Development of an eight-panelist single port, forced-choice, dynamic dilution olfactometer

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Feddes, J.J.R., Qu, G., Ouellette, C.A. and Leonard, J.J. 2001. **Development of an eight-panelist single port, forced-choice, dynamic dilution olfactometer**. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **43**: 6.1-6.5. An eight panelist automated force-choice dynamic dilution olfactometer was developed to evaluate odour concentrations in and around animal production facilities. A system was designed to analyse more samples per hour than that of a single-panelist olfactometer and to minimize any necessary purge time to clean odourous lines. The olfactometer can be calibrated with carbon dioxide to ensure that the flow rates are correct for each dilution ratio and that the resultant concentrations are the same at each panelist station (within 8%). The sensitivity of the panelists to n-butanol was 56.8 ± 2.9 ppb which is similar to the Dutch standard and within the range of the European standard. This olfactometer is a reliable unit to measure odour dilution to detection thresholds and can analyse up to nine odour samples per hour. **Keywords**: olfactometer, 8 panel station, sensitivity, calibration, carbon dioxide.

Un olfactomètre à dilution dynamique automatisée pouvant être utilisé par un jury de 8 membres a été développé afin de mesurer l'intensité des odeurs à l'intérieur et à l'extérieur des bâtiments d'élevage. Le système a été conçu pour être en mesure d'effectuer un plus grand nombre d'analyses à l'heure qu'un olfactomètre pour un seul juré, et pour minimiser le temps requis pour purger les conduits de toute odeur. La calibration de l'olfactomètre avec du gaz carbonique permet de s'assurer que les débits d'air sont adéquats pour chacun des facteurs de dilution, et que la concentration résultante est la même à chacune des 8 stations (à 8% près). Les jurés furent sensibles à des concentrations de n-butanol de 56.8 ± 2.9 ppb ce qui est semblable à la norme hollandaise, et du même ordre de grandeur que la norme européenne. Cet olfactomètre est un appareil fiable qui permet de mesurer des concentrations d'odeur jusqu'au seuil de perception et d'analyser jusqu'à neuf échantillons d'odeur à l'heure. **Mots clés**: olfactomètre, sensibilité, gaz carbonique, calibration, station de 8 jurés, gaz carbonique.

INTRODUCTION

Intensive livestock production can result in odour problems to nearby land users and therefore can become an environmental constraint to expanding the livestock industry, especially in areas where feed stuffs are grown, water is available, and transportation costs are reasonable. The odours produced by these livestock operations originate from manure storages, exhaust air from animal confinement buildings, and from manure applied to land.

To evaluate odour nuisance or odour control technology, a reliable method of quantifying odour concentration is required. Olfactometers have been developed for this purpose. Barth et al. (1984) and Li et al. (1997) describe the importance of olfactometry in evaluating odour control technology and odour dispersion downwind from a source.

Many types of olfactometers are currently available. They range from single port, forced-choice, dynamic dilution olfactometers to three port, forced-choice, dynamic dilution olfactometers. All olfactometers use human panelists to detect odours and current olfactometers range from single panelist to multi-panelist units.

Dynamic dilution olfactometry is now accepted as standard (ASTM 1986) and has been described by numerous researchers including Bulley and Phillips (1980) and Voorburg (1986). Its use in the United States, Europe, and Australia has been reported by Huang et al (1996), Carney and Dodd (1989), and Jones et al. (1992, 1994), respectively.

Dynamic olfactometry is a technique whereby continuously diluted odourous air is presented to panelists through a sniffing port. Carney and Dodd (1989) suggested that odour concentration be related to the odour detection threshold. As a result, olfactometers now present odours in concentrations ascending by factors of 2 or 3 until the odour is detected. Also, with current olfactometers, the panelist must choose between three samples presented. Two of the samples are odour-free air and one contains diluted odour. The panelist must choose one of these as a "forced choice." The dilution threshold is established when 50% of the panelists have correctly identified the odourous sample from the odour free samples (Choiniere and Barrington 1998). This dilution threshold is equivalent to the odour concentration described as odour units. A sample diluted by a factor of 100 at the detection threshold has an odour concentration of 100 odour units (Huang et al. 1996; Jones et al. 1994).

The design described in this paper can accommodate up to eight panelists and presents the odour-free air and the odourous air to each panelist through a single sniffing port.

