TECHNICAL NOTE

Design and evaluation of an open biofilter for treatment of odour from swine barns during sub-zero ambient temperatures

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Mann, D.D., DeBruyn, J.C. and Zhang, Q. 2002. **Design and evaluation of an open biofilter for treatment of odour from swine barns during sub-zero ambient temperatures.** Canadian Biosystems Engineering/Le génie des biosystèmes au Canada **44**:6.21-6.26. Open biofilters have previously been shown to reduce odour from typical swine production facilities, but it was not known whether the exhaust air contained sufficient heat to prevent the biofilter beds from freezing during ambient temperatures below -20˚C without the use of insulation or supplemental heat. Four experimental biofilter units were retrofitted to a 2000-hog, 4-room feeder facility in southern Manitoba. Temperatures within the biofilter bed were constant at approximately 16˚C when ambient temperatures ranged between +9.2 and –34.2˚C during the period from September 1999 to February 2000. Due to inconsistent odour concentration reductions, which ranged from 56 to 94%, the effectiveness of different air plenum designs and biofilter media mixtures were not apparent. **Keywords**: open biofilter, biofiltration, livestock odour, odour concentration.

On a déjà démontré que les biofiltres ouverts réduisaient l'odeur provenant de bâtiments porcins typiques. Cependant, on ne savait pas si l'air évacué contenait suffisamment de chaleur pour empêcher les biofiltres de geler à des températures de -20°C, sans utiliser d'isolant ou d'air chaud supplémentaire. Quatre biofiltres expérimentaux furent installés dans un bâtiment porcin du sud du Manitoba d'une capacité de 2000 porcs et comportant 4 chambres d'engraissement. Entre septembre 1999 et février 2000, les températures à l'intérieur du biofiltre ont été constantes à environ 16°C, alors que les températures ambiantes ont varié de 9.2 à –34.2°C. Il n'a pas été possible d'observer l'efficacité des différents designs de chambre de répartition d'air et matériaux composant les biofiltres parce que les variations d'odeur, de 56 à 94%, étaient contradictoires. **Mots-clés**: biofiltres ouverts, biofiltration, odeur du bétail, concentration d'odeur.

INTRODUCTION

Biofiltration is an odour removal technology in which an odourous airstream is passed through a moist, porous filter medium prior to emission into the atmosphere. Odourous compounds are removed from the airstream by absorption and diffusion into a moist film on the surface of the filter media known as the biofilm. Odourous compounds either accumulate in the biofilm, or are digested by the resident microorganisms. The process of digestion, called bio-oxidation, occurs when microorganisms digest the gases, particulate matter, and volatile organic compounds in the presence of oxygen. Water, carbon dioxide, other non-odourous gases, biomass, and mineral salts are the end products of these reactions (Williams 1993). The result of the biofiltration process is a decrease in odour emissions.

Because biofiltration is a biological process, environmental conditions within the biofilter must be maintained at specified levels to enable survival of, and efficient bio-oxidation by, the microorganisms. Bacteria and fungi are the two dominant groups of microorganisms found in biofilters, but bacteria will likely dominate under favourable conditions (Devinny et al. 1999). Mesophilic bacteria are of most importance for agricultural biofilters because they prefer temperatures between 10 and 50°C. von Bernuth et al. (1999) found that moisture content must be kept between 40 and 70% to maintain stable microbial growth in a biofilter. When the moisture content is too high, anaerobic conditions, which reduce biofilter performance, can occur. In addition to requirements for water, oxygen, and a suitable temperature, microorganisms also require a source of nutrients. Odourous compounds are a good source of energy and carbon, but the microorganisms also require nutrients such as nitrogen, phosphorus, potassium, and sulfur. Compost is an ideal biofilter medium because it provides a well-developed community of microorganisms and is a source of the required nutrients (Devinny et al. 1999). For practical reasons, compost should be mixed with another substrate such as wood chips to increase the porosity of the biofilter medium. With increased porosity, less fan power will be required to move air through the biofilter due to the decreased resistance to airflow.

