Final Report

Biofilter Demonstration

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Objective:
Demonstrate the effectiveness of biofilters to reduce odor, hydrogen sulfide, and ammonia emissions from livestock facilities and manure storages using low cost biofilters with different designs, media, operating conditions, and management.

Summary:
The performance of twelve biofilters with different residence times (approximately 4, 7 and 13 s) was measured on a dairy, swine, and poultry facility. Odor and hydrogen sulfide reduction improved from 56% to 94% as residence times increased from 4 to 7 s for the dairy and swine. Percent reduction remained above 89% as residence time increased from 7 to 13 s on the dairy and swine. A 5-s residence time is recommended for designing biofilters on swine and dairy facilities to achieve more than 80% reduction in emissions. The biofilter on the poultry facility was installed without a dust filter and dust on the fans prevented accurate airflow measurement. Reductions were less than 40% on the poultry biofilters.

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BIOFILTER DEMONSTRATION PROJECT[1]

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INTRODUCTION

Biofiltration is an effective technology to reduce odor, hydrogen sulfide, and ammonia emissions from livestock facilities (Nicolai and Janni, 1997, and1998a; Noren, 1985). Scholtens and Demmers (1990) reported that even though biofilters have been known to reduce odor, hydrogen sulfide, and ammonia, they are hardly used in intensive livestock farming in The Netherlands. One reason is the cost of treating large quantities of exhaust air. Nicolai et al. (1998) demonstrated that biofilters can be cost effective if low cost construction and an efficient design is used. For a biofilter to be both effective in removing odor and low cost, the biofilter size must be optimized. Two important parameters needed to optimize biofilter design are the airflow rate and the residence time of the air being treated. The maximum livestock building ventilation rate establishes the biofilter airflow rate. The residence time is defined as the time the air is in contact with the biofilter media. It is a function of the media depth, cross sectional area and airflow rate. An indicator of the residence time is called "empty bed contact time" (EBCT). EBCT is determined by dividing the volume of the biofilter media bed by the airflow rate.

The correct residence time must be known for an efficient biofiltration design. With insufficient residence time, odors and gases will not be reduced. With excessive residence time, the odors and gases will be controlled but the cost may be prohibitive. Residence times reported in the literature for livestock facilities vary from a few seconds to almost one minute. Zeisig (1987) indicated sufficient odor reduction with a residence time of 5 s for pigs and 3 s for chickens. Nicolai and Janni (1998b) reported 4 s was sufficient for a swine nursery barn. Pearson (1990) used 20 s when estimating biofilter costs for swine and poultry barns. Wright (1989) used residence times between 10 and 60 s. Hartung et al. (1997) investigated a six year old biofilter for odor reduction efficiency and determined 6 s residence time was achieving 78% to 80% odor reduction.

The object of this study was to determine the optimum residence time for dairy, swine and poultry facilities to achieve 80% reduction of odor, hydrogen sulfide, and ammonia emissions and construction cost.

MATERIALS AND METHODS

Since most of the reported residence times reported in the literature are less than 15 s, three residence times of approximately 4 s, 7 s, and 13 s were compared. Biofilter residence times can be changed by varying either the media depth or surface area. Both methods were used in this experiment. Table 1 shows the initial design data. Each cell was replicated twice. For ease of construction the residence times did not match for each of the three groups (i.e. 4 s, 7 s, and 13 s).

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Twelve open bed biofilters (Figure 1) were built at each of the three sites to treat exhaust air from swine, dairy, and poultry (laying hens) facilities. The swine barn was a mechanically ventilated deep-pit finishing barn. The air treated by the biofilters came from a pit fan. The dairy barn was a naturally ventilated deep-pit freestall barn for dry cows. A pit fan was added to a pump out (Figure 1) to supply air to the biofilters. The poultry facility was a two-story mechanically ventilated caged-layer barn. The air treated by the biofilters came from a fan exhausting air from the lower level manure storage.

