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# Comparison of a wind tunnel and vented flux chamber in measuring odour emission rates

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Navaratnasamy, M., I. Edeogu and J. Feddes. 2009. **Comparison of a wind tunnel and vented flux chamber in measuring emission rates.** Canadian Biosystems Engineering xx:xxx-xxx. Preliminary studies showed that odour emission rates measured by a wind tunnel (WT) or a vented flux chamber (VFC) can differ considerably. The accuracy of each technique is not known, however their relative measurements differ. A VFC and a WT, each covering a 0.80 m × 0.40 m surface area with a height of 0.25 m, were positioned over a reservoir of n-butanol solution at concentrations of 1000, 1920, 2000 and 3000 mg L<sup>-1</sup>. Emission rates from the WT were compared to those from the VFC at airflow rates of 1, 2, 15 and 30 L s<sup>-1</sup>. At a typical WT airflow rate of 30 L s<sup>-1</sup>, emission rates were 2.9 times higher than those measured by the VFC operated at its typical airflow rate of 1 L s<sup>-1</sup>. Theoretical emission rates calculated corresponded more closely with the VFC emission rates. The ratio of measured to theoretical emission rates for the VFC is 1.2 whereas that for the WT was 3.4 times higher. Odour concentrations of samples obtained using the VFC method were within the operating range of an olfactometer but were too low for samples obtained using the WT method. The coefficient of variation for the WT measurement is considerably higher. This study shows that the VFC method is a better sampling method for odour emission rate assessment because it provides more consistent, less variable results. **Keywords:** odour emission rates, wind tunnel, vented flux chamber.

Des études préliminaires ont démontré que les taux d'émission en odeur mesurée par un tunnel de vent (TV) ou par une chambre de flux ventilé (CFV) peuvent varier considérablement. La précision de chacune des techniques n'est pas connue, mais leur mesure relative diffère. Un TV et une CFV couvrant chacun une superficie de 0,80 m par 0,40 m et une hauteur de 0,25 m, ont été placés sur un réservoir d'une solution de n-butanol ayant des concentrations de 1 000, 1 920, 2 000, et 3 000 mg L<sup>-1</sup>. Les taux d'émission du TV ont été comparés à ceux de la CFV à des débits d'air de 1, 2, 15, et 30 L s<sup>-1</sup>. À un débit d'air typique pour le TV de 30 L s<sup>-1</sup>, les taux d'émission ont été 2,9 fois plus élevés que ceux mesurés par la CFV opérée à un débit d'air typique de 1 L s<sup>-1</sup>. Les taux d'émission théorique ont présentés des valeurs plus près de celles obtenues avec la CFV. Le ratio du taux d'émissions mesurés sur le théoriques pour la CFV et le TV furent de 1,2 et de 3,4 respectivement. Les concentrations d'odeur pour les échantillons obtenus en utilisant la méthode de CFV sont à l'intérieur de la plage de fonctionnement d'un olfactomètre mais ceux obtenus à l'aide de la méthode du TV sont trop faibles. Le coefficient de variation pour la mesure du TV est considérablement plus élevé. Cette étude démontre que la CFV est une meilleure méthode d'échantillonnage pour l'évaluation des taux d'émission en odeur car elle présente plus de cohérence

et moins de variabilité dans les résultats. **Mots clés:** taux d'émissions d'odeur, tunnel de vent, chambre de flux.

## INTRODUCTION

Odour has become a limiting factor in expanding the livestock industry across the prairies. To predict down-wind concentrations, the source odour emission must be known. A major source is considered to be the outside manure storage. Historically, wind tunnels (WTs), vented flux chambers (VFCs) and static chambers (SCs) have been used to determine odour emission rates from solid and liquid manure surfaces. Wind tunnels were used in research studies in Australia and the USA (David and Jose 2002). The VFC method was used in odour research studies at the University of Alberta (Edeogu et al. 2001) and in France (Leyris et al. 2000).

The design and operating conditions of VFCs and WTs are quite different. A WT is a hollow, open bottom rectangular unit through which a supply of filtered odourless air sweeps across a liquid or solid surface emitting odours and samples of odorous air are collected at the exhaust. For a VFC, odourless air is introduced into a mixed headspace above the odour-emitting surface. Air samples from the headspace are assumed to be homogeneously mixed and therefore, representative of a uniformly distributed concentration across the entire VFC headspace.

