MOISTURE SENSING METHODS FOR BIOFILTERS TREATING EXHAUST AIR FROM LIVESTOCK BUILDINGS

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ABSTRACT. Biofilters using media of crop residue materials have been shown effective in removing odorants from air exhausted from livestock buildings, especially swine facilities. Adequate media moisture is critical in maintaining biological growth in filters, and most biofilter installations use either portable or permanently installed equipment for adding water to the media. However, there has not been a reliable method for continuously evaluating media moisture for the purpose of determining when water should be added to the filter to replenish moisture levels deep within the filter. This project tested five different types of moisture meters in a typical biofilter medium: Lincoln Irrigation soil moisture meter, Farmex HMT-3 digital hay moisture meter, Campbell Scientific Hydrosense digital soil moisture meter, Vaisala Hummiter50Y relative humidity probe, and a site-built radio-frequency large-area capacitive plate sensor.

None of the soil and hay moisture meters performed adequately in predicting biofilter media moisture content. The relative humidity probe did, however, produce a useful calibration curve and was subsequently used for some months in a field application. The large-area capacitive plate sensor showed linear response with moisture content on preliminary tests and is undergoing further testing and refinements. Based on the limited testing and short term field applications, the authors intend to pursue the development of the relative humidity sensor and/or the large-area capacitive plate sensor as components of an automated system for monitoring and controlling the moisture content of biofilters. Such a development could greatly improve the acceptance, performance, and economic viability of biofilters for cleaning ventilation exhaust air, thereby reducing odor emissions and improving community relations with livestock facilities.

Keywords. Biofilter, odor control, livestock, moisture measurement.

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INTRODUCTION

One effective technology to mitigate odors from livestock facilities is biofiltration. A biofilter is a porous organic substrate – typically wood chips, peat, compost, or a combination – supporting a microbial colony within a thin film of water, or biofilm, on its surface. These microbes, both bacterial and fungal, are capable of digesting certain organic compounds such as organic acids, phenols and other substances that cause livestock odor (Classen et al., 2000). When air from animal facilities is blown through the biofilter, the odorous substances partition into the biofilm and the microbes metabolize the compounds into carbon dioxide, water and inorganic salts (Haug, 1993), removing them from the discharged air. Odor removal efficiency is therefore dependent upon the rate of metabolism of the colony and the airflow rate through the biofilter; but at its most efficient, biofiltration can reduce odor and hydrogen sulfide emissions by up to 95% and ammonia by 65% (Nicolai et al., 2002).

While management of airflow speeds is relatively straightforward, control of metabolic rate is more complicated. In addition to incoming concentrations of organic compounds, the metabolic rate of the colony is dependent upon providing the microbes with the correct balance of nutrients, moisture and oxygen and with appropriate pH, temperature, and surfaces on which to multiply (Devinny, et al., 1999). The biofilter substrate, or biomedium, must therefore have sufficient porosity, nutrient content, and moisture holding capacity, and be slow to degrade (Nicolai et al., 2002). However, although good biomedia can retain ample water, incoming air inevitably dries the medium unless the humidity ratio of the air is equal to or greater than that which establishes moisture equilibrium at the present moisture content of the media. Therefore, the moisture level of a biofilter steadily decreases as it is used, if water is not replenished either by irrigation with liquid or by humidifying the air. Maintaining biomedium moisture content is crucial because, although the microbes require oxygen, they cannot exist outside of the biofilm. An automatic control system for maintaining biofilter moisture is needed.

OBJECTIVES

The objective of this project was to identify a moisture sensor suitable for incorporation in a system built to automatically control the moisture of a farm scale emission-control biofilter.

MATERIALS AND METHODS

At the outset of this project we looked for simple moisture measurement methods that might be able to give a pass/fail reading of biofilter moisture content that could then be used to trigger an irrigation system on and off. We attempted to calibrate soil moisture and hay moisture probes, with the hypothesis that a biofilter medium might react somewhat similarly to soil, hay, or perhaps compost.

BIOMEDIA

"Debark" biofilter medium identical to that used in a newly constructed biofilter, used at a farrow-to-wean swine facility, was selected as a test medium. Debark is the byproduct of stripping wood of its bark for processing. This medium was varied in particle size and had a porosity of about 57% as tested in the field using the method of MWPS (2002).

SOIL MOISTURE METER TESTING

Three soil moisture meters were tested for their applicability to biofilter media: the Lincoln Irrigation Soil Moisture Meter (Lincoln Irrigation, Lincoln, NE), the Farmex HMT-3 digital hay meter (Farmex Electronics, Streetsboro, OH), and the Campbell Scientific Hydrosense digital soil moisture meter (Campbell Scientific, Inc., Logan, UT). Because soil meters show a linear response to water, any calibration curve for soil meter reading to biomedium moisture content was assumed to follow a linear shape. Therefore, by measuring the meter response at biomedia saturation and the meter response for completely dried media, a calibration graph can theoretically be constructed.

The first soil probe we tried, the Lincoln Irrigation Soil Moisture Meter, has two contacts with a voltage imposed across them. The soil moisture reading is related to the amount of current passed through the conductive soil pathway between the contacts, the higher moisture soil having a lower electrical resistance and thus conducting more current. That meter is sold not only as a soil moisture meter but also as a compost windrow moisture tester, so we hoped it would be useful for biofilter media as well. Even though the soil moisture probe analog readout was calibrated only across wide ranges, we hoped it might prove useful as an inexpensive pass/fail meter for the biofilter. To test the meter we pulled a sample of biofilter medium and tried the probe in it at the as-delivered moisture content and at various stages of saturation.

