m^2 s. The ratio of average

9 emission rate values varied from about 60 to 240, whereas the ratio of median values

10 ranged from about 14 to 198 (wind tunnel OER to flux chamber OER). The magnitude

11 of the differences in ratios between the two devices appears to be related to the actual

12 source from which the sample is collected. The impact of the surface on emission rate

13 was not immediately apparent however. The compost surfaces (which appeared

14 visually dry and friable) produced similar ratios of wind tunnel to flux chamber

15 emission rate to surfaces of a distinctly wet nature (anaerobic liquor or permeable

16 cover). Visually dry and wet feedlot surfaces produced ratios that were approximately

17 one-third larger and four times larger than those of the other surfaces respectively. The

18 impact of moisture content of feedlot pads on measured odour emission rate is discussed

19 separately in Section 3.4.

20 *3.3 Relationship between two devices by source*

21 The relationship between all wind tunnel and flux chamber emission rates for all

22 sources is shown in Figure 1. The data set has a pronounced vee-shape, radiating out at

23 about 50° from the origin of the chart. Regression analysis indicated a highly

24 significant relationship (p < 0.001), but with a small proportion of the variance

1   accounted for by the model (39%). The error variance also appeared to be a function of

2   the size of the measured response. While log-log transformation improved the model

3   performance, it was still able to account for only about 47% of the variance in the data.

4   The data were further investigated using a series of regression models developed

5   for the emission rate values derived by the two devices from the various sources.

6   ### 3.3.1   Compost sources

7   No relationship was identified between emission rates derived from the wind

8   tunnel of flux chamber on compost sources. No explanation can be offered for the

9   results observed. The odour samples were not very odorous and dilution of the emitted

10   odour within the wind tunnel appeared to take place. The nature of the emitting

11   surfaces was also quite different to the other surfaces. The surfaces were very friable

12   and porous. Odour samples were characterised by a faint but distinct "essential-oil"

13   tone, derived from the sawdust used as a carbon source, as opposed to the highly

14   offensive products of anaerobic putrefaction.

15   ### 3.3.2   Feedlot pad sources

16   A simple linear regression between all emission rates derived from the wind tunnel

17   and flux chamber from these sources indicated a highly significant relationship (p

18   <0.001), while the regression model accounted for about 58% of the variance in the

19   data. The correlation coefficient for the two devices was -0.830. The overall

20   relationship between the values derived from the devices was described by Eq. (4):

$$OER_{wt} = 223.8\,OER_{fc} - 54.1 \tag{4}$$

where OER_{wt} and OER_{fc} are the emission rate for the wind tunnel and flux chamber respectively.

These data were then examined on the basis of the visually identified wet or dry status. The relationship between the emission rates of the two devices was not as strong for dry pad samples (p = 0.002), and the regression model [Eq. (5)] was only able to account for 33% of the variance in the data set.

$$OER_{wt} = 104.9\,OER_{fc} - 3.6 \qquad (5)$$

In contrast, the relationship was very strong (p < 0.001) for samples collected from visually wet sources, with the model [Eq. (6)] able to account for nearly 93% of the variance in the data.

$$OER_{wt} = 348.6\,OER_{fc} - 103.4 \qquad (6)$$

The relationships between emission rates derived from wind tunnel and flux chamber for wet and dry feedlot pad sources is shown in Figure 2. There is a different slope and intercept for these two relationships. For more odorous sources, the flux chamber appears to have a higher residual odour, which may indicate that for high emission samples the flushing rate may be inadequate.

3.3.3   Anaerobic pond sources

The relationship between wind tunnel and flux chamber odour emission rates by source are illustrated in Figure 2. Reasonably significant relationships existed between emission rate values derived from the two devices for both the liquid surfaces (p < 0.001) and the polypropylene cover surfaces (p < 0.064). A linear regression model accounted for about 82% and 71% of the variance in the data for the liquid and cover

1 surface types respectively. The relationship between emission rates derived from the

2 two devices are described in Eq. (7) (liquid surfaces) and Eq. (8) (cover surfaces):

$$OER_{wt} = 48.33\,OER_{fc} + 24.24 \tag{7}$$

$$OER_{wt} = 95.9\,OER_{fc} - 68.4 \tag{8}$$

3 Log transformations had mixed impact on model performance. Log-linear

4 regression models were able to account for about only 47% of the variance in the cover

5 data set, in contrast to 86% of the variance in the data arising from the open liquid

6 surfaces.