WTs are operated at different airflow rates from VFCs. Previous studies indicate that WTs were operated at airflow rates ranging between 14 and 210 L s<sup>-1</sup> (Jiang et al. 1995; Smith and Watts 1994) whereas Edeogu et al. (2001) operated a VFC at a much lower airflow rate of 1 L s<sup>-1</sup>. Leyris et al. (2000) did not report airflow rates; however, they did report that VFC air velocities near the surface ranged between 0.3 and 1 m s<sup>-1</sup>. Gholson et al. (1991) and Rienhart and Cooper (1992) used VFCs to measure organic carbon emissions. They used a very low flow-rate of 150 and 18.5 L min<sup>-1</sup> respectively. Leyris et al. (2000) categorize these VFCs as static chambers as their flow rate was lower than 34 L min<sup>-1</sup> and suggested that these methods usually resulted in an underestimation of emission. Edeogu et al. (2001) based their selection of airflow rate on the desire to achieve a headspace odour

concentration within the VFC that was comparable to the concentration outside the chamber, such as just above the manure surface as might occur on a calm windless day. From the literature, airflow rates through WTs and VFCs appear to be 30 and 1 L s<sup>-1</sup>, respectively. Gostelow et al. (2003) reported in their study that wind tunnel and flux chambers can be both used to measure odour emission rates.

Static chambers (SCs) are also hollow open-bottom vessels; however, they have not been successfully used for odour sampling and subsequent emission rate determination. With SCs odorous air is allowed to accumulate in the headspace above the emitting surface, while sampling is performed at specific time intervals. However, a concern with this technique is that SCs undergo pressurization, which impacts diffusion and may cause a change in emission rates (Hutchison and Livingston 2001). Furthermore, since several samples, sometimes as much as 15 L per sample, tend to be required to maintain the accuracy of this technique, the volume of sample removed from the headspace of the SC may exceed that of the volume emitted. Of the three direct measurement techniques, the SC technique seems to be the most variable, inaccurate and unreliable technique. Consequently, the latter was not considered for use in this study.

Odour emission rate measurements from non-point source surfaces are dependent on the odour concentration and airflow rate through the odour collection apparatus. Odour concentration is commonly measured by olfactometry (BSI 2003; Feddes et al. 2001). According to the European standards (BSI 2003), to achieve reliable olfactometer readings, the odour concentration of samples should be at least 16 times higher than the background odour concentration level or lowest detectable limit (LDL) of the sampling apparatus. David and Jose (2002) reported that the background odour concentration of Tedlar™ sampling bags is 30 OU m<sup>-3</sup>, implying that the concentration of odour samples should exceed 480 OU m<sup>-3</sup>.

Design airflow rates through a WT or VFC also affect odour concentration and have an indirect effect on the ability to achieve reliable measurements. At high airflow rates, odour concentration is typically lower than at lower airflow rates for the same source. In a preliminary study conducted at the University of Alberta, Edmonton, odour concentrations and odour emission rates from stored manure were measured using a WT operated at different airflow rates (16, 27, 45 and 63 L s<sup>-1</sup>) and a VFC operated at 1 L s<sup>-1</sup>. Odour concentrations measured with the WT were under 100 OU m<sup>-3</sup>, which is similar to the detection limit (DL) of the University of Alberta olfactometer (UA olfactometer) whereas 1250 OU m<sup>-3</sup> was measured by the VFC technique (Edeogu et al. 2001). Gostelow et al. (2003) and Frechen et al. (2004) also reported very low odour concentration measurements from WT. In contrast, the mean odour emission rates associated with the WT were higher than the mean emission rates associated with the VFC.

Comparing theoretically calculated and measured emission rates from an n-butanol source is useful in determining the accuracy of air sampling methods.