The Farmex HMT-3 digital hay moisture meter was tested in a similar fashion as the soil moisture meter. We expected the hay moisture meter to exhibit better performance than the soil moisture meter in a biofilter, because the performance of resistive meters appeared to be very dependent on density of the tested material; biofilter media would be closer in density to hay than to soil. The Farmex hay meter had larger probe contact areas than the Lincoln Irrigation soil meter, another reason we thought it might give a more reliable moisture reading.

As a first trial, six samples of debark medium were wetted until a Lincoln Irrigation Soil Moisture Meter registered 0, 2, 4, 6, 8, and 10 respectively. Each sample was then weighed and dried in a drying oven at 120 C for over 24 hours. The samples were again weighed and the total moisture contents were calculated.

In a second experiment, saturation of the biomedium without being in direct contact with a pool of water was accomplished by using a small humidity chamber constructed of a 1.5 ft x 2.5 ft x 1 ft clear plastic Rubbermaid box with a tightly fitting lid further sealed with duct tape. Inside, a smaller Rubbermaid plastic basket elevated by 1” x 1” x 3” pieces held the biomedium, which had been previously soaked overnight directly in water. The floor of the chamber was then filled with water to a one-inch depth. The soil meter was inserted into the biomedium through a hole cut in the lid of the chamber and sealed with duct tape or with a stopper. The medium was allowed to come to equilibrium with the 100% relative humidity air inside the chamber overnight (room temperature approximately 20C), and then readings of the medium moisture were taken with each of the three probe-type meters.

RELATIVE HUMIDITY SENSOR TESTING

Relative humidity measurements of the air immediately surrounding the biomedium were assumed to be proxy measurements for the medium moisture content. A layer drying model was also assumed, wherein the biofilter would remain approximately saturated above a drying front (with air moving upward through the biofilter). As drying of the biofilter proceeds upward, a stationary sensor located in the medium should register a rapid drop in moisture content as the drying front passes the sensor. To more accurately assess the efficacy of a relative humidity probe within the biofilter, an apparatus simulating biofilter conditions was constructed. A variable speed fan set to produce an air average velocity of 20 ft/min (the high end of the biofilter air flux range suggested in MWPS [2002]) drew air into a 65-gallon plastic drum and then into a 3 foot, vertical section of 4 inch diameter PVC pipe filled with debark biomedium. The drum was fitted with fogger nozzles attached to a hose with water pressure of 45 psi that could be used to humidify the air entering the simulated biofilter. A Vaisala Hummiter50Y (Vaisala Inc., Woburn, MA) relative humidity probe was inserted into the biomedia through a hole one foot from the top of the biofilter. The probe was connected to a data logger for continuous readings of the probe's output.

Two laboratory tests and a field trial were performed with the Vaisala probe. In the first laboratory test, the column was filled with medium in equilibrium with the atmosphere (approximately 55% RH for the day) and the fan was turned on without the humidifier. After fifteen minutes, three biomedium samples were taken from the area surrounding the humidity probe and were analyzed for moisture content using standard oven drying and weighing. Relative humidity measurements were taken at one-minute intervals. This process was repeated for medium that had been kept in a 95% humidity chamber for 5 days and for medium that had been soaked in water overnight.

In the second laboratory experiment, the biofilter column was filled with biomedium that had been soaked overnight in water. The fan was turned on and the medium was allowed to dry without the humidifier. Relative humidity readings were taken at one-minute intervals via the Vaisala sensor.

A field trial was run by installing the Vaisala relative humidity sensor probe on a biofilter that was used to clean exhaust air from a manure tank headspace. The purpose of the trial was to test the use of the sensor probe extension tube (3/4 inch PVC conduit) and to test the durability of the apparatus in field conditions. An estimate of moisture equilibrium development depth was made (about 1/3 of the depth of the biofilter) and the relative humidity sensor probe extension tube was inserted near that point, such that the probe would sample air at a point deep in the biofilter where air traveling upward would reach moisture equilibrium. Then when the bottom layer of the biofilter dried to less than the desired moisture content, the air passing through it would be at a correspondingly lower equilibrium relative humidity and would signal via the relative humidity sensor that the biofilter medium required irrigation. A soaker hose was embedded in the biofilter and irrigation was turned on manually, based on the relative humidity sensor reading (Fig. 1).

Figure 1. Relative humidity sensor with extension tube in biofilter medium, field trial.

LARGE-FORMAT EMBEDDED MOISTURE SENSOR

A prototype sensor was developed to exploit the change in biomedium dielectric properties with moisture change. The sensor was made 91.4 cm by 76.2 cm (36 in by 30 in), the idea being to sense a large area within the biofilter being monitored, thus giving a more representative moisture reading than that from a single point in the biofilter. The capacitor plates were constructed from a steel grid material and were embedded in the biomedium, excitation of the non-grounded plate being performed at a range of frequencies to test sensor response. Biomedium samples were tested for moisture content and a calibration curve was developed from the results.

RESULTS AND CONCLUSION

Overall the soil and hay moisture meters were found to be inadequate for biofilter moisture content sensing. The results of the first test are presented in Figure 2. Although the soil meter readings generally increased linearly with increased moisture content, they covered a range of less than 20% moisture content. This suggests either that the range of the soil meter was insufficient or that it was not accurately gauging the biomedium moisture. In either case, the calibration was not sufficient. Because water was simply poured into the biomedia container, it is suspected that the soil meter was reading the water generally surrounding the media rather than the water directly absorbed by and adsorbed to the media's surface. For this reason, the small humidity chamber was constructed to allow saturation of the media without direct contact with water.

