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Determining Pressure Drop Through Compost-Wood Chip Biofilter Media

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Abstract. *Biofilters are an effective air pollution control technology that uses microorganisms to breakdown gaseous contaminants. Compost and wood chip media mixtures ranging from 30:70 to 50:50 percent by weight are recommended for removing odors and hydrogen sulfide from livestock wastes. The relation between unit flow rate through the biofilter media and the unit pressure drop across the media is needed for biofilter design. The purpose of this project was to develop a method for characterizing compost and wood chip mixtures and predicting the relation between flow rate and pressure drop. A field method for estimating the media's percent voids was highly correlated with sieve analysis results. Relations to estimate the unit pressure drop given the unit flow rate and percent voids were developed for media with between 40 to 60% voids. These can be used to evaluate alternative biofilter designs and for selecting fans with adequate fan performance characteristics.*

Keywords. Biofilter, Odors, Compost, Wood chips, Air pollution control, Livestock

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R. E. Nicolai and K.A. Janni

INTRODUCTION

Biofilters are an air pollution control technology that uses microorganisms to breakdown gaseous contaminants and produce innocuous end products. They are effective in reducing odor and hydrogen sulfide emissions from livestock facilities (Nicolai and Janni, 2000). Biofilters use a porous solid medium to support microorganisms and allow access to the contaminants in the airflow. Most biofilter media include various proportions of biological residues (compost, peat, soil) and bulking agents (wood chips, heather, or synthetic material). Environmental and nutritional requirements for microbial growth (i.e., moisture, temperature, and nutrients) must be considered in both media selection and management. The media must also have a high porosity for minimizing pressure drop across the biofilter, good moisture holding capacity, and a sufficiently long useful life (Devinny et al., 1999; Nicolai, 1998).

Biofilters have been demonstrated to reduce odors on swine barns (Nicolai and Janni, 2000). A major consideration when adapting biofilters to livestock facilities is the media cost. To reduce costs, media materials should be locally available. Mixtures of wood chips and compost have been widely used since they are generally locally available and low cost (Zeisig, 1987; Nicolai and Janni, 1998 and 1999; von Bernuth et al., 1999). Nicolai and Janni (2001) recommended a 30:70 to 50:50 by weight ratio of compost and wood chips for biofilters installed on livestock facilities. The compost provides a source of microorganism and micronutrients while the wood chips improve porosity and reduce the pressure drop.

To design biofilters for efficient operation and energy consumption, a fairly accurate prediction of the pressure drop through the media is needed. Although several media samples may have the same compost and wood chips mixture ratio by weight, they may have different pressure drop performance characteristics depending upon the compost and wood chips particle size distribution. Factors affecting particle size include wood chipper screen size, compost residue source and type, and screen size used to remove fines.

Little published research data is available to predict pressure drop knowing the media and loading rate. Recommended air surface loading rates for biofilters are based on operational experience with full-scale systems. Williams and Miller (1992) recommend loading rates between 20 and 100 $m^3/m^2/hr$. Prokop and Bohn (1985) recommend loading rates of 35 to 180 $m^3/m^2/hr$ for high porosity media such as bark and peat moss, while for compact media such as soil, lower loading rates of 2 to 10 $m^3/m^2/hr$ are recommended. Loading rates in sand, bark, and soil/bark biofilters at rendering plants in New Zealand have been measured at 10 to 14 $m^3/m^2/hr$, 4 to 7 $m^3/m^2/hr$, and 1 to 3 $m^3/m^2/hr$ respectively (Luo, 2001). Rendering plants in The Netherlands and Canada have reported biofilter loading rates of 100 and 123 $m^3/m^2/hr$ respectively (Prokop and Bohn, 1985).

After the test cell was filled and the unpacked measurements taken, the media was then packed by placing a 23 kg (50 lb) weight evenly distributed on top of the media for 48 hours. Flow rate and pressure drop measurements were taken at various media depths for the packed media by removing 10 cm (4 in.) sequentially. Airflow and pressure differential measurement were made for the packed condition by the same method used for the unpacked media.