Theoretical emission rates (TER) can be calculated by multiplying the mass transfer coefficient ( $k_c$  in mg s<sup>-1</sup>) and the equilibrium concentration ( $C_a$  in mg m<sup>-3</sup>) of n-butanol as follow:

$$\text{TER} = k_c C_a \quad (1)$$

The mass transfer coefficient is calculated using boundary layer theory for a fluid flow parallel to a flat smooth surface (Geankopolis 2003; Bliss et al. 1995). The following empirical model is used to calculate  $k_c$ :

$$k_c = 0.66 D_a L^{-1} N_{re}^{0.5} S_c^{0.33} \quad (2)$$

where:  $D_a$  = Diffusivity = 8.06 10<sup>-6</sup> m<sup>2</sup> s<sup>-1</sup> at 17 C (Geankopolis 2003)

$L$  = distance between inlet and exhaust location, m  
 $S_c$  = Schmidt number = 1.88 (McCabe et al. 2005),  
 and

$N_{re}$  = Reynolds number.

$$N_{re} = X V \rho \mu^{-1} \quad (3)$$

where:  $X$  = distance between inlet and exit (0.8 m for WT and 0.75 m for VFC),

$V$  = velocity (m s<sup>-1</sup>),

$\rho$  = density (1.23 kg m<sup>-3</sup>), and

$\mu$  = viscosity (1.81 × 10<sup>-5</sup> N s m<sup>-2</sup>).

The n-butanol equilibrium concentration ( $C_a$ ) was determined using the ideal gas law:

$$C_a = P_a R^{-1} T^{-1} \quad (4)$$

$R$  = 8314 m<sup>3</sup> Pa kg mol<sup>-1</sup> K<sup>-1</sup>, and

$T$  = 293 K.

The partial pressure ( $P_a$ ) in the gaseous interface was determined using Henry's law (Geankopolis 2003):

$$P_a = H X_a \quad (5)$$

$H$  = Henry's constant = 5.57 10<sup>-6</sup> atm m<sup>3</sup> mol<sup>-1</sup> (Howard 1990), and

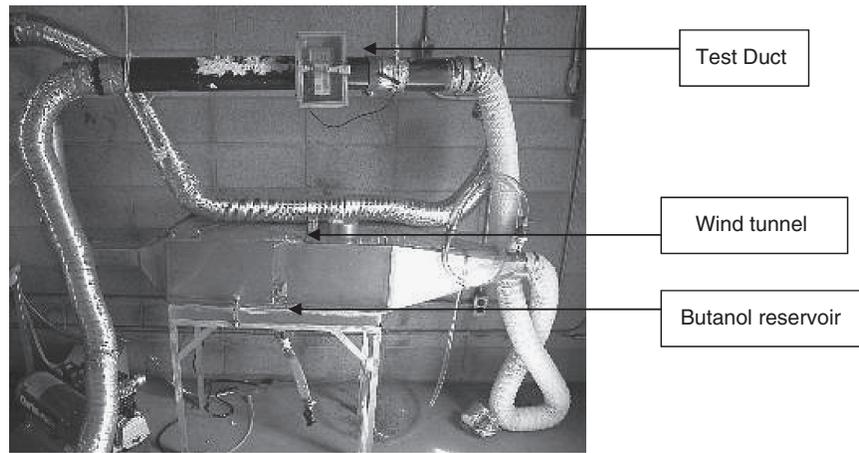
$X_a$  = Mole fraction in liquid phase.

A study was conducted to compare the WT and VFC techniques and to explain the differences in odour emission rates.

## MATERIALS and METHODS

### WT and VFC air distribution

An open bottom stainless steel WT (Fig. 1) and aluminum VFC (Fig. 2) were used in this study. Each unit measured 0.80 m by 0.40 m by 0.25 m in length, width and height, respectively. A rectangular perforated Teflon™ baffle was placed in the WT inlet to distribute air uniformly over the inlet cross-section to facilitate laminar flow across the emitting surface. Air supplied to the WT by a centrifugal fan was filtered through an activated carbon filter to remove all background odours. Similarly, filtered air was supplied to the VFC. This was directed over a low speed (245 rpm) axial 20-cm fan installed to prevent the incoming air from short circuiting through the device