7 ### *3.4   Relationship between device and source moisture content*

8 The comparison of results derived from the two feedlot pad sources indicated that

9 the moisture content influenced the measured emission rate, and probably determined

10 the relationship between results derived from the two devices.

11 A regression was performed between measured emission rate and the average pad

12 surface and base moisture content for both devices. A very weak relationship was

13 observed between the emission rate derived from each sampling device and the average

14 feedlot pad base moisture content. Reasonable relationships were however observed

15 between the odour emission rate and average pad surface moisture for both the wind

16 tunnel and flux chamber. The relationship between wind tunnel odour emission rate

17 and surface moisture content of the feedlot pad (p < 0.001) is described in Eq. (9),

18 while that between flux chamber emission rate and surface moisture content of the

19 feedlot pad (p < 0.001) is described in Eq. (10):

$$OER_{wt} = 3.95\ Moisture_{top} - 89.9 \qquad (9)$$

$$OER_{fc} = 0.01461\ Moisture_{top} - 0.010 \qquad (10)$$

1 where $Moisture_{top}$ is the average moisture content of the feedlot pad surface (%).

2 The two linear regression models were able to account for about 31% and 37% of the

3 variance in the two datasets respectively, indicating that factors other than the surface

4 moisture content of the manure pad also influenced the odour emission rate.

5 *3.5 Consideration of measured odour concentrations*

6 Forced-choice, dynamic olfactometry is a well-established technique.

7 Internationally recognised Standards [e.g. (Standards Australia and Standards New

8 Zealand, 2001; CEN, 1999)] have been developed to minimise variability within a

9 conforming laboratory and improve consistency between laboratories. The published

10 results of inter-laboratory comparison attest to the value of following standardised

11 procedures. Despite these procedures, however, this assessment technique may be

12 expected to provide relatively imprecise results. A number of reasons may be cited to

13 explain this variability:

14 1. The assessment process involves a panel of human assessors, each of whom brings a

15 range of personal experiences to the assessment process;

16 2. Age and gender differences may also introduce variability into the process;

17 3. Assessors may be more or less sensitive to specific odorants which dominate odours

18 from different sources;

19 4. The nature of presentation of the sample also introduces variability; currently all

20 olfactometers present increasing concentrations of sample in a series of presentation

1   rounds. The sample concentration is increased serially in each step, i.e. the odour

2   concentration is doubled during each presentation step, creating the potential to

3   provide a series of "stratified" results – this creates the potential to maximise

4   variability;

5   5.   While the Standards guiding olfactometry practice specify a range of calibration

6   actions intended to minimise variability in dilution accuracy across the range of

7   flows supported by an instrument, it remains likely that variability will not be

8   consistent across all flow ranges for all instruments.

9   As a consequence of these factors, variability is likely to be inherent to the

10   technique. It is possible that the strong vee shape evident during regression provides

11   some insight to the variability arising from assessment of a range of samples of varying

12   concentration derived from different sources by two different techniques. Formal

13   statistical testing also indicated that error variance was a function of the magnitude of

14   the measured response, i.e. error variance was larger for larger concentration and

15   emission rate values.

16   In previous publications, we drew attention to the range of physical chemistry

17   properties of discrete chemicals present in a sample of odorous air (Hudson and Ayoko,

18   2007b), as well as the very different aerodynamic conditions that may exist across all

19   sampling devices (Hudson and Ayoko, 2007a). The results of the current research has

20   demonstrated that the relationship between the emission rates provided by the two

21   devices may be related, but the nature of the relationship is influenced by:

22   1. Physical differences in the nature of the emitting surfaces (e.g. solid versus liquid

23   surfaces – probably surface roughness and porosity);

2. Physical differences in the nature of solid surfaces (moisture content, porosity and surface roughness);

3. Physical differences in the nature of liquid surfaces and a permeable cover on a liquid surface (surface roughness, mass transfer across a liquid-air boundary as opposed to a composite liquid-permeable barrier-air boundary).

The average emission rates derived from the wind tunnel samples were generally higher than those measured from other area sources in our other published work (Table 1). A larger number of much higher emission rate values were observed in this study as well. It is well known that emission rates can be positively correlated with wind speed [e.g. (Liss and Slater, 1974; Wanninkhof, 1992)]. While tunnel wind velocities were about 0.3 m/s, the effect of slightly differing wind speeds was minimised by calculating and reporting the equivalent emission rate at a height of 1 m at a wind speed of 1 m/s using Eq. (3). In contrast, there is no ability to normalise emission rates derived from a flux chamber to account for small variations in flushing rate because of the non-directional flows and spatially inhomogeneous velocities within the flux chamber. The impact of these slight variations on a relatively small flushing rate might be quite significant, but remain unexplored at present.