Table 1. Design data for each of the biofilter cells.

	Cells varying media area			Cells varying media depth		
Cell area	0.7 m^2	1.67 m^2	2.79 m^2	1.40 m^2	1.40 m^2	1.40 m^2
Media depth	0.30 m	0.30 m	0.30 m	0.15 m	0.30 m	0.46 m
Airflow	0.050 m^3/s	0.059 m^3/s	0.062 m^3/s	0.062 m^3/s	0.058 m^3/s	0.053 m^3/s
Media volume	0.21 m^3	0.50 m^3	0.84 m^3	0.21 m^3	0.42 m^3	0.64 m^3
Residence time	4.2 s	8.5 s	13.5 s	3.4 s	7.2 s	12.1s

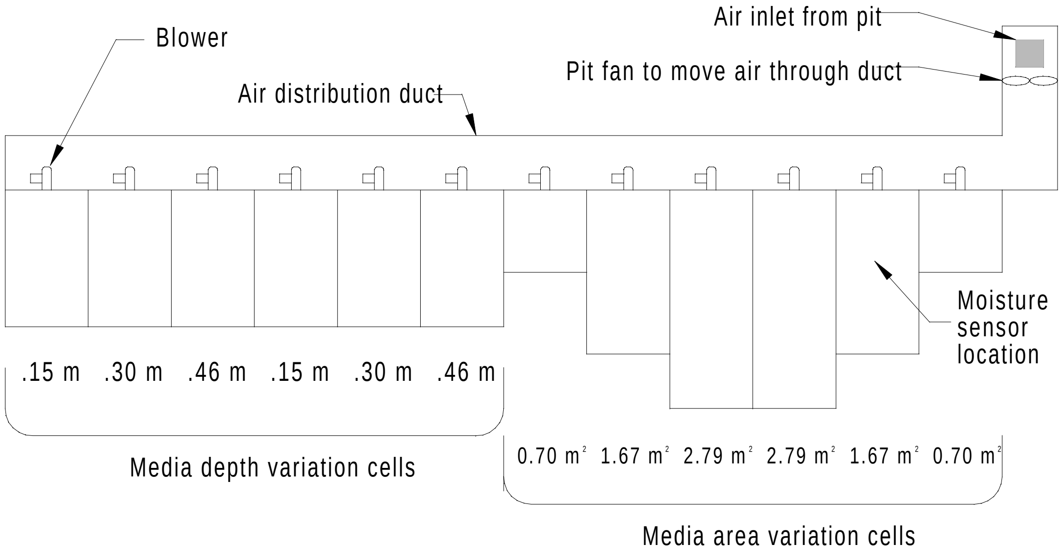

Figure 1. Twelve cell biofilter layout used at each livestock facility.

The biofilter media used at the dairy and swine facilities was 50% by weight compost and 50% brush wood chips. The media at the poultry facility was 50% by weight brush wood chips and 50% sandy loam soil. A laboratory test was conducted to determine the pressure drop-air flow relationship for each media.

Pit exhaust air from each barn was directed through a distribution duct. Twelve blowers (Dayton model # 4C442) located in the distribution duct moved exhaust air to a 0.15 m (6 in) plenum beneath each biofilter cell. The airflow in Table 1 was determined from the expected media pressure drop.

An automated sprinkler system was installed at each site to add water to the biofilters to control the moisture. A Watermark block was placed in the biofilter media in the second large (i.e., 1.67 m^2) biofilter on the right end (Figure 1) to sense the media moisture content. When the sensor output dropped below a specified limit, a solenoid valve attached to a water line was opened for five minutes. Water was supplied only once for five minutes every two hours. The water was distributed through flexible plastic tubing with rotating sprinkler heads. The large biofilters (i.e., 2.79 m^2) had three sprinkler heads, the medium biofilters (i.e., 1.67 m^2) had two sprinkler heads, and the other biofilters had one sprinkler head.