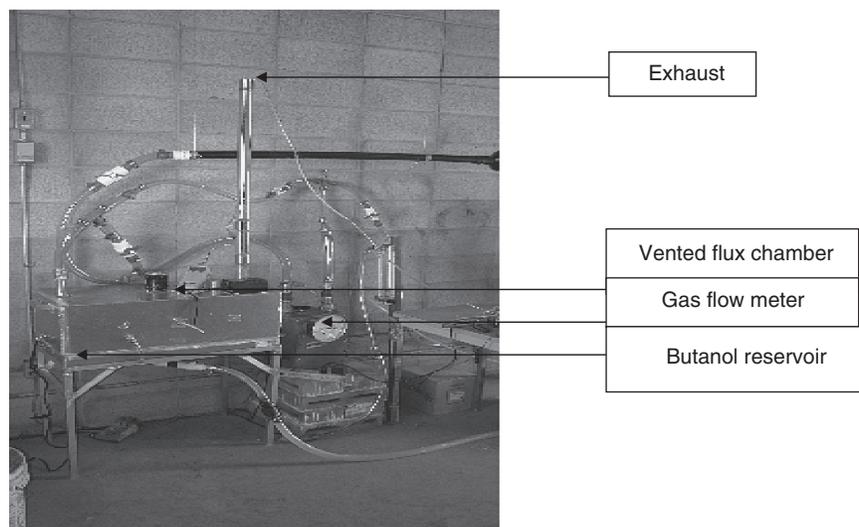
**Fig. 1. Wind tunnel (WT) placed over a reservoir containing the n-butanol solution.**

and to create a homogeneously mixed headspace n-butanol concentration.

To validate the distribution of air within the WT and VFC, air velocity measurements were taken at several traverse points spanning the cross-section of both devices. Prior to measuring air velocity, the open bottoms of the devices were covered with sealed rigid plastic sheets with a series of 6-mm diameter openings drilled along their length and width as follows. The openings were drilled along the length of each plastic sheet at intervals of 0.15, 0.39 and 0.64 m from one end of the sheet and along the width of the sheet with the first hole located 25 mm from the end of the sheet and then at 50-mm intervals thereafter. A total of 27 openings were drilled in each sheet, namely three openings along the length and nine openings along the width of the sheets. Five air velocity measurements were taken at each location within each device using a hot-wire anemometer (Velocicalc Model 8345-M-GB, TSI

Inc., St. Paul, MN) at heights of 25 mm from the internal surface of the plastic sheets and then at 50-mm intervals thereafter. A total of 135 measurements were obtained in three replicates from both devices. During the measurements, all but one of the openings was covered with tape to reduce leakage.

Airflow rates supplied to the devices were determined either by measuring the velocity at the centre of a 100-mm diameter test duct (ASHRAE 2001) using the hot-wire anemometer (airflow rates greater than  $3.5 \text{ L s}^{-1}$ ) or by using a gas flow meter (DTM-325, American Meter, Horsham, PA) (airflow rates less than  $3.5 \text{ L s}^{-1}$ ). For airflow rates above  $3.5 \text{ L s}^{-1}$ , the velocity measurement at the centre of the duct was related to the airflow rate derived from a tracer gas technique, with carbon dioxide ( $\text{CO}_2$ ) as the tracer gas.  $\text{CO}_2$  concentration was measured using a hand-held  $\text{CO}_2$  detector (YES-206, Falcon, Calle Real Golette, CA). A relationship between the air velocity



**Fig. 2. Vented flux chamber placed over a reservoir containing the n-butanol solution. A low speed (245 rpm) axial 20-cm fan inside the VF prevents air short circuiting.**

at the centre of the duct and the airflow rate through the test duct was derived as follows:

$$y = 0.94x + 0.71 \quad (R^2 = 1) \quad (6)$$

where:  $y$  = airflow rate ( $\text{L s}^{-1}$ ), and  
 $x$  = center-line velocity ( $\text{m s}^{-1}$ ).

Airflow rates below  $3.5 \text{ L s}^{-1}$  were measured with the gas flow meter.

### N-butanol emission rates

Two 25-L aluminum n-butanol solution reservoirs, each measuring 0.80 m by 0.40 m by 0.08 m in length, width and height, respectively, were fabricated such that the WT and the VFC could be placed precisely overtop the reservoirs and then sealed to prevent leakage of n-butanol emissions into the room air. The reservoirs were used to conduct three experiments as outlined below.

N-butanol concentrations in the exhaust air were measured using a handheld photo ionization detector-PID (Minirae 2000, Raesystems, Sunnyvale, CA). To obtain a representative sample, sampling was traversed across the 2.54 and 10 cm exhaust port area of the VFC and WT respectively, in accordance with the sampling procedures specified by BSI (2003). The PID instrument had a sampling period of 60 s with five readings taken and averaged during that time period. Considering the error of the airspeed sensor (3%) and the n-butanol detector (1%), the water vapour correction (3%), the error of the n-butanol emission rates was considered to be less than 10%. The accuracy of measuring airflow rate through the WT and VFC using  $\text{CO}_2$  or the velocity meter were assumed to be similar.