There are many examples of elaborate industrial biofilters. In their book, Devinny et al. (1999) provide details for 13 actual biofilters that represent typical field applications of biofiltration. The high costs associated with such elaborate systems may not be compatible with the agricultural industry and low-cost, open biofilters have been designed to treat the exhaust ventilation air from livestock barns (Nicolai and Janni 1997; von Bernuth et al. 1999; Classen et al. 2000; Martinec et al. 2001). However, there is a lack of data on performance of these biofilters at low temperatures. The objectives of this research, therefore, were to monitor the temperatures within, and the odour concentration

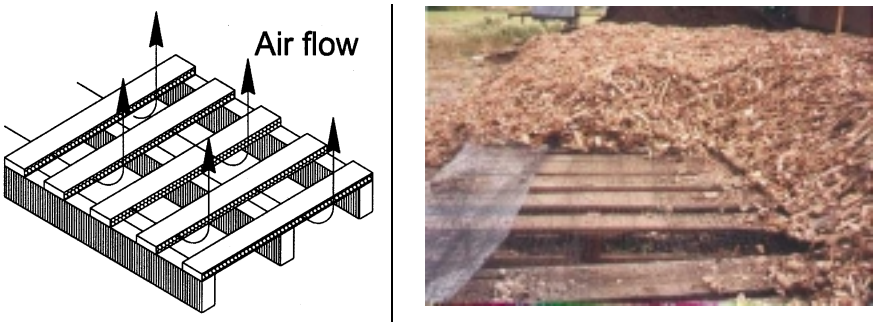

Fig. 1. Air plenum designed to permit upward air flow using a standard shipping pallet (left). Air plenum overlaid by vinyl mesh and covered with biofilter media (right).

reductions from, an open biofilter during a Manitoba winter. Odour concentration reduction was determined for two air plenum designs and two mixtures of biofilter media.

BIOFILTER DESIGN

Location of prototype biofilters

Four experimental biofilters were constructed at a swine finishing facility, which consisted of four 500-animal rooms, in southern Manitoba. Each biofilter captured and treated the exhaust air from an operating ventilation exhaust fan (either 1.9 or 2.6 m^3/s). Two biofilters (BF1 and BF2) were constructed on the south side of the barn and two biofilters (BF3 and BF4) were constructed on the north side of the barn.

Air plenum

An air plenum was constructed from standard shipping pallets to permit upward air flow through the biofilter bed (Fig. 1). Two different pallet arrangements were investigated. In the "standard" pallet arrangement (Fig. 2), all pallets were placed directly on the ground. In the "modified" pallet arrangement (Fig. 3), a larger inlet cross-sectional area was created by supporting the pallets on wooden legs of varying lengths. It was anticipated that the increased inlet area would decrease pressure losses associated with air travelling through long, narrow passages. Of the four prototype biofilters, BF1 and BF2 were built using the modified pallet arrangement and BF3 and BF4 were built using the standard pallet arrangement.

Vinyl mesh netting, which rested on the pallets, was used to prevent the biofilter media from falling into the air plenum. Because the biofilters had no airtight walls (i.e., the shipping pallets were not airtight along their edges), polyethylene sheets were used to seal the perimeter of each biofilter. This was done to prevent horizontal airflow along the perimeter.

Biofilter media

The biofilter media consisted of mixtures of wood chips and compost in ratios of 1:1 (BF1 and BF3) and 3:1 (BF2 and BF4) by mass. The wood chips originated as debris wood (i.e., pine, spruce, fir, cedar, aspen, birch, willow, and alder) on Cedar Lake in northern Manitoba. A mobile industrial chipper was used to create the wood chips used in this research. Wood chip size, determined by sieving prior to the start of this research, varied according to the following distribution (expressed as a percentage of total wet mass): < 64 mm (43%); 64-127 mm (29%); 127-191 mm (16%); 191-254 mm (6%); and > 254 mm (6%). The compost, which was made from waste produce from local supermarkets, was obtained from Rockwood Agribusiness, Stony Mountain, Manitoba. Prior to the start of this research, the compost had the following characteristics: total porosity = 42.6%; pH = 7; moisture content at saturation = 73%; and density at saturation = 1350 kg/m^3.

Following formulation of the appropriate mixtures using a total mixed ration (TMR) mixer, the biofilter media was dumped onto the pallet structure using a front-end loader. The

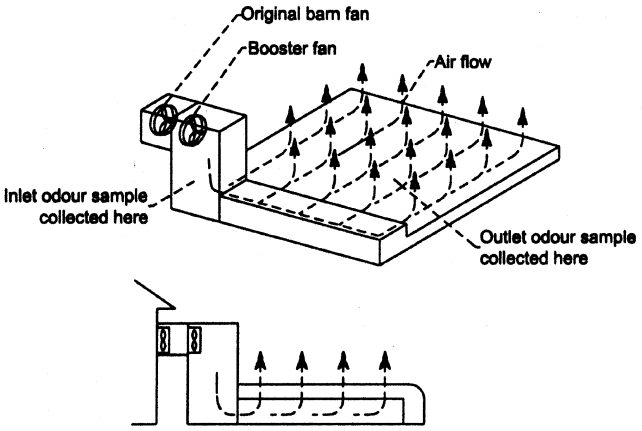

Fig. 2. Schematic of the "standard" pallet arrangement illustrating the predicted flow of air through the biofilter bed and the odour concentration sampling locations.