It has been demonstrated that devices with low flushing rates (such as flux chambers) are subject to external wind effects which may increase or depress emission rates (Gao and Yates, 1998a). While these effects are probably minimised over the long periods of chamber placement necessary to collect odour samples, the influence of external wind speed on odour emission rate remains unknown.

1   Low flushing rates within any sampling device will probably cause the

2   concentrations of volatile chemicals in the headspace to increase , depressing emission

3   rates (Gao and Yates, 1998a; Gao and Yates, 1998b). It is clear from this research that

4   odour samples derived from flux chambers are more concentrated than those from wind

5   tunnels. While the impact of the likely increase in headspace odour concentrations on

6   flux chamber emission rates remains speculative at present, it is more likely to depress

7   emission rates than increase them. Further research is required to address this issue.

8   The relationship between the manure pad moisture content and emission rate

9   requires additional research. It was previously demonstrated that odour emissions from

10   feedlot pads increased a few days after rainfall – an induction period of two to three

11   days appeared necessary for peak odour emission (Watts et al., 1994). While the visual

12   appearance and average pad moisture content of the feedlot pad was considered in the

13   current investigations, the time elapsed from rainfall was not considered. The results

14   from both devices would be influenced equally by this factor. The same may not be

15   true with regard to physical changes to the feedlot pad that may result following rainfall.

16   For the first time, two commonly used devices were used to measure rates of odour

17   emission from a selection of sources typical of intensive livestock operations. Despite

18   the significant numbers of samples, the relationships between measured odour emission

19   rates derived from these devices remains unclear. These results demonstrate consistent

20   differences in measured emission rates. The differences appear to be primarily related

21   to the nature of the sampling equipment, with secondary influence from the nature of

22   the emitting surfaces. While the explanations offered to explain these results may be

23   debated, these results clearly demonstrate that identical concentration and emission rate

24   results should not be anticipated from different sampling devices. Consideration of the

1   principles determining mass transfer (Hudson and Ayoko, 2007a), as well as the

2   physical differences caused by the dimensions and operation of various sampling

3   devices (Hudson and Ayoko, 2007b) supports these experimental results.

4   These results should be of concern to all users of dispersion models. Model

5   outputs (typically separation or buffer distance required to achieve an agreed odour

6   criterion), are highly dependent on the emission rate value used as model input. Our

7   results show that different devices may provide quite different emission rate values for

8   identical odour sources. While the choice of device may be debated, it is clear that

9   emission rate estimates from different devices should not be used in a single modelling

10   exercise, unless an accurate relationship between measured emission rates derived from

11   the different devices can be demonstrated.

12   **4   Conclusions**

13   Collection of paired samples of odorous air from a range of sources, using two

14   commonly-used sampling devices, operated under carefully controlled conditions,

15   followed by analysis using a single, well-managed dynamic olfactometer, demonstrated

16   that consistently different odour emission rates were derived from the two devices. A

17   number of hypotheses were proposed to explain the observed results. While these

18   remain speculative, it is certain that emission rate values derived from the two devices

19   should not be interchanged. A considerable volume of data is required to demonstrate a

20   relationship between the two devices for a given odour source. Odour dispersion

21   modellers and regulators who use the output of dispersion modelling to determine

22   buffer distances should be mindful of these results. These results indicate that

23   additional research is necessary to further explain the differences observed, from which

24   a rational sampling standard should emerge.

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Table 1. Representative odour emission rates measured from anaerobic

ponds treating piggery wastes

Sampling device[1]	Odour emission rate by surface (number of results) (OU/m² s)				Reference
	Uncovered liquor	Covered liquor (exposed)	Straw cover	Polypropylene cover	
A	16 to 29 (302)		2.1 (28)	1.7 (8)	(Hudson et al., 2006)
A	44 (42)	57 to 88 (126)	25 (31)	12.2 to 57 (131)	(Hudson et al., 2008)
A	20.42 (117)			10.22 (81)	(Bicudo et al., 2004)
A	3522 (3)		2192 (3)		(Cicek et al., 2004)
B	5.12 (24)				(Lim et al., 2003)

Notes:

1   Device A is the UNSW-style wind tunnel, Device B is a "Buoyant Convective Flux Chamber"

2   Odour emission rate scaled to a value corresponding to a wind tunnel velocity of 1 m/s at half tunnel height according to Smith and Watts (1994a), as detailed in Hudson et al. (2006)

10

1

Table 2. Comparison of odour concentrations (OC) in samples collected from a range of

area sources using UNSW-style wind tunnel (WT) or US EPA flux chamber (FC).