In a preliminary study, the moisture content of the air was found to interfere with the PID readings. Therefore, to calibrate the PID readings, n-butanol concentrations in mixtures comprising of 30, 60, 90 and 120 ppm of n-butanol gas and water vapour at dew points of 5, 10, 15,  $20^\circ\text{C}$  were prepared and measured with the PID and compared to control measurements where no water vapour was added to the dry gas samples. The dewpoints of the mixtures were measured with a dewpoint hygrometer (Model- Hygro-M1, General Eastern, Watertown, MA). This procedure was replicated three times and a relationship between a dry n-butanol and a moist n-butanol mixture is as follows:

$$y = -0.00021 x^2 - 0.0073x + 0.998 \quad (7)$$

where:  $y$  = ratio of PID measurement dry to moist air n-butanol mixture, and  
 $x$  = dewpoint meter reading (C).

In the experiments that followed, the dewpoint temperatures were measured alongside n-butanol concentrations using the PID. Subsequently, Eq. 7 was used to correct all n-butanol concentration measurements taken using the PID dividing the PID values by  $y$ .

Three experiments were conducted using different concentrations of n-butanol solution obtained by mixing

99.4% pure n-butanol with tap water. In the first experiment, the n-butanol emission rates determined by using the WT were compared with the emission rates obtained using the VFC for an n-butanol solution at an initial concentration of  $1920 \text{ mg L}^{-1}$  and air flow rates of 1, 2, and  $15 \text{ L s}^{-1}$ . The WT also was operated at  $31 \text{ L s}^{-1}$  whereas the VFC was unable to operate at this airflow rate. In the second experiment, emission rates were determined for the WT at an airflow rate of  $30 \text{ L s}^{-1}$  and VFC at an airflow rate of  $1 \text{ L s}^{-1}$ . These rates were compared to theoretically derived emission rates from n-butanol solutions at concentrations of 1000, 2000, and  $3000 \text{ mg L}^{-1}$ . The third experiment was conducted with n-butanol solutions of the same concentrations and the same airflow rates through the WT and VFC as those used in the second experiment. However, odour emission rates were determined rather than N-butanol emission rates. Samples of the exhaust air from both devices were collected in Tedlar™ bags and shipped to the University of Alberta for analysis by dynamic forced-choice olfactometry. The odour concentration data from the olfactometer results were multiplied by the airflow rates through the devices. Each experiment was replicated three times.

The data collected in the three experiments were analyzed for statistical significance using a mixed model analysis of variance procedure (SAS, 1999) at a 95% level of significance ( $p < 0.05$ ), unless stated otherwise.

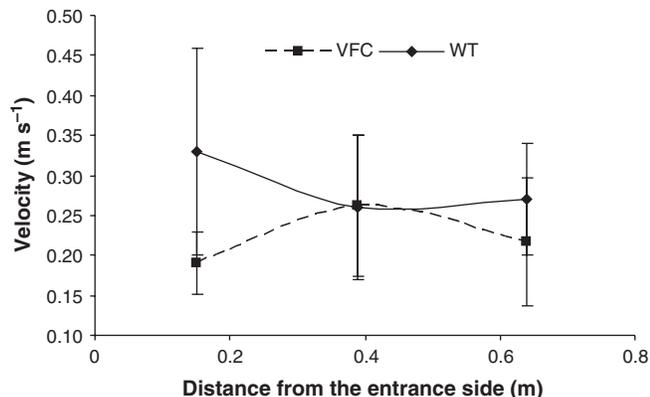
## RESULTS and DISCUSSION

The average velocities, standard deviations (STDEV), coefficients of variation (CV) and Reynolds numbers ( $N_{re}$ ) corresponding to the velocity profile measurements in the WT and VFC are presented in Table 1. In addition, the overall velocity profiles within the two devices are shown in Fig. 3. Figure 3 shows that the change in air speed along the length of the WT or VFC was not significant. The results indicate that the average air velocity within the VFC and WT were  $0.23$  and  $0.28 \text{ m s}^{-1}$ , respectively, regardless of the large variation in the airflow rate through both devices. Intuitively, the average velocity in the VFC ought to have been much lower than the result presented, however, the air mixing fan installed within the VFC contributed to this increase in air velocity within the device. Consequently, the  $N_{re}$  values,  $1.41 \times 10^4$  and  $1.12 \times 10^4$ , attributed to the flow through the WT and VFC, respectively, were also comparable. Theoretical mass transfer coefficients ( $k_c$ ) were determined by applying the  $N_{re}$  values to Eq. 1.