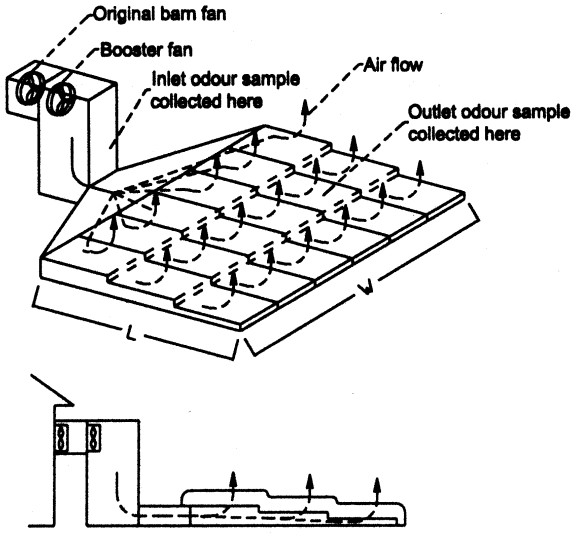

Fig. 3. Schematic of the "modified" pallet arrangement illustrating the predicted flow of air through the biofilter bed and the odour concentration sampling locations.

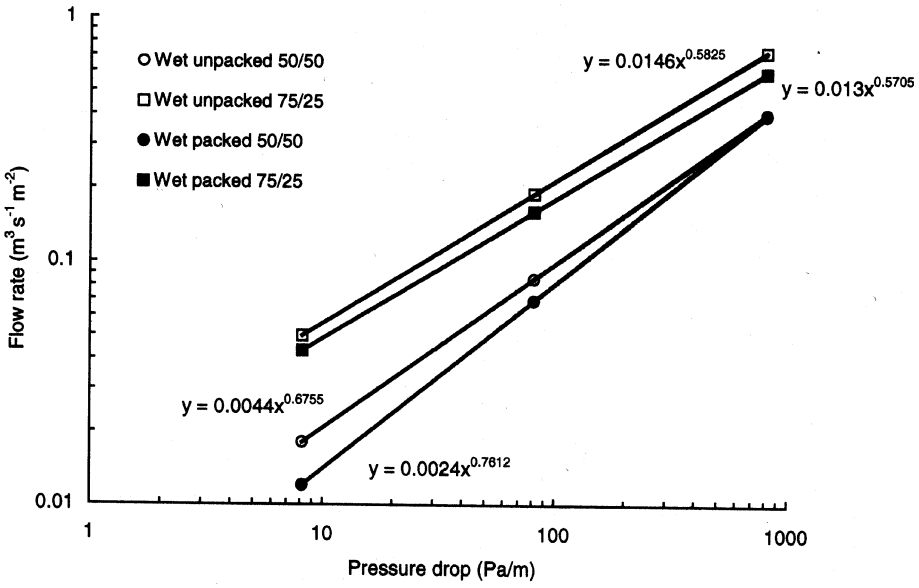

Fig. 4. Airflow resistance characteristics of biofilter media consisting of mixtures of wood chips and compost in 1:1 and 3:1 ratios.

top surface of the biofilter was left uncovered. Garden sprinklers were used to irrigate the top surface of the biofilter media on a daily basis. Although water was applied at a rate of approximately 0.4 L/s, the amount of water added to the biofilter media is not known because the sprinklers applied water beyond the edges of the biofilters. No attempt was made to collect leachate. Irrigation ceased in the first week of October when heavy frost cracked a plastic hose fitting.

Biofilter dimensions

Biofilter dimensions can be calculated based on the desired treatment, or residence, time. Devinny et al. (1999) estimate the "true residence time" as the volume of air space within the filter bed divided by the airflow rate:

$$\tau = \frac{V_f \theta}{Q} \qquad (1)$$

where:

τ = true residence time (s),
V_f = filter bed volume (m^3),
θ = porosity of biofilter media, and
Q = airflow rate (m^3/s).

