Evaluation of airflow through a horizontal-airflow biofilter with a non-pressurized headspace

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The control of odour from livestock barns continues to be an issue of importance for the livestock industry. A horizontal-airflow biofilter without a pressurized headspace was designed to eliminate problems that had been observed with a previous pressurized-headspace design. Seven distinct biofilter units were constructed adjacent to a commercial hog barn in southern Manitoba. Air velocity was measured across the top and side surfaces of each biofilter. Exit velocity was uniform across the sides, but more air exited through the top surface of the biofilter than was anticipated based on the design of the biofilter. Zeolite added to the biofilter medium (woodchip and compost mixture) enhanced the effectiveness of hydrogen sulfide reduction by up to 30% without negatively affecting airflow characteristics. **Keywords**: biofilter, biofiltration, airflow uniformity, horizontal airflow, hydrogen sulfide reduction.

Le contrôle des odeurs provenant des bâtiments d'élevage demeure un défi important en production animale. Un biofiltre non pressurisé à écoulement horizontal a été conçu pour éliminer les problèmes observés précédemment avec des biofiltres pressurisés. Sept biofiltres de ce nouveau type ont été construits et installés près d'une porcherie commerciale située dans le sud du Manitoba. Les vitesses d'écoulement de l'air au travers du sommet et des parois latérales de chacun des biofiltres ont été mesurées. Il a été observé que la vitesse d'évacuation de l'air était uniforme au travers des parois latérales des biofiltres. De plus, une plus grande quantité d'air que ce qui avait été estimé lors de la conception de ce nouveau type de biofiltre était évacuée par le sommet de ceux-ci. L'addition de zéolite au substrat du biofiltre (mélange de copeaux de bois et de compost) a résulté en une augmentation de 30% de son efficacité à réduire les émissions de sulfure d'hydrogène sans qu'il n'y ait d'effets négatifs sur les caractéristiques d'écoulement d'air des biofiltres. **Mots clés**: biofiltre, biofiltration, uniformité de l'écoulement d'air, écoulement d'air horizontal, réduction de sulfure d'hydrogène.

INTRODUCTION

Control of odour from hog barns continues to be a challenge to the hog industry. Biofiltration is a technology that can effectively eliminate the odour from the air being exhausted from a hog barn. The challenge is to design a biofilter that best integrates with the barn system.

An experimental study completed by Sadaka et al. (2002) demonstrated that the resistance to airflow through woodchips is less in the horizontal direction than in the vertical direction. Garlinski and Mann (2005) reviewed the literature, but found only limited mention of horizontal-airflow biofilters. In both cases, the research was conducted using lab-scale biofilter units (Lee et al. 2001; Choi et al. 2003). Garlinski and Mann (2005) described a field-scale horizontal-airflow biofilter that relied on a pressurized headspace created by an inflatable bladder to prevent short-circuiting of the air through the biofilter without treatment. The concept of a pressurized headspace was shown to work; however, the design is subject to failure if the integrity of the inflatable bladder is jeopardized. Garlinski and Mann (2005) concluded their paper by recommending that other horizontal-airflow designs be considered. The objective of this paper is to describe and evaluate a horizontal-airflow biofilter that functions without the need of a pressurized headspace. Garlinski and Mann (2005) used exit velocity uniformity to evaluate the pressurized-headspace design. In this paper, exit velocity uniformity will be used to evaluate the proposed biofilter design.

A secondary objective is to determine the effect of zeolite as an additive to biofilter medium. Milic et al. (2005) described zeolites as "naturally occurring three-dimensional, microporous, hydrated aluminosilicate minerals characterized by high internal surface area and high cation exchange capacities." In their research, Milic et al. (2005) found that 2% zeolite added to pig feed resulted in a decrease in ammonia emission of 33%. In more recent work, Cai et al. (2007) evaluated the use of zeolite (up to 10% by weight) as an additive to poultry manure. Odour was reduced by approximately 50% when the zeolite was applied topically. In this study, hydrogen sulfide reduction will be used to determine whether zeolite might be an effective biofilter additive.

THEORY OF A HORIZONTAL-AIRFLOW BIOFILTER WITH A NON-PRESSURIZED HEADSPACE

Biofilters were constructed using the non-pressurized headspace design as shown in Fig. 1. Solid barriers (i.e., plywood), mounted along the top edge of the biofilter chamber, were used to direct the movement of air through the biofilter bed. Theoretically, air will travel straight through the biofilter bed (solid arrow in Fig. 1) if the resistance in the horizontal direction is less than the resistance in the vertical direction. If the resistance in the vertical direction is less than the resistance in the horizontal direction, airflow is likely to follow the hollow arrows (Fig. 1). Thus, the top layer of the medium is not used to treat the air stream; its function is to create a barrier to prevent