4

Statistic	Odour concentration by source and sample device (OU/m³)									
	Compost		Anaerobic liquor		Polypropylene permeable cover		Dry feedlot pad		Wet feedlot pad	
	FC	WT	FC	WT	FC	WT	FC	WT	FC	WT
No. observations	8	8	18	18	10	10	23	23	8	8
Mean	303	66.6	1732	504	3361	910	978	298	1373	1065
Median	274	67.5	1245	386	3728	528	790	232	1050	772
Minimum	36	25	37	17	974	39	145	16	420	66
Maximum	624	107	5547	1448	5792	2580	2623	1599	3351	3043
Standard deviation	266	34.5	1685	377	1806	1000	668	345	905	991
Ratio mean WT OC: FC OC	0.22		0.29		0.27		0.30		0.77	
Ratio median WT OC: FC OC	0.25		0.31		0.14		0.29		0.73	

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Table 3. Comparison of odour emission rates measured from a range of area sources

using UNSW-style wind tunnel (WT) or US EPA flux chamber (FC).

4

Statistic	Odour emission rate (OER) by source and sample device (OU/m^2 s)									
	Compost		Anaerobic liquor		Polypropylene permeable cover		Dry feedlot pad		Wet feedlot pad	
	FC	WT	FC	WT	FC	WT	FC	WT	FC	WT
No. observations	8	8	18	18	10	10	23	23	8	8
Mean	0.194	13.47	1.147	79.5	1.973	119	0.628	62.3	0.9525	229
Median	0.176	13.35	0.879	56	2.158	31	0.51	48.3	0.845	167
Minimum	0.023	5.1	0.02	3.2	0.116	6	0.093	3.4	0.27	14
Maximum	0.401	21.3	3.918	222.6	3.72	368	1.68	351.6	2.15	650
Standard deviation	0.171	7.02	1.13	60.1	1.262	140	0.4294	74.7	0.5873	211
Ratio mean WT OER: FC OER	69		69		60		99		240	
Ratio median WT OER: FC OER	76		64		14		95		198	

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1 List of figures

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2 **Figure 1. Relationship between wind tunnel and flux chamber odour**
3 **emission rate (OER, OU/m^2 s) for all surfaces**