OBJECTIVES

With most existing multi-port olfactometers, three air-mixing devices are used to randomly deliver either clean air or odourous air. These olfactometers must be purged between dilution levels and, consequently, this process becomes time consuming, requires larger quantities of sample, and the system may become contaminated by odourous samples, which decreases the system's sensitivity. A system was required where

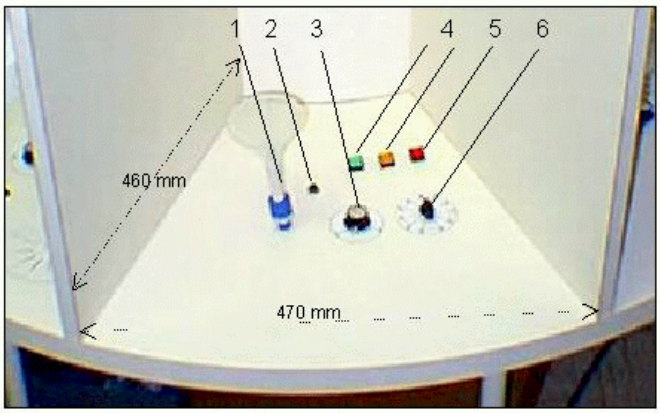

Fig. 1. A panelist station. 1 - sniffing port; 2 - green light indicator; 3 - three-position rotary switch; 4 - decision button (guess or detect odour presence); 5 - hedonic tone button; 6 - rotary, hedonic tone (-5 to 5) selector switch.

clean and odourous air delivery were not interchangeable, panelists could all be presented with identical samples at the same time, and the amount of sample required was minimized. This implies that the amount of tubing used to convey a sample to each panelist should be minimized. Other requirements of this unit were that the mixing of the odourous sample with the dilution air must be accurate and precise. The tubing selected, and any other materials coming into contact with samples, must not absorb odour and leakage of the odourous sample must not occur into the room other than the blended odour-dilution air sample.

OVERALL LAYOUT and DESIGN

The olfactometer consists of a circular table partitioned radially into eight stations to ensure privacy for each panelist. Each panelist station is 470 mm wide and 460 mm in depth and the partitions are 610 mm in height. When seated at a station, a panelist cannot see the response buttons or faces of adjacent panelists. The center of the table is occupied by a cylindrical housing (600 mm in diameter) for flow control and mixing components. This arrangement minimizes the length of tubing carrying the odourous air to each station (Fig. 1). To ensure that odours are not absorbed, all the components that contact the non-diluted odour are made of stainless steel or Tedlar ™. The sniffing port consists of a Teflon™ funnel (70 mm in diameter, cone angle of 50°) and tubing with 4-mm inner diameter connects the funnel with the flow control and mixing components. A computer with appropriate software is used to control the type of air (odourous or odour-free) presented at each station, and the dilution of the odourous air. The computer also scans the output responses from each panelist station and stores the response data for each dilution level.

Computer-actuated mass flow controllers (MKS, Andover, MA) are used to deliver the correct odour flow rate at each dilution level. The controllers deliver the odour sample to the odourous air chamber (Fig. 2) at rates from 2^{15}:1 to 2^{3}:1. Four mass flow controllers are used (0 – 10 mL/min), (0 – 100 mL/min), (0 - 1,000 mL/min), and (0 - 20,000 mL/min). If the required flow rate of the odour sample exceeds the capacity of a mass flow controller, the computer software activates the larger flow controller. A solenoid valve is installed down stream from each flow controller. These flow controllers can adjust the flow rates for 14 dilution levels. The odour-free air and odourous air are delivered to each panelist station where a three-way rotary switch, operated by the panelist, controls the operation of solenoid valves so that either odour-free or odourous air is presented to the panelist at a rate of 10 L/min. The velocity of air in the tubing connecting to the funnel is 42 m/s. Secondary dilution occurring from outside air entraining with the odourous air at nose level was less than 2%. This was calculated from CO_2 concentration measurements both of the sample and where the air enters the nose. This air flowrate can be easily adjusted to as high as 20 L/min if desired. The position of the three-way rotary switch that corresponds to odourous air is set randomly by the computer for each dilution level. As shown in Fig. 2, there are two air chambers in the olfactometer, one clean air and one odourous. For example, when the computer sets position 1 and 2 of the rotary switch as clean air and 3 as odourous, the air sample comes from the clean air chamber if the panelist's choice is 1 or 2 and the odourous chamber if the choice is position 3. Therefore, whatever sample the computer assigns to each of the three positions of the rotary switch, the clean air chamber always contains clean air while the odourous chamber always contains odourous air, and thus there is no need to purge chambers between the dilution levels. This generates the advantages of fast response, conserving the sample, and less contamination of the tubing.