Performance of each biofilter was monitored by collecting air samples from each cell outlet and comparing the results to a sample collected at each end of the inlet air distribution duct. The collection period was from July 1998 until May 1999. Air samples were analyzed using a dynamic olfactometer to determine odor detection threshold (Nicolai et al., 1997). Hydrogen sulfide gas concentrations were measured with a Jerome^{TM} meter. Ammonia gas concentrations were measured with NH_3 detector tubes. Air pressure differential across the biofilter media of each cell was measured weekly during the summer months and monthly during the winter using a manometer. Moisture content was determined by oven drying media samples and reporting on a wet basis.

RESULTS AND DISCUSSION

Laboratory results of the pressure drop-airflow measurements for the media used on swine and dairy biofilters are shown in Figure 2. The unpacked data was obtained by placing the media loosely in the test chamber. A 19-kg (50-lb) weight was placed on the media in the test chamber for 48 hours to obtain the packed data. Unpacked data would represent a newly built biofilter and

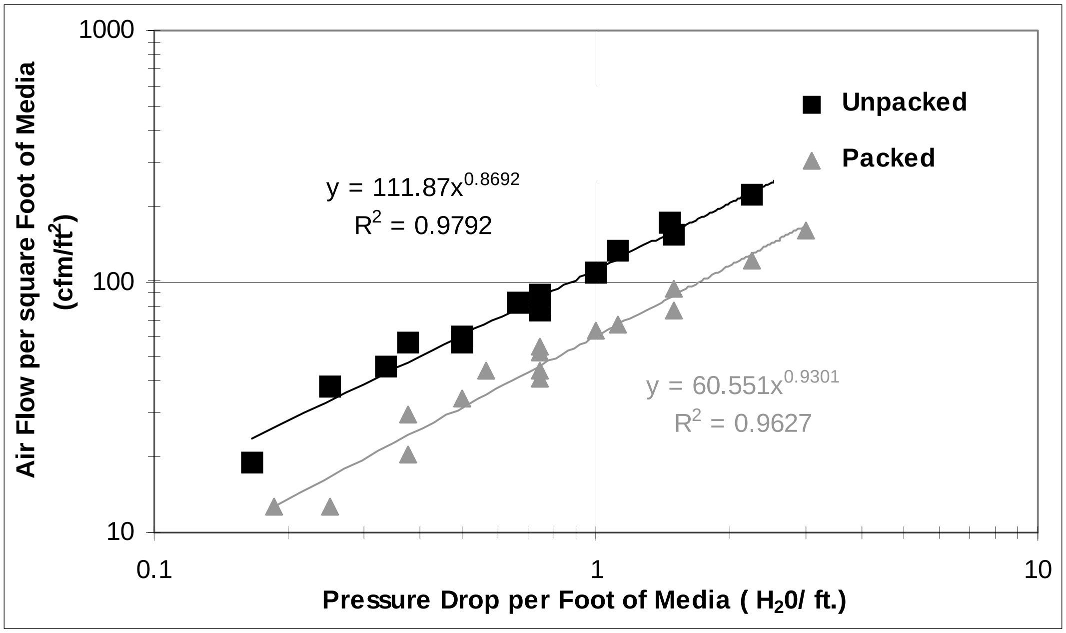

Figure 2. Media pressure drop.

packed data would be representative of media which has settled over time. With this information and the rated capacity of the blower, the target packed airflow rate was calculated for each biofilter cell and is shown in Table 1.

Table 2 shows odor detection threshold levels of air samples from inlet air and biofilter cell outlet air. At the dairy and swine sites, increasing the residence time, by either increasing the depth or surface area, improved odor reduction. Odor reduction on the poultry barn was poor and a paired t-test indicates no significant difference between the inlet and outlets for any of the biofilters.

Table 2. Odor detection threshold in odor units and percent reduction.