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Figure 2. **Relationship between wind tunnel and flux chamber odour emission rate (OER, OU/m² s) by surface**
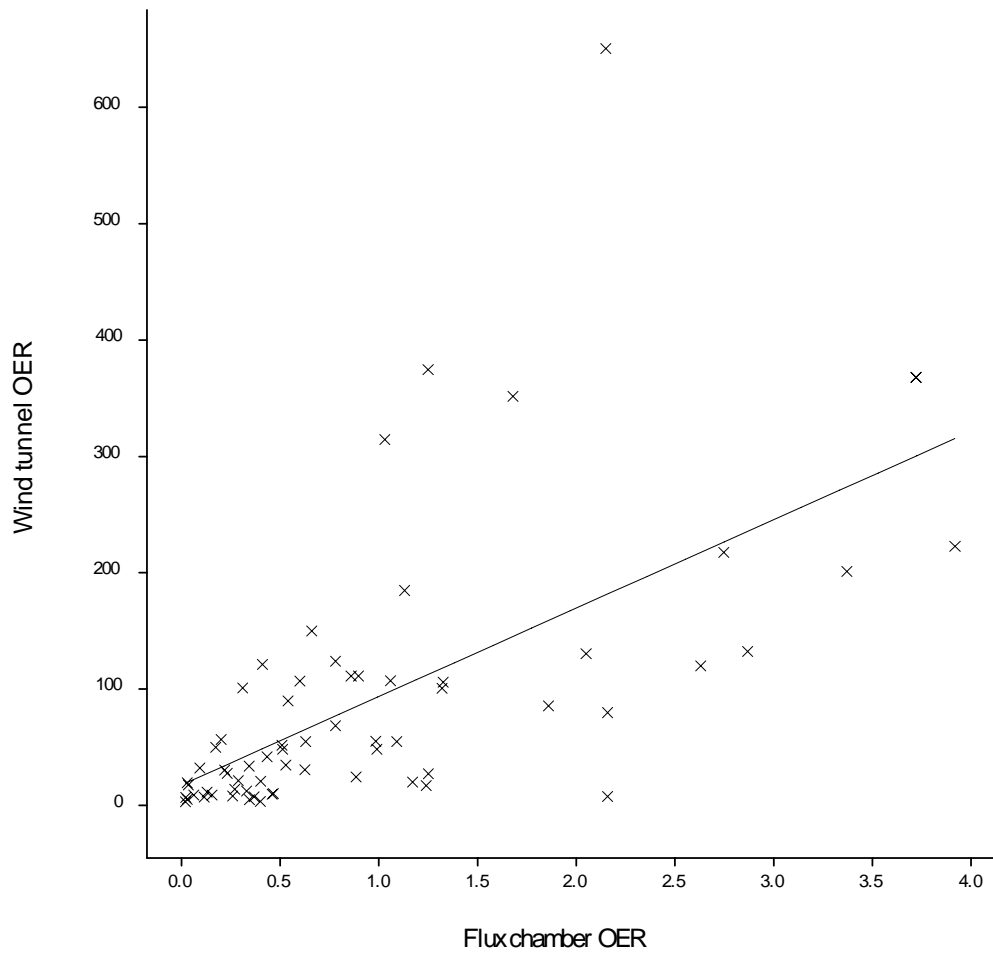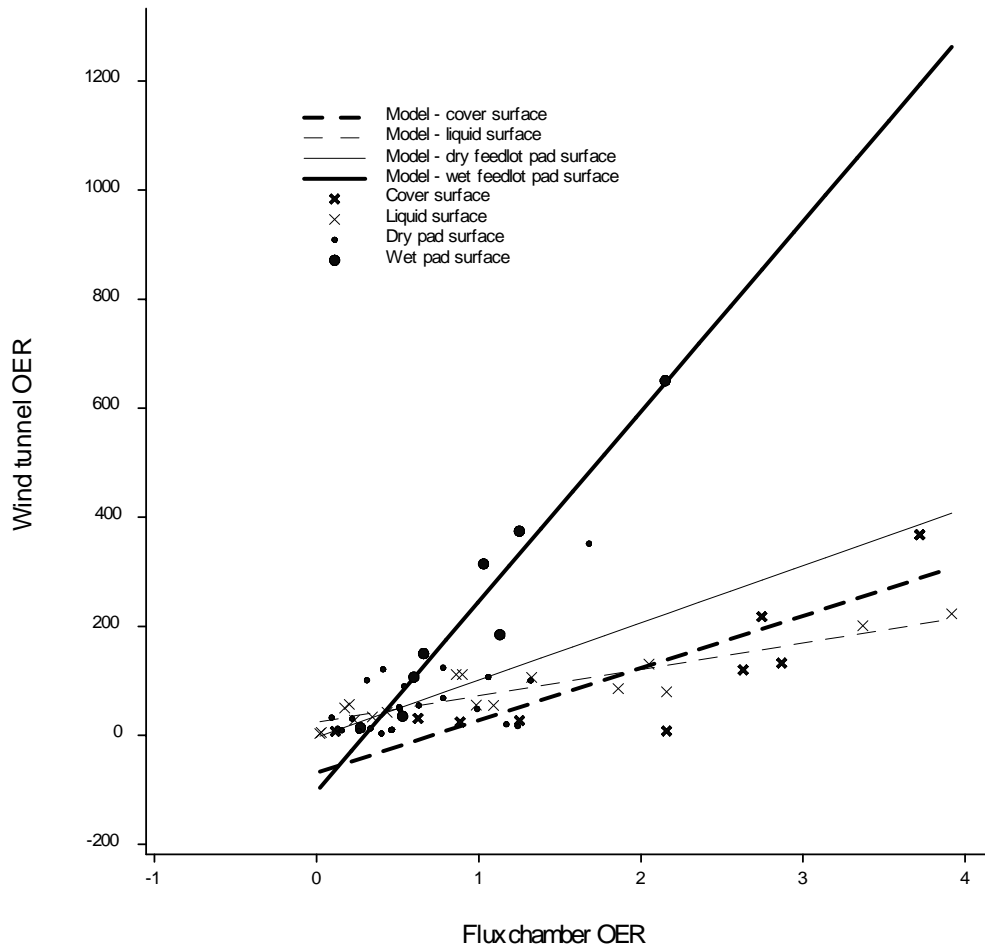
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