Hedonic tone also can be measured with the olfactometer. A 11-point scale of –5 to +5 is used to rate the pleasantness of the odours: +5 the most pleasant odour, -5 the most unpleasant odour, and 0 a neutral odour (Choiniere and Barrington 1998). The 11-point scale is expressed by the eleven positions on a rotary switch. Presenting non-diluted manure odours to panelists often saturates their olfactory sense mechanisms. For this reason, hedonic tone is evaluated on diluted odour samples that are two dilution levels less than that of the first successful detection. Panellists use their personal experience and memories of odours as a reference scale to make judgment which they express by setting the hedonic rotary switch and pressing the hedonic button. The computer softerware scans the hedonic rotary switches and the hedonic tone buttons and records the result.

Odourous air samples are contained in 10 L-sample bags, up to three of which can be placed in the pressurized chamber (Fig. 2). The chamber pressure is maintained at 48.3 kPa to ensure sufficient sample flow from the flow controllers to the mixing chamber for all the dilution levels. For calibration purposes, both n-butanol and CO_2 are injected into the 10-L sample bags and placed in the pressurized chamber.

Computer software was written in QUICKBASIC to control the operation and scan the input signals from the I/O boards (P10-24 Keithley Metrabyte, Staunton, MA) installed in the computer. The software program reads the required dilution level from the keyboard and then communicates the odour sample flowrate to the mass flow controllers (Fig. 2). Each panelist operates the three-way rotary switch and samples the air for odour at each setting . The panelist then makes a choice by adjusting the rotary switch and pressing the guess or detect

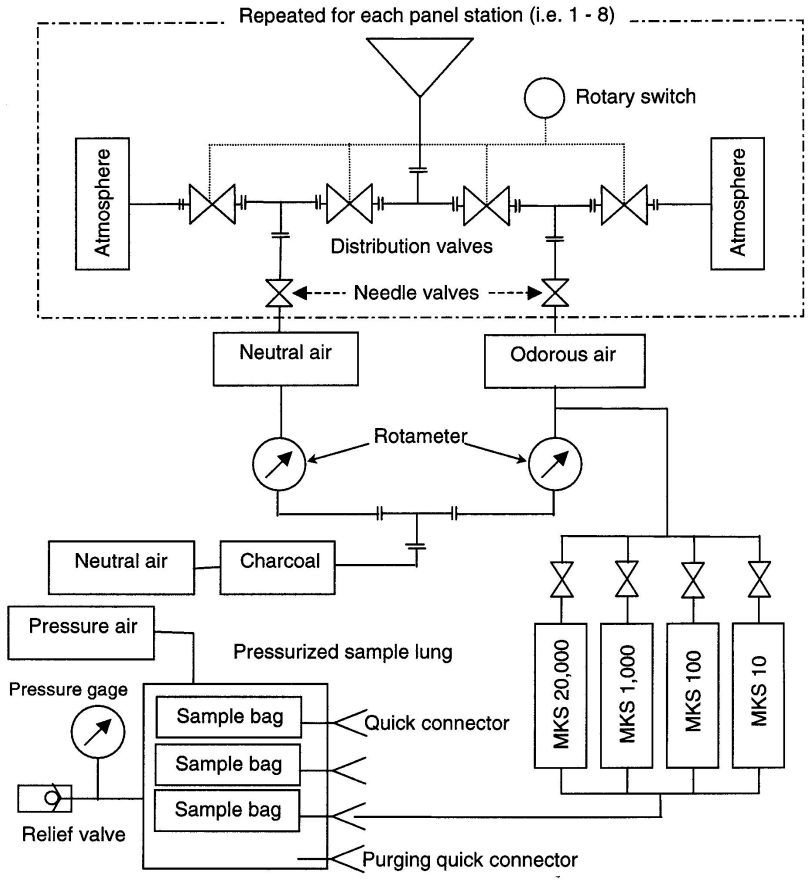

Fig. 2. Eight-port olfactometer.

button. The software stores the responses of all panelists. Once all of the panelists have responded, the next ascending dilution level is selected and the process is repeated. Once a panelist has detected odour correctly at two dilution levels, a green light flashes to indicate that the panelist has completed the odour detection session for that sample. The dilution level is again decreased by one level. At this level, the panelist evaluates the hedonic tone.