According to Geankopolis (2003) and Seader and Hentley (2006), laminar flow conditions exist for  $N_{re}$  values less than  $5 \times 10^5$  for air flowing over a flat surface. Therefore, relative to the  $N_{re}$  values obtained for the WT and VFC, it may be assumed that the airflow patterns through both devices were laminar. The mass transfer coefficients ( $k_c$ ) calculated on the basis of  $N_{re}$  values are shown in Table 1.

**Table 1. Average velocity, standard deviation (STDEV), coefficient of variation (CV) and mass transfer coefficients ( $k_c$ ).**

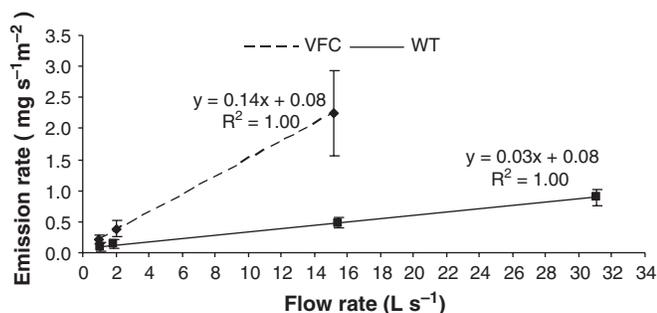
Description	Average velocity (m s <sup>-1</sup> )	Flow rate (L s <sup>-1</sup> )	STDEV	CV	N <sub>re</sub> (10 <sup>4</sup> )	k <sub>c</sub> (10 <sup>-4</sup> m s <sup>-1</sup> )
Wind tunnel	0.28	30	0.10	36	1.41	9.8
Vented flux chamber	0.23	1	0.08	33	1.12	9.3



**Fig. 3. Velocity profile from a wind tunnel (WT) and vented flux chamber (VFC).**

**Experiment 1 – Comparing the emission rates at different airflow rates**

N-butanol emission rates from the WT and VFC devices over the 1920 mg L<sup>-1</sup> n-butanol solution differed with air flow rates (Fig. 4). At low flow rates of 1 and 2 L s<sup>-1</sup>, the emission rates relative to the two techniques appear similar. When airflow rates above 1 and 2 L s<sup>-1</sup> were used, emission rates in the VFC increased rapidly while they only increased marginally in the WT. At an airflow rate of 15 L s<sup>-1</sup>, the emission rate from the VFC was approximately 4.7 times higher than that from the WT. At an airflow rate of 31 L s<sup>-1</sup>, the emission rate from the WT was about 4.5 times higher than that of the VFC operated at an airflow rate of 1 L s<sup>-1</sup> even though the air velocities near the surface were similar. The design of the VFC may



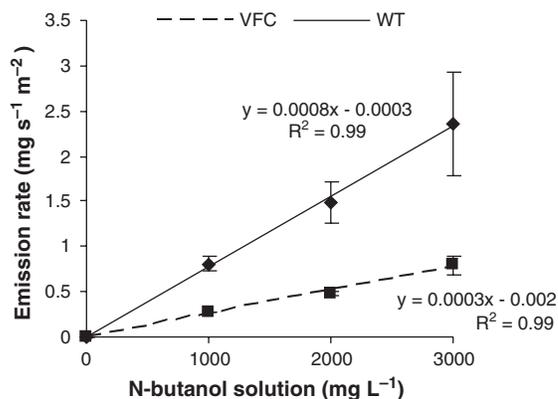
**Fig. 4. Emission rates from a wind tunnel (WT) and vented flux chamber (VFC).**

explain this increased emission rate. The VFC has a narrower inlet and outlet contributing to a high turbulence at an airflow rate of 15 L s<sup>-1</sup>. As indicated in the material and methods section, the VFC device could not handle flow rates exceeding 15 L s<sup>-1</sup>. The high turbulence in the VFC could disturb the emitting surface and result in significantly higher emission rate. Turbulence increases mass transfer rates significantly (Geankopolis 2003). In the other case, both devices were operated under laminar airflow conditions. Lower flow rate in VFC (1 L s<sup>-1</sup>) could result in a lower concentration gradient over the emitting surface compared to the WT method. The concentration gradients are proportional to the emission rates.