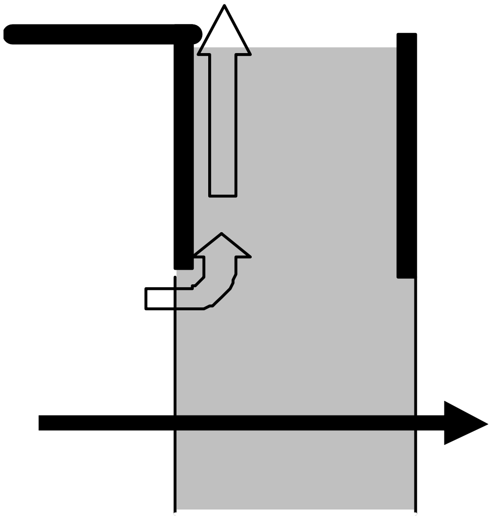

Fig. 1. Schematic of the horizontal-airflow biofilter with a non-pressurized headspace illustrating the desired movement of air through the biofilter medium (black arrow) and the movement of air that will occur as the medium settles (hollow arrow).

vertical movement of the air. To limit the amount of unused medium, the horizontal path should be short (i.e., the biofilter bed should be narrow). By comparison, the design described by Garlinski and Mann (2005) used an inflatable bladder to prevent vertical movement of the air.

Garlinski and Mann (2005) reported significant settling of biofilter medium with time. In the non-pressurized headspace design, settling of the medium will reduce the depth of the "barrier" medium and will cause air to leave through the top of the biofilter (hollow arrows in Fig. 1). When this occurs, the top layer of the biofilter bed may be considered to be a vertical-airflow biofilter (as described by Mann et al. 2002). Complete failure of the biofilter will not occur unless settling is so severe that air is allowed to by-pass the solid barrier without passing through any medium.

EXPERIMENTAL METHODS

Experimental biofilters

Each biofilter unit consisted of two biofilter chambers linked by a central plenum (Fig. 2). Each chamber was 0.5 m wide, 3.7 m long, and 3.0 m high. Based on these dimensions, each chamber contained approximately 5.5 m ^{3} of biofilter medium. Air was forced through the 0.5 m bed of biofilter medium. With an estimated true residence time of 3 s, it was anticipated that 70% reduction of odour (or hydrogen sulfide concentration) might be achieved (Nicolai and Janni 1998, 1999). There was no roof covering the biofilter (Fig. 3).

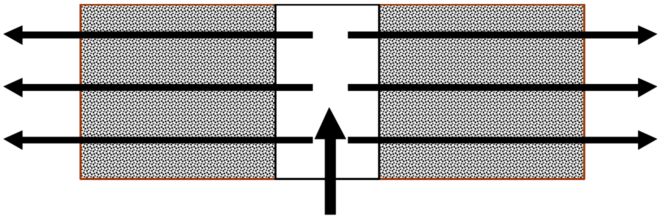

Fig. 2. Top view of a horizontal-airflow biofilter consisting of a central, internal plenum bounded on both sides by chambers filled with porous medium. Arrows indicate the movement of air through the biofilter. In the text, the chamber on the left is referred to as Side A and on the right is Side B.

Fig. 3. Top view of a biofilter unit showing the two chambers filled with medium on alternate sides of a central plenum. There was no roof covering the unit.

Seven distinct biofilter units were constructed, one for each of the ventilation fans present on the adjacent hog barn. The biofilter units were constructed approximately 5 m away from the hog barn. Biofilter fans, aligned with the barn's ventilation fans, were used to draw odorous air from the region between the barn and the biofilter unit into the central plenum and through the biofilter chambers (Fig. 2).

Side A (the north side) of each biofilter was filled with woodchips and compost in a ratio of 80:20 by mass. Added to Side B (the south side) were varying quantities of zeolite (Table 1). The proportion of zeolite added (mass basis) ranged from 0 to 0.32. The zeolite was in the form of crushed rock (similar to crushed limestone that might be added to a residential driveway); it was not in powdered form.

Table 1. Proportion of zeolite added to the woodchip: compost mixture.

Biofilter	Zeolite added (proportion of mass of biofilter medium)	
	Side A	Side B
1	0	0
2	0	0.32
3	0	0.11
4	0	0.15
5	0	0.19
6	0	0.23
7	0	0

Fig. 4. Side view of one of the seven biofilters; yellow circles highlight some of the sampling locations.

Measurement of exit velocity uniformity

Airflow sampling was conducted with a custom-built amplifying cone. A hotwire anemometer was used to monitor velocity of the air exiting the centre of the amplifying cone. Sampling occurred at 18 locations on each side of the biofilter (Fig. 4) and at nine locations on the top. Side sample locations were approximately one-third and two-thirds from the top, with nine evenly spaced samples at each level. Data were collected on six dates during June and July of 2005.