	Inlet	Varying media depth						Varying media surface area					
		0.15 m		0.30 m		0.46 m		0.7 m^2		1.67 m^2		2.79 m^2	
		Residence Time											
		3.4 s		7.2 s		12.1 s		4.2 s		8.5 s		13.5 s	
	ou	ou	%	ou	%	ou	%	ou	%	ou	%	ou	%
Dairy	120	53	56%	38	68%	44	64%	49	60%	36	70%	32	73%
Swine	757	265	65%	85	89%	68	91%	138	82%	49	94%	51	93%
Poultry	117	80	31%	83	29%	71	39%	106	9%	110	6%	76	35%

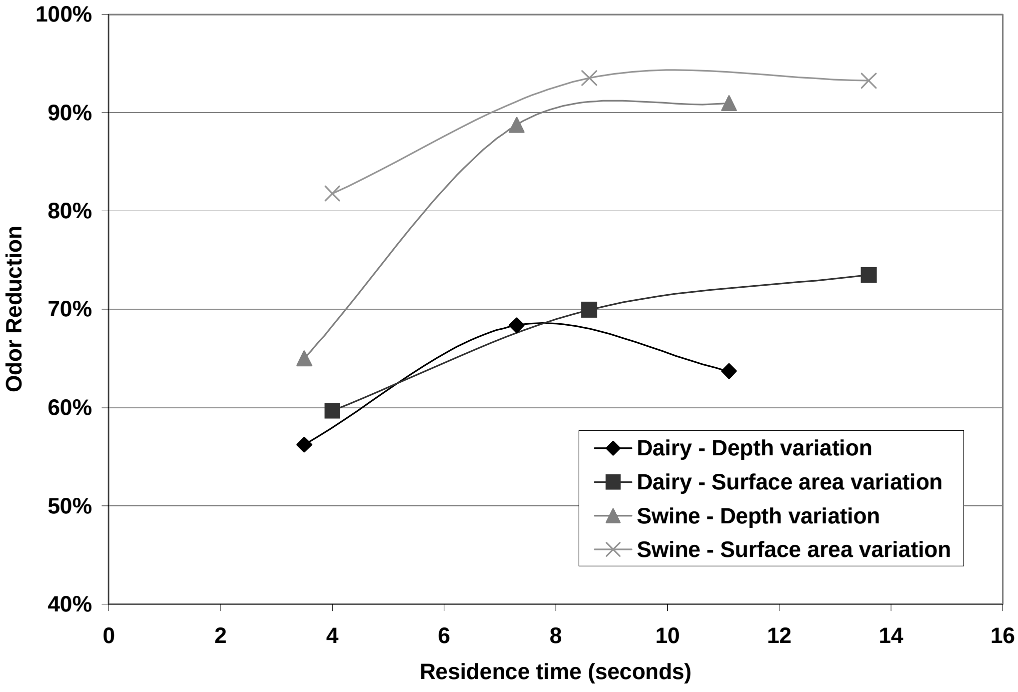

Figure 3. Residence time versus odor reduction.

Figure 3 shows the relationship of residence time and percent odor reduction for dairy and swine. The swine biofilters with residence times of 7.2 s or more were able to achieve 89% or more odor reduction. The dairy biofilters with residence times of 7.2 s or more had odor reductions between 64 to 73%. The percent reduction for the dairy was less than the swine because the dairy inlet odor was significantly less than the swine and the outlet ranged from 7 to 20 ou. The odor character of the exhaust air changed as it went through the biofilters. The outlet air had more of a compost and woody character. This suggests that the biofilter exhaust air may have a minimum detection threshold, which may limit the percent reduction in some cases.

Comparing the two minimum residence times obtained either by depth or area adjustment, the 0.15 m deep biofilter for swine had a residence time of 3.4 s and did not show significant odor reduction (i.e. 65 %), whereas the 0.7 m^2 with a 4 s residence time had significant odor reduction (i.e. 82%). Effective odor reduction can be achieved at a low residence time if it is achieved by maintaining the depth and decreasing the media area.