OLFACTOMETER OPERATION

A panel leader is responsible for the olfactometer operation. The panel leader selects the individual panelists and trains them to comply with the ASTM (1986) standards. Once the panelists are seated at each panelist station, the panel leader initiates the control software, selects the dilution ratio, observes each panelist's response on the computer screen, and informs the panelists when each sample session is complete.

Once the green indicator light is on, each panelist is given sufficient time to determine which of the three positions on the rotary switch is associated with the odour sample. At each dilution level, the panelist must depress the guess or the detect button (Fig. 1) at one of the three rotary switch positions. Once all the panelists have activated the buttons, the panel leader proceeds to the next dilution level and the green indicator is activated once more. Once the odour has been correctly detected two consecutive times by the panelist, a green light flashes in that panelist's station (Fig. 1). The computer software then adjusts the odour flow to the next level and the panelists are instructed to turn a rotary switch indicator between –5 and +5 to indicate the hedonic tone of the odour. Once the rotary switch is set, the panelist depresses the hedonic tone button and the panelist has completed the odour assessment of the sample. The operating procedure is shown in Fig. 3.

Because samples can be presented to eight panellists simultaneously, the olfactometer has been able to analyze nine samples per hour, which is about 4-5 times faster than a single-panelist olfactometer.

CALIBRATION

Two types of periodic calibration are necessary to ensure that the olfactometer-panelist system provides reliable results. The first involves checking the olfactometer to ensure that the odour samples are delivered uniformly to the eight panelists and that the actual odour sample flow rates to the panelists agree with the required flow rates for each dilution level. This is necessary because the solenoid valves at each panelist station may fail, or remain partially open, affecting the distribution of odour to each panelist station.

The second type of calibration involves checking that the results obtained with the system are comparable, not only from one session to the next, but also to results obtained with other olfactometry sytems.

The first (internal) calibration is carried out by using carbon dioxide gas (CO_2) in place of the odourous air and measuring CO_2 concentrations at each panelist station. This is done using a non-dispersive, infra-red gas analyzer (Model 846, Beckman, Fullerton, CA). Results of a typical calibration are presented in Table 1, which show that the CO_2 concentrations at each sniffing port are very similar and the flow rate predicted from the CO_2 concentration is similar to the actual flow (within 8%). The mass flow controllers do drift over time. Therefore, as a precaution, they are checked and calibrated once a week by an airflow meter (DryCal DC-Lite, Bios International, Pompton Plains, NJ) and every two months with CO_2. The total air flowrate at channels of both fresh and odourous air is investigated routinely at random dilution levels. The drift is recorded in a time logbook. The calibration results in Table 1 show that the olfactometer is operating as designed. The sniffing ports also were tested by measuring CO_2 concentrations to ensure that fresh air from the room was not drawn into the port to further dilute the sample to the panelist. Again, the CO_2 concentration at the nose was within 2% of the CO_2 concentration upstream from the port opening.

The second (system) calibration utilizes n-butanol as a reference odour. A concentration of 40 ppm n-butanol in air is used to test the sensitivity of the olfactometry system