Furthermore, Fig. 4 shows a linear relationship between n-butanol emission rate and airflow rate. However, the air velocity data show similar air speeds for both devices when the WT is operated at 30 L s<sup>-1</sup> and the VFC is operated at 1 L s<sup>-1</sup>. The higher VFC emission rate at 15 L s<sup>-1</sup> appears to be due to an increased n-butanol liquid-to-air transfer rate due to the increased air speeds near the surface. This result supports those of previous researchers who operated the WT at 30 L s<sup>-1</sup> and the VFC operated at 1 L s<sup>-1</sup>.

**Experiment 2 – Comparing the theoretical and actual emission rates at the typical operating airflow rates**

Figure 5 shows that the emission rates of n-butanol increased linearly with concentration of n-butanol solution. At an airflow rate of 30 L s<sup>-1</sup>, the emission rate



**Fig. 5. Comparison of emission rates from the wind tunnel (WT) and vented flux chamber (VFC) for the 1000, 2000 and 3000 mg L<sup>-1</sup> n-butanol solutions.**

**Table 2. Emission rates from wind tunnel (30 L s<sup>-1</sup>) and vented flux chamber (1L s<sup>-1</sup>).**

Device	Solution Conc. (mg L <sup>-1</sup> )	Mean measured emission rate (mg s <sup>-1</sup> m <sup>-2</sup> )	Theoretically calculated emission rates (mg s <sup>-1</sup> m <sup>-2</sup> )
Wind tunnel	1000	0.81	0.23
Wind tunnel	2000	1.48	0.46
Wind tunnel	3000	2.36	0.69
Vented flux chamber	1000	0.27	0.22
Vented flux chamber	2000	0.50	0.43
Vented flux chamber	3000	0.83	0.65

measured from the WT was 2.9 higher and significantly different, from the rate measured using the VFC operated at a flow rate of 1 L s<sup>-1</sup>.

For the n-butanol concentrations of 1000, 2000 and 3000 mg L<sup>-1</sup>, their theoretical equilibrium concentrations were 232, 465 and 701 mg m<sup>-3</sup>, respectively (Eq. 3). To obtain the theoretical emission estimation (Eq. 1), these concentrations were multiplied by the k<sub>c</sub> coefficient from Eq. 2. Table 2 shows the theoretically calculated and measured emission rates using the WT and VFC. The theoretical emission rates for the WT and VFC were considerably lower than those measured. The theoretical emission rates for the WT and VFC were approximately 3.4 and 1.2 times the measured emission rates, respectively. This suggests that the measured emission rates from VFC are comparable to the theoretically estimated ones. However, theoretical emission rates from WT will also be comparable if a multiplication factor of 3.4 is applied to Eq. 2.

### Experiment 3. Comparing odour emissions with the corresponding emission rates

Odour emission rates (OERs) from the 3 n-butanol concentration treatments were significantly different. The OERs determined relative to the WT increased from 5.6 to 47 OU s<sup>-1</sup> m<sup>-2</sup> with increasing n-butanol concentration from 0 to 3000 mg L<sup>-1</sup> (Table 3; Fig. 6). In contrast, the OER within the VFC increased from 0.2 to 5 OU s<sup>-1</sup> m<sup>-2</sup>. The OER measured using the WT method was

higher by a factor of 9 than that measured using the VFC method at 3000 mg L<sup>-1</sup>. However, from the Table 3, the n-butanol gas emission rates from the WT method are approximately five times higher than the gas emission rates measured by using the VFC method. The gaseous emission rates increase linearly with the increase in n-butanol solution concentrations for the WT whereas the increase in odour concentration appears to increase exponentially. The exponential increase in OER relative to the WT may be largely influenced by the accuracy of the odour measurement noting that samples collected from the WT exhaust had low odour concentrations and were comparable to the background odour concentration of the Tedlar™ bags. In other words, greater uncertainty exists in the results of the experiment relative to the WT. Further evidence of this uncertainty is shown by the higher CVs, on average, associated with the WT measurements as opposed to the VFC. In addition, odour intensity (Feddes 2006) and odour concentration relationship for a VFC better fit a power function relationship derived based on psychophysical principles than the WT.