Particle size distributions of each media sample were determined by passing it through a stack of nine sieves arranged in decreasing mesh size order. The media samples were air dried to less than 5% wet basis before passing through the sieves. The weight of media retained on each sieve was obtained. The mesh size of each sieve was 7.6 cm (3 in.), 5.1 (2 in.), 2.5 cm (1 in.), 1.9 cm (0.75 in.), 1.3 cm (0.5 in.), 0.635 cm (0.25 in.), 0.23 cm (0.09 in.), and 0.13 cm (0.05 in.). Approximately 400 g (1 lb.) of media placed on the largest sieve was shaken for 2 min. Using the midpoint of the lower and upper size limit of each sieve, the mass mean diameter (d_{mm}) of each sample was determined using equation 1.

$$d_{mm} = \frac{\Sigma m_i d_i}{M} \qquad (1)$$

where m_i is the weight on each sieve, M is the total weight of the sample , and d_i is the midpoint of the upper and lower size limit for each sieve range. The upper size limit of each interval coincides with the lower limit of the next-higher interval.

A simple five-gallon pail method (Rosen, 2000) was used to determine the void space in each of the media samples. The following procedure was used:

1. Five gallons of water were placed into a pail and its level was marked ("full line") on the inside of the pail.
2. Media was placed into the pail until it was about one-third full. The pail was dropped ten times from a height of 15 cm (6 in.) onto a floor.
3. Media was added to fill the five-gallon pail two-thirds full and dropped ten times from a height of 15 cm (6 in.) onto a floor.
4. Media was added to the full line as marked in step 1 and dropped ten times from a height of 15 cm (6 in.) onto a floor.
5. Media was added to fill the five-gallon pail to the "full line."
6. The volume of water added to the five-gallon pail "full line" was recorded.

The percent voids in the media sample was determined by (equation 2):

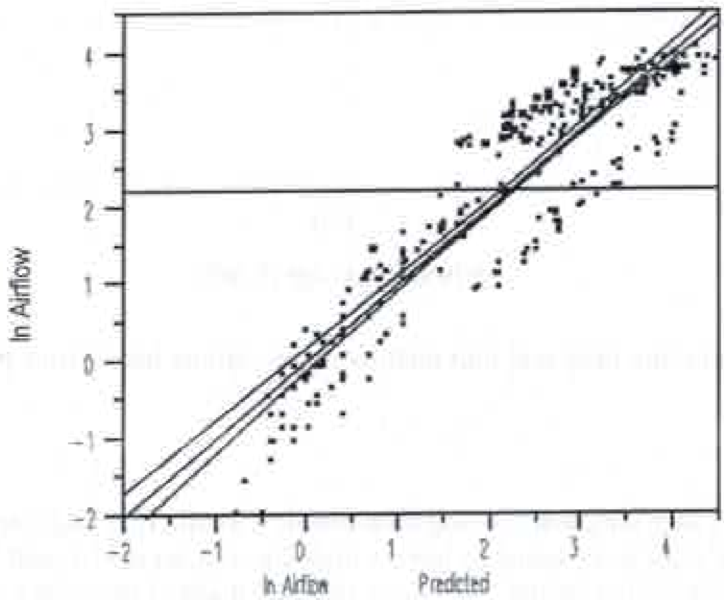
$$\text{Percent voids} = \frac{\text{Volume of water added (gallons)}}{5\text{ (gallons)}} \times 100 \qquad (2)$$

RESULTS AND DISCUSSION

Table 1 summarizes the results obtained using the two methods to characterize the nine-biofilter media. The percent void was determined by the five-gallon pail method and mass mean diameter was determined from the sieve particle size data. The correlation coefficient between the two media characterization methods was 0.95. Both methods adequately describe the material and transformed to the natural log and a multiple regression preformed using percent void and natural log of the pressure drop as the independent variables. The resulting regression is:

$$\mathrm{UFR} = e^{0.135(\%V) + 0.961(\ln \mathrm{UPD}) - 8.78} \tag{3}$$

where UFR is the unit airflow rate ($m^3/min/m^2$), %V is the percent voids, and UPD is the unit pressure drop (Pa/m). The regression model accounts for 84% of the variation around the mean (R square). The remaining residual errors are estimated to have a standard deviation of 0.58. A distribution of the residuals comparing the model predication and recorded data indicates a fairly normal distribution, indicating that none of the normality assumptions for the regression were violated. A whole model F-test (Figure 3) preformed on each of the parameters shows a high significance level or p-value < 0.0001.



Analysis of Variance				
Source	Deg. of Freedom	Sum of Squares	Mean Square	F Ratio
Model	2	517.9253	258.963	716.1387
Error	278	94.24387	0.340	Prob.>F
C total	280	612.1692		<0.0001

Figure 3. Whole model F-test.

Figure 4 shows the relation between unit pressure drop and unit airflow rate for 40%, 50%, and 60% voids based on the regression model. When sizing a biofilter, this information is needed to predict the expected pressure drop and may also be used to help select the exhaust fan(s) for adequate building ventilation using fan performance data.

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