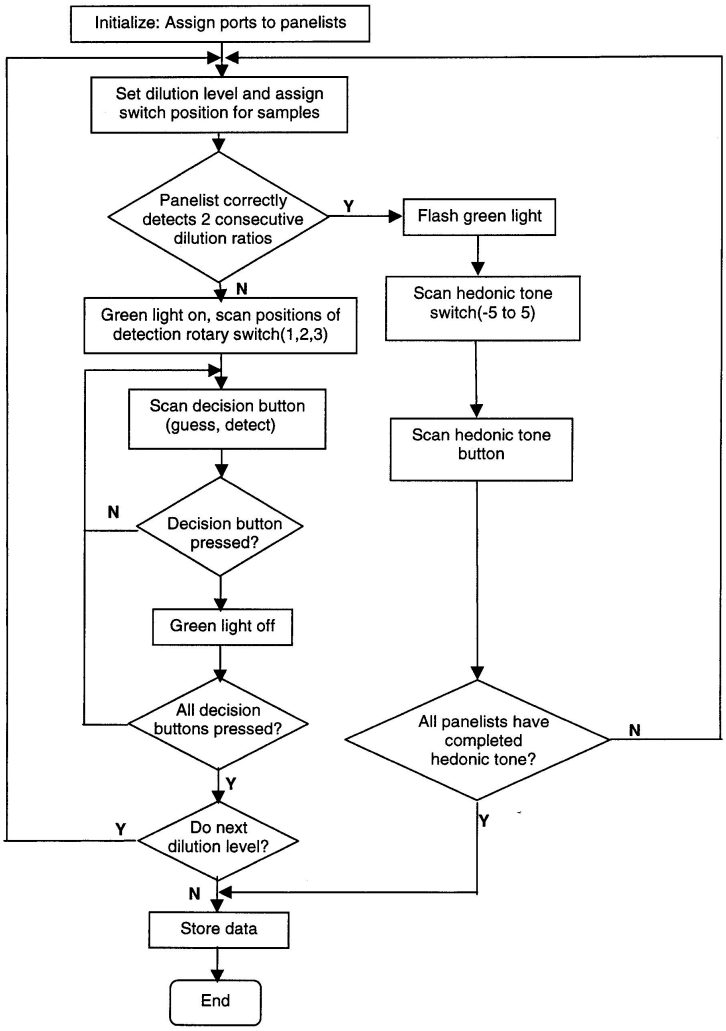

Fig. 3. Flow chart for olfactometer.

(olfactometer and odour panel). N-butanol is used as a scale basis to standardize the odour response from each panelist. Prior to an odour evaluation session, each panelist is presented with a diluted sample of 40-ppm concentration n-butanol. The geometric mean of the n-butanol's 50% detection threshold for 24 measurements during three months was 56.8 ± 2.9 ppb, which is within the range of the draft European standard (20-80 ppb) (CEN 1999) and published values (Den Hartigh 1985; Dravnieks et al. 1986; Hangartner et al. 1991; Jones et al. 1994; van Harreveld 1991) and agrees with the Dutch recommended expectation mean of 50 ppb (European Standard 1995).

The odour threshold response to both n-butanol and 'manure' odour will change for different panelists and also for the same panelist over different time periods. Currently, a study is underway to normalize the response by presenting n-butanol to panelists as a reference odour.

CONCLUSIONS

1. The eight- panelist olfactometer system can analyze nine samples per hour.
2. With this design, less tubing is contaminated by non-diluted odour than that of the three- air-chamber system.
3. Less odour-free air is required to operate this unit than those using three sniffing ports at each panelist station.
4. The carbon dioxide calibration procedure ensures that the flow rates are correct for each dilution ratio and that the odour concentrations are the same at each panelist station.
5. System calibration with n-butanol indicated that the sensitivity of the olfactometer system meets the European standard.

Table 1. Carbon dioxide concentrations (%) at each port and dilution level.

Dilution level		6	7	8	9	10	11	12	13	14
Port number	1	0.025*	0.051	0.101	0.205	0.377	0.695	1.424	3.326	6.530
	2	0.025	0.052	0.101	0.204	0.378	0.694	1.425	3.235	6.651
	3	0.024	0.052	0.101	0.204	0.378	0.694	1.424	3.326	6.591
	4	0.024	0.052	0.101	0.203	0.377	0.695	1.426	3.326	6.591
	5	0.025	0.052	0.101	0.204	0.378	0.695	1.425	3.295	6.621
	6	0.026	0.052	0.101	0.204	0.378	0.695	1.425	3.326	6.621
	7	0.026	0.052	0.102	0.204	0.378	0.695	1.424	3.265	6.561
	8	0.025	0.052	0.102	0.205	0.378	0.695	1.425	3.265	6.561
Measured	Concentration (%)	0.025	0.052	0.101	0.204	0.378	0.695	1.425	3.296	6.591
	Dilution ratio	3968	1920	987.4	490	264.7	144	70.19	30.3	15.2
	SD (10^{-4})	0.59	0.32	0.27	0.53	0.54	0.27	0.73	36.14	39.58
Predicted	Concentration (%)	0.025	0.05	0.1	0.2	0.4	0.8	1.587	3.124	6.25
	Dilution ratio	4000	2000	1000	500	250	125	63	32	16

* Each port reading is the average of three readings taken on three separate days
Dilution ratio = (clean air + sample)/sample
SD = standard deviation

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