As stated earlier, BSI (2003) recommends that the concentration of an odour sample should be at least 16 times higher than the background concentration of the sample bags for the bags to be considered odourless. Table 3 shows that the odour concentrations of the odour samples collected using the VFC method were significantly higher than those collected using the WT method and several times higher than the background odour concentration of the sampling bags measuring 26 OU m<sup>-3</sup> as

**Table 3. Wind Tunnel (WT) and Vented Flux Chamber (VFC) odour concentration and emission rates.**

Method	Solution conc. (mg L <sup>-1</sup> )	Odour concentration			Odour emission rates		
		OU m <sup>-3</sup>	STD	CV	OU s <sup>-1</sup> m <sup>-2</sup>	STD	CV
WT	0	30	–	–	5.6	–	–
WT	1000	115	38	33	11	4	33
WT	2000	193	107	55	18	10	55
WT	3000	502	397	79	47	37	79
VFC	0	30	–	–	0.2	–	–
VFC	1000	670	200	29	2	1	29
VFC	2000	1174	257	21	4	1	21
VFC	3000	1644	363	22	5	1	22

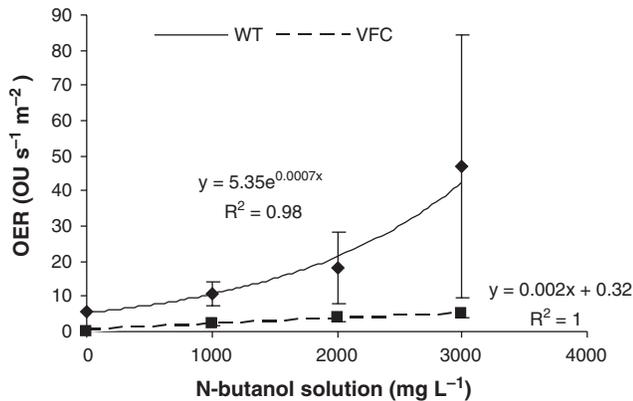


Fig. 6. Comparison of odour emission rates using a wind tunnel (WT) and vented flux chamber (VFC).

reported by Feddes (2006). For n-butanol solution concentrations of 1000, 2000 and 3000 mg L<sup>-1</sup>, the odour concentrations of samples collected using the VFC were higher by a factor of 5.8, 6.1 and 3.3 times the concentration of samples collected from the WT. In addition, the CV for measurements associated with the VFC were less variable than the results associated with the WT.

### CONCLUSIONS

The velocity measurements showed that overall velocity profile in WT and VFC are comparable even though the flow rates are different. The fan in the VFC was necessary to increase the VFC velocities. Comparable velocity profile also means comparable  $N_{re}$  and  $k_c$  values. Measured emission rates from VFC and WT are 1.2 times and 3.4 times higher than the theoretical emission rates. This means that emission rates measured from VFC are more comparable to the theoretically calculated emission rates.

In experiment 1 the emission rates from VFC and WT increased linearly with airflow rates, which means the flow rates and actual emission rates can be related in each method. VFC had considerably higher emission rates, which can be attributed to its unique design affecting the velocity profile. Also when different n-butanol concentrations were used to compare WT and VFC at their typical 30 and 1 L s<sup>-1</sup>, the emission rates increased almost linearly and emission rates from WT is 2.9 times higher than VFC. However, odour emission rates from the WT increased exponentially with n-butanol concentrations unlike the linear increase in odour emission rates from the VFC. This may be due to the error in measuring the low odour concentrations from the wind tunnel. Also the odour emission rates from WT had considerably higher CVs (33–79) unlike the VFC, which had consistent CVs (21–29). In addition measured odour concentrations from VFC are considerably higher than the WT. BSI (2003) standards suggest that the measurable odour concentration should be considerably higher than the background odour to measure odour confidently. Therefore, the VFC method appears to be the better method for confident

odour concentration measurements. The relationships obtained from the comparisons of these two methods will be useful in standardizing odour measurements.

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