Garlinski and Mann (2005) reported the tendency for higher exit velocity against the back wall of the biofilter (i.e., at the point furthest from the inlet to the central plenum). It was speculated that air reached the back wall and was diverted along the wall through the biofilter medium. Because of this previous observation, it was important to compare the exit velocity across the entire exit face with specific attention to the region nearest the back wall. To facilitate this comparison, the exit face was divided into thirds; the front third (nearest the inlet to the plenum) was compared with the rear third (nearest the back wall). Statistical analysis was completed using the T-test (two-tailed test, two sample equal variance).

A further concern with this design is that air may travel vertically out the top of the biofilter rather than traveling horizontally through the biofilter. Statistical analysis (two-tailed T-test, two sample equal variance) was used to compare the mean exit velocity from the side of the biofilter with the mean exit velocity from the top of the biofilter.

Measurement of hydrogen sulfide reduction due to zeolite

Hydrogen sulfide levels were measured using a Jerome 631-X Hydrogen Sulfide Analyzer (Arizona Instrument, Tempe, AZ). Hydrogen sulfide data were collected from Biofilter 4 (containing 15% zeolite on Side B) on six dates between August and October of 2005. Sampling occurred at 18 locations on each side of the biofilter (Fig. 4) and at 9 locations on the top.

RESULTS and DISCUSSION

Exit velocity uniformity

Data from the front third of each biofilter were compared to data from the rear third for each of the six sampling dates. Comparisons were made for both Side A and Side B. Of the 84 comparisons that were made, there were no significant differences between the mean exit velocity from the front third and the mean exit velocity from the rear third in 73 cases (87% of cases) (Table 2). With this evidence, it has been concluded

Table 2. Comparison of mean exit velocity from the front third of the biofilter (nearest the inlet to the plenum) with the mean velocity from the rear third of the biofilter (nearest the back wall).

Date	Biofilter	Exit velocity (m/s)			
		Side A		Side B	
		Front	Back	Front	Back
June 15	1	0.91	0.30*	0.43	0.73
	2	1.32	1.24	1.04	0.76
	3	0.54	1.77*	1.08	1.00
	4	0.93	0.29*	0.30	0.70
	5	0.76	0.94	0.97	0.65
	6	0.69	2.03*	1.18	1.41
	7	1.00	0.86	0.54	0.58
June 23	1	0.07	0.35	0.20	0.26
	2	0.12	0.20	0.20	0.11
	3	0.11	0.13	0.34	0.14
	4	0.19	0.09	0.07	0.10
	5	0.26	0.36	0.05	0.16
	6	0.17	0.16	0.19	0.31
	7	0.00	0.09*	0.02	0.03
July 4	1	1.33	0.92	0.73	0.78
	2	1.05	0.75	0.43	0.73*
	3	1.07	1.30	0.92	0.67
	4	0.27	0.07	0.10	0.58*
	5	0.61	1.13	1.19	0.70*
	6	1.64	1.25	1.59	1.38
	7	0.65	0.66	0.89	0.63
July 6	1	0.29	0.86	0.36	0.40
	2	0.71	0.15*	0.50	0.31
	3	1.57	1.10	0.51	1.64
	4	0.52	0.29	0.43	0.43
	5	0.52	0.46	0.48	0.23
	6	1.90	1.01	1.05	1.84
	7	0.39	0.50	0.28	0.50
July 14	1	0.30	0.38	0.41	0.42
	2	0.47	0.80	0.53	0.34
	3	1.42	0.32*	0.82	0.60
	4	0.46	0.30	0.29	0.34
	5	0.29	0.58	0.41	0.30
	6	0.59	0.89	0.54	0.79
	7	0.44	0.20	0.63	0.12*
July 24	1	0.38	0.76	0.13	0.39
	2	0.08	0.02	0.22	0.20
	3	0.31	0.30	0.06	0.05
	4	0.21	0.32	0.33	0.26
	5	0.22	0.32	0.23	0.19
	6	0.54	0.39	0.64	0.62
	7	0.12	0.25	0.11	0.31

* Means between the front and back are significantly different.

Table 3. Comparison of mean exit velocity from the side of the biofilter with the mean exit velocity from the top of the biofilter.