Table 3. Hydrogen sulfide in ppb and percent reduction from inlet.

	Inlet	Varying media depth						Varying media surface area					
		0.15 m		0.30 m		0.46 m		0.7 m^2		1.67 m^2		2.79 m^2	
		Residence Time											
		3.4 s		7.2 s		12.1 s		4.2 s		8.5 s		13.5 s	
	ppm	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%	ppm	%
Dairy	102	17	83%	11	89%	10	91%	20	81%	13	87%	7	93%
Swine	786	335	57%	65	92%	33	96%	142	82%	45	94%	32	96%
Poultry	89	87	3%	77	13%	66	26%	82	8%	67	25%	62	31%

The hydrogen sulfide reduction results were similar compared to the odor results (Table 3). The biofilter on the poultry facility did not significantly reduce hydrogen sulfide. The 0.15 m deep cell on the swine barn had a lower removal efficiency, only 57%, when compared to the other cells, which ranged from 82% to 96%. As with odor reduction, effective hydrogen sulfide reduction can be obtained at low residence time if it is achieved by maintaining the depth and decreasing the media area.

Pressure drop did not change with time during the test period at any of the sites. Figure 4 shows the comparison of the actual pressure drop across each biofilter and the model predicted range between packed and unpacked for each biofilter cell. The laboratory tests and model (Figure 2) predict an increase in pressure drop in a biofilter as the media settles over time. The biofilters designed for low-pressure drops tended to end up at the high end of the predicted range. There is an inverse relationship between pressure and residence time. Reducing the residence time by decreasing the area while maintaining constant media depth increases the pressure drop. Reducing the residence time by decreasing the depth while maintaining constant surface area decreases the pressure drop.

The media moisture content increased as the residence time increased for both the depth and area adjustment. All the biofilter cells received the same moisture application during the dry summer

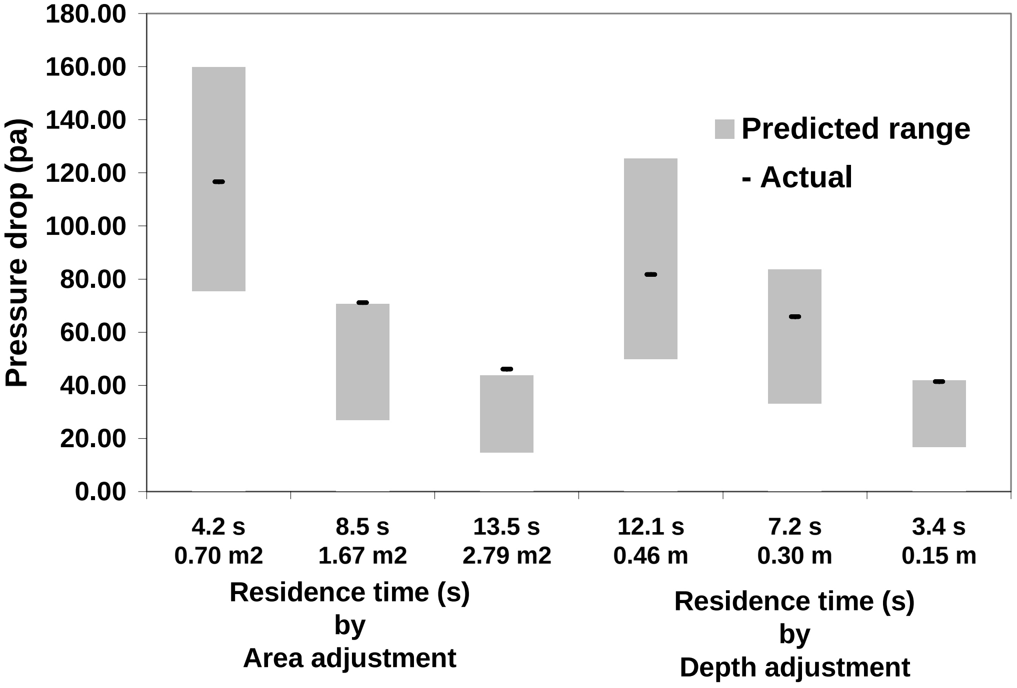

Figure 4. Actual versus predicted range of pressure drop across each biofilter.