It should be noted, however, that the "true residence time" also is likely to be affected by the tortuosity of the biofilter media. To simplify the design process, an "empty bed residence time" (EBRT) can be calculated as the filter bed volume divided by the airflow rate:

$$EBRT = \frac{V_f}{Q} \qquad (2)$$

where: EBRT = empty bed residence time (s).

For industrial and commercial applications, an EBRT greater than 25 s may be necessary for the treatment of odour (Leson and Winer 1991). For composting facilities, an EBRT ranging from 30 to 60 s is recommended (Haug 1993). For agricultural applications, however, it has been argued that an EBRT of 5 s is adequate for odour reduction (Zeisig 1987; Nicolai and Janni 1998, 1999). For this research, an EBRT of approximately 5 s was desired.

To ensure that the biofilter does not interfere with the operation of the barn's ventilation fans, the airflow rate through the biofilter should be equal to the airflow rate leaving the barn. Consequently, the biofilter dimensions can be determined by rearranging Eq. 2.

$$V_f = Lwd = EBRT\ Q \qquad (2)$$

where:

L = biofilter bed length (m),
w = biofilter bed width (m), and
d = biofilter bed depth (m).

The biofilter bed depth for a given airflow depends on the airflow resistance characteristics of the biofilter media. Airflow resistance characteristics for this media (Fig. 4) were determined at the University of Minnesota using an apparatus developed by Nicolai (1998). The biofilter bed depth was determined based on the airflow rate required to match the characteristics and the airflow rate of the existing ventilation fans. Length and width dimensions were selected based on the space limitations around the barn (Table 1). The subsequent EBRTs ranged from 5.2 to 6.7 s (Table 1).

BIOFILTER EVALUATION

Temperature monitoring

Due to difficulties with the data acquisition system, biofilter temperature was recorded for only two periods: i) November 26, to December 15, 1999 and ii) January 7 to January 26, 2000. Type-T copper-constantan thermocouples were placed along two lines on each south-facing biofilter at depths of 0.05, 0.175, and 0.35 m below the surface (Fig. 5). Ambient temperature was recorded 3 m south of the barn at a height 1 m above ground. When the data acquisition system was operating, temperatures were recorded every 30 s.

Table 1. Dimensions and EBRTs of the prototype biofilters.

Biofilter	Airflow rate (m^3/s)	Length (m)	Width (m)	Depth (m)	EBRT (s)
BF1	2.6	8.0	4.8	0.35	5.2
BF2	1.9	7.3	5.0	0.35	6.7
BF3	1.9	6.5	5.5	0.35	6.6
BF4	2.6	10.4	4.0	0.35	5.6

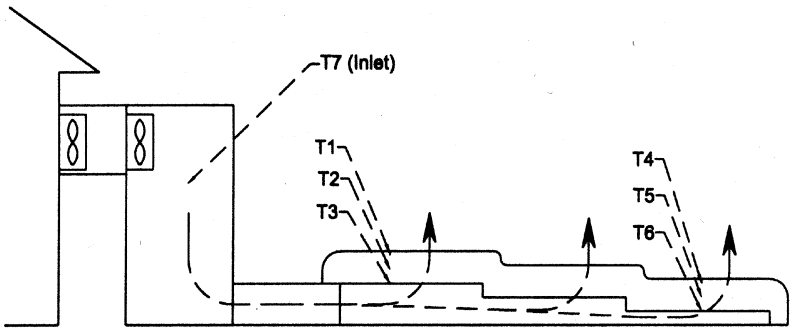

Fig. 5. Thermocouple placement in the south-facing biofilter beds.

Odour measurement

Odour concentration reduction was measured by comparing the odour concentration of the air entering and leaving the biofilter. Odour concentration is measured by the dilution to detection threshold (or odour units, OU) which is the ratio of the volume of odour-free air required to dilute an odourous air sample so that only 50% of a group of human panelists are able to detect the odour (European Committee for Standardization 1999). Odour concentration was measured using a dynamic dilution olfactometer (AC'SCENT® International Olfactometer, St. Croix Sensory, Stillwater, MN). Odour samples were collected in 10 L Tedlar bags at the duct entering the biofilter and inside a collection hood placed on the surface of the biofilter. Odour samples were presented to panelists within 24 h of collection.

Eighteen panelists were selected using a two level sequential screening procedure which means that they had to pass two levels of screening using forced-choice triangle tests. In triangle tests, each participant was presented with three flasks, one of which was different in odour intensity from the other two. Participants were asked to choose the odd sample. At the first level of screening, each participant was given 3 sets of 2 flasks of water (reverse osmosized) and 1 flask of 40 ppm butanol; and 3 sets of 2 flasks of water and 1 flask of 80 ppm butanol. The order of presentation of the sets and the position of the odd sample within each set were both randomized for each participant. The number of correct choices was plotted against the number of triangle tests (Meilgaard et al. 1991). Each participant was placed in one of three regions: *reject, continue testing,* or *accept.* For those who fell in the category of *continue testing,* the first level tests were repeated on subsequent days until they moved into either the *accept* or *reject* region. Those participants who moved into the *accept* region moved to the second level of screening where each participant was presented with 3 sets of 2 flasks of 10 ppm butanol and 1 flask of 40 ppm butanol; and 3 sets of 2 flasks of 20 ppm butanol and 1 flask of 80 ppm butanol. Participants who were eventually moved to the *accept* region were selected as panelists. Six panelists were used for each session.

The biofilters were operational for one month prior to collecting the first odour samples in September 1999 to ensure that a microbial community was established. Samples were collected once per month. Although it had been planned to collect data for a full year, the biofilters were shut down in February 2000 at the request of the co-operating producer. The producer blamed a malfunction of the controller for one of the ventilation fans on the presence of the biofilter. Although an electrician concluded that the malfunction was not due to the presence of the biofilter, the producer felt uneasy with our continued presence on his farm.

RESULTS and DISCUSSION

Biofilter temperature

For any given sampling time, it was concluded that temperature was constant for all three levels within both south-facing biofilters based on standard deviations that ranged from 0.5 to 3.2˚C with an average standard deviation of 1.7˚C. Consequently, an average biofilter temperature was calculated for each sampling time by pooling the data for both south-facing biofilters. The average temperature within the biofilter over the entire period was 16.3˚C with a standard deviation of 1.8˚C.

For each 24-h period, the maximum and minimum average biofilter temperatures were plotted (Figs. 6 and 7). Daily fluctuations within the biofilter were < 2˚C. During the same recording period, minimum and maximum ambient temperatures were plotted for each 24-h period (Figs. 6 and 7). In many cases, daily ambient fluctuations exceeded 10˚C. The average ambient temperature was -7.7˚C. The maximum and minimum ambient temperatures were 9.2 and -34.2˚C, respectively.

According to the co-operating producer, the temperature in the barn was maintained at approximately 20˚C throughout this

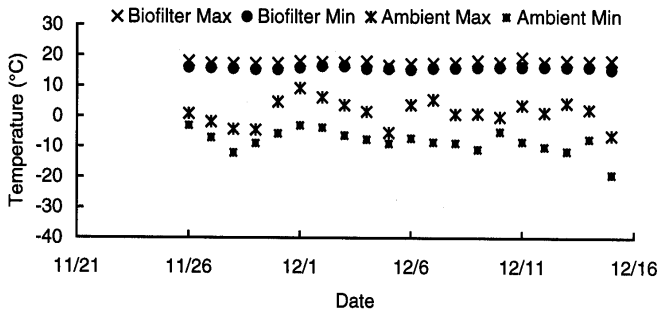

Fig. 6. Daily maximum and minimum ambient and biofilter bed temperatures observed during the period November 26 to December 15, 1999.

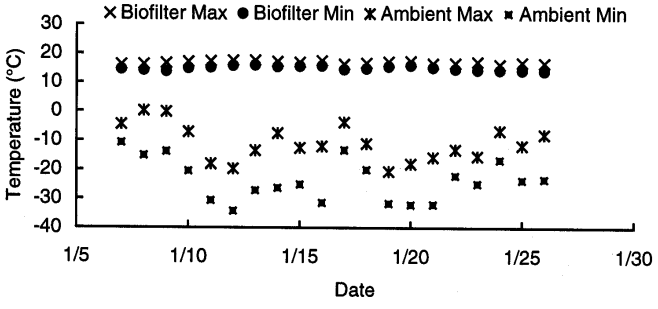

Fig. 7. Daily maximum and minimum ambient and biofilter bed temperatures observed during the period January 7 to January 26, 2000.

Table 2. Inlet and outlet concentrations for each of the four biofilters measured at monthly intervals from September 1999 to February 2000.

Date	Biofilter	Inlet		Outlet		Odour concentration reduction (%)
		Odour concentration (OU)	S.D. (OU)	Odour concentration (OU)	S.D. (OU)	
September	1	753	2.0	110	1.7	85
	2	588	1.7	45	2.4	92
	3	464	1.5	153	2.2	67
	4	1061	2.4	88	2.6	92
October	1	1640	2.2	551	2.3	66
	2	1661	2.5	388	2.2	77
	3	884	2.2	343	1.5	61
	4	1271	1.8	434	2.3	66
November	1	2169	2.1	343	2.4	84
	2	1376	2.7	384	2.0	72
	3	1724	2.3	766	1.7	56
	4	2185	1.8	785	1.8	64
December	1	3036	1.8	250	1.8	92
	2	812	1.5	323	2.2	60
	3	1216	1.6	420	1.8	65
	4	1361	2.1	369	1.7	73
January	1	1937	1.7	293	1.4	85
	2	1222	2.1	297	2.3	76
	3	972	2.1	331	1.7	66
	4	1738	1.7	374	1.9	79
February	1	1544	1.8	93	1.5	94
	2	1092	2.1	233	1.5	79
	3	1934	1.7	184	1.6	90
	4	1092	2.1	164	1.7	85

period. The heat provided by the warm exhaust air maintained the biofilter temperature in a range suitable for microbial survival. During periods of extreme cold and high winds, some drifting of snow onto the surface of the biofilters was observed, however, airflow channels always remained open through the snow drifts. Once the drifting stopped, the snow melted off the surface of the biofilters.

Odour reduction

Inlet and outlet odour concentrations for all four biofilters are given in Table 2. Inlet odour concentrations ranged from 464 to 3036 OU with an average of 1406 OU. Outlet odour concentrations ranged from 45 to 785 OU with an average of 322 OU. Consequently, odour concentration reduction ranged from 56 to 94% with an average of 76%.

The observed outlet odour concentrations were higher than expected. DeBruyn et al. (2001) demonstrated that small biofilter cells containing mixtures of either yard-waste or grocery-waste compost combined with either wood chips or hemp hurds reduced the outlet odour concentration below 50 OU with a residence time of 70 s. In the same research, DeBruyn et al. (2001) forced “clean farmyard” air (mean of 34 OU) through small biofilter cells. Outlet odour concentrations ranged from 26 to 51 OU. From their results, it can be concluded that an open biofilter functioning at optimum efficiency should reduce the odour from a hog barn to levels that cannot be distinguished from ambient farmyard odour using olfactometry. It is apparent, therefore, that the biofilters used in this research were not operating at optimum efficiency. Due to several obvious problems (see below), there was much variation in the results. Consequently, neither the pallet arrangements nor the biofilter media mixtures were compared statistically. It should be noted, however, that there was no apparent reduction in biofilter effectiveness during the winter months (Table 2).

Problems observed

Short-circuiting of the airstream through rodent burrows was a problem until poison was used to eliminate the rodents. When short-circuiting occurs, a disproportionate volume of air travels through a small channel resulting in inadequate contact between the airstream and the biofilter. After the rodent burrows were eliminated, short-circuiting of the airstream was eliminated.

Weed growth was not a significant problem because the biofilters were operational for only two months before sub-zero

ambient temperatures occurred. It was observed, however, that weed growth caused clumping of filter media in the roots. It is likely that root growth clogged pore spaces decreasing airflow, but this was not measured.

When the biofilters were taken apart, the biofilters constructed using the standard pallet arrangement were seen to have a substantial accumulation of dust in the biofilter media adjacent to the air inlet box. This layer of dust likely impeded airflow, although no airflow measurements were taken prior to disassembly. Based solely on visual observation, the modified pallet arrangement resulted in less dust accumulation possibly due to the larger contact area between the incoming air and the biofilter media surface.

The results from this research are both positive and negative. Based on the observed temperatures within the biofilter beds, it should be possible to use uninsulated open biofilters without supplemental heat to treat the exhaust air from a swine barn during a Manitoba winter. It is not known, however, whether the inconsistent odour concentration reductions were due to inadequate residence time (EBRT), problems with the management of the biofilters, or biofilter bed temperature.

CONCLUSIONS

Biofiltration may be an effective means of reducing the odour emissions from mechanically-ventilated swine barns during sub-zero ambient conditions. At ambient temperatures below -20˚C, biofilter bed temperatures were maintained at approximately 16˚C without the need for insulation or supplemental heat. This temperature is adequate to ensure survival of the microbial population. The effectiveness of the biofilters, however, was inconsistent. Odour concentration reduction ranged from 56 to 94%. Some outlet odour concentrations were as high as 785 OU. It is not known whether the inconsistent results are due to inadequate residence time, problems with management of the biofilters, or biofilter bed temperature.

ACKNOWLEDGEMENTS

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