Date	Biofilter	Exit velocity (m/s)			
		Side A		Side B	
		Side	Top	Side	Top
June 15	1	0.59	0.11*	0.72	0.10*
	2	1.35	0.13*	1.03	0.43*
	3	1.19	0.04*	0.94	0.12*
	4	0.63	0.07*	0.56	0.08*
	5	0.85	0.07*	0.74	0.04*
	6	1.34	0.24*	1.16	0.14*
	7	0.90	N/A	0.48	N/A
June 23	1	0.22	0.29	0.17	0.58*
	2	0.19	0.17	0.19	0.43*
	3	0.14	0.29*	0.20	0.29
	4	0.16	0.07	0.07	0.14
	5	0.24	0.08	0.11	0.05
	6	0.13	0.18	0.18	0.44
	7	0.06	0.19*	0.02	0.18*
July 4	1	1.16	0.37*	0.90	0.49
	2	0.82	0.61	0.67	0.82
	3	0.95	0.56	0.78	0.11*
	4	0.21	0.28	0.39	0.27
	5	0.79	0.13*	0.81	0.23*
	6	1.29	0.45*	1.27	0.39*
	7	0.71	0.13*	0.69	0.16*
July 6	1	0.55	0.53	0.46	0.54
	2	0.52	0.65	0.56	1.11*
	3	1.29	0.46*	1.20	0.44*
	4	0.39	0.06*	0.55	0.13*
	5	0.50	0.07*	0.57	0.18*
	6	1.36	0.53*	1.53	0.47*
	7	0.44	0.16*	0.42	0.13*
July 14	1	0.29	0.31	0.36	0.27
	2	0.54	0.21	0.51	0.31
	3	0.69	0.10*	0.61	0.23*
	4	0.43	0.06	0.44	0.05*
	5	0.41	0.18	0.39	0.17
	6	0.75	0.21*	0.74	0.12*
	7	0.29	0.09	0.32	0.13
July 24	1	0.42	0.27	0.22	0.26
	2	0.04	0.02	0.14	0.09
	3	0.41	0.24	0.31	0.13
	4	0.20	0.12	0.35	0.06*
	5	0.26	0.34	0.16	0.18
	6	0.48	0.26	0.52	0.18
	7	0.16	0.19	0.22	0.13

* Means between the side and top are significantly different.

that there is no significant difference between the exit velocity from the front third and rear third of the biofilter. In other words, the exit velocity is uniform. In further analysis, exit velocity from the side can be represented by the mean of the 18 samples taken from each side.

Mean exit velocity from each side was compared with mean exit velocity from the top for each biofilter for each of the six sampling dates. Comparisons were made for both Side A and Side B. On the first sampling date, significantly lower exit velocity was observed from the top for all six of the biofilters for which data are available (Table 3). The same trend was not evident on all of the other sampling dates. On some occasions, there were no significant differences. On some occasions, the exit velocity from the top was actually higher than the exit velocity from the side of the biofilter. Of the 82 comparisons that were made, there was significantly greater exit velocity from the top in 6 cases (7% of cases), there was significantly greater exit velocity from the side in 36 cases (44% of cases) and there were no significant differences in exit velocity in the remaining 40 cases (49% of cases). Both inadequate moisture in the biofilter medium in the top region and excessive settling of the biofilter medium could have contributed to the observed airflow from the top of the biofilter. Based on observed airflow patterns, the non-pressurized headspace design did not behave as predicted. The "barrier" layer of woodchips did not prevent vertical air movement.

One final concern related to exit velocity relates to the presence of zeolite in Side B of biofilters 2 through 6. Based on statistical analysis (two-tailed T-test, two sample equal variance), there were no significant differences in exit velocity between Sides A and B for any of the seven biofilters on any of the sampling dates (with the exception of Biofilter 4 on June 23 where Side A had significantly higher exit velocity than Side B). The experimental evidence suggests that the zeolite has no influence on airflow through the biofilter.

Hydrogen sulfide reduction due to zeolite

With the exception of the first sample date, the side of the biofilter containing the zeolite was observed to have greater reduction in hydrogen sulfide concentration (Table 4). Compared to the control (Side A), the zeolite caused further reduction in hydrogen sulfide concentration of 8 to 30%. Thus, zeolite could be added to a biofilter medium to improve the effectiveness of treating hydrogen sulfide.

CONCLUSIONS

In terms of airflow uniformity, there is insufficient evidence to suggest that the exit velocity varies from front to rear. With significant movement of air through the top "barrier" portion of the medium, it can be said that the non-pressurized headspace design did not behave as predicted. Finally, there is an indication that zeolite added to the biofilter medium improves the effectiveness of hydrogen sulfide removal from the air stream.

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Table 4. Effect of zeolite (15% of total biofilter medium mass) on hydrogen sulfide reduction from Biofilter 4.

Date	Plenum	Side A (control) (woodchips and compost only)		Side B (treatment) (15% zeolite added)	
	H_2S concentration (ppm)	H_2S concentration (ppm)	Reduction (%)	H_2S concentration (ppm)	Reduction (%)
August 19	0.096	0.046	51.9	0.074	22.8
September 11	0.338	0.132	60.9	0.083	75.4
September 13	0.426	0.267	37.4	0.174	59.1
September 24	0.426	0.307	28.0	0.216	49.3
September 30	0.757	0.514	32.1	0.453	40.2
October 2	0.233	0.198	14.9	0.127	45.2

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