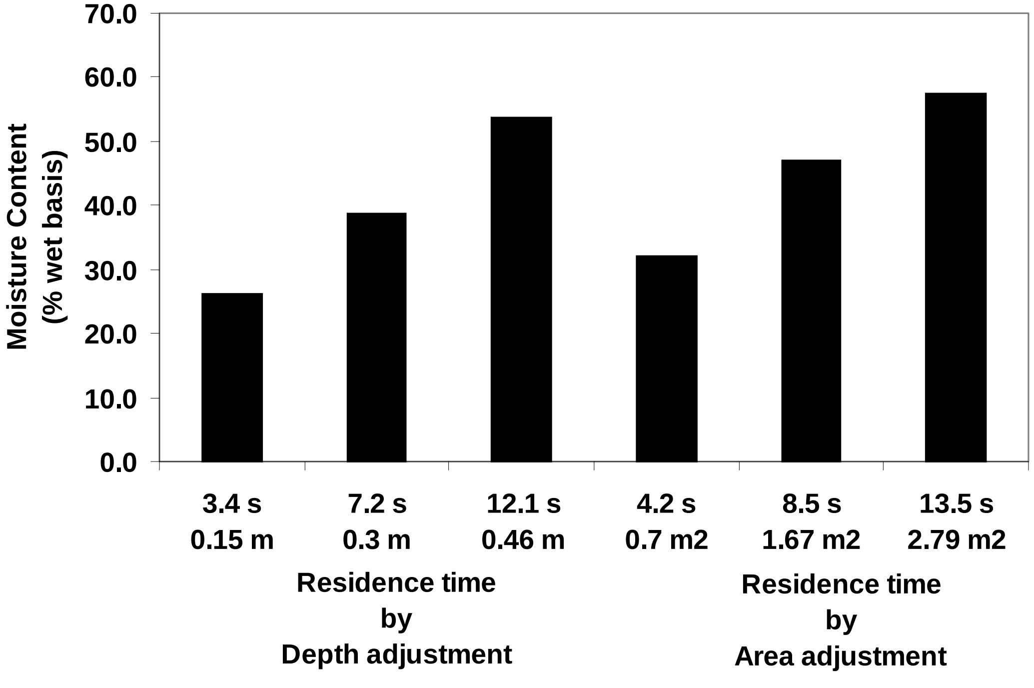

Figure 5. Average media moisture content for biofilter residence time cells.

months. Moisture was not applied during the cold winter months. The media moisture change can be explained by a drying effect from the increased airflow. Biofilters do not operate efficiently with media below 40% wet basis (Hartung et al., 1997) Reducing the residence time below 5 s caused excessive drying in these biofilters.

CONCLUSION

There was no significant increase in odor reduction with residence time of 6 s or more for either dairy or swine. Odor reduction was less than optimal at residence times less than 4 s. For adequate odor and hydrogen sulfide reduction, the recommended design residence time for a biofilter on a dairy and swine facility is 5 s. Hydrogen sulfide reduction was also adequate at 5 s residence time.

Reducing residence time by decreasing depth below 0.15 m (6 in) had reduced odor and hydrogen reduction below 65%. But reducing the residence time by decreasing area with a depth of 0.3 m (12 in) maintained effective odor and hydrogen reduction. Therefore, the recommended minimum depth of a compost/wood chip media biofilter is someplace between 0.15 m (6 in) and 0.3 m (12 in). A minimum of 0.25 m (10 in) is recommended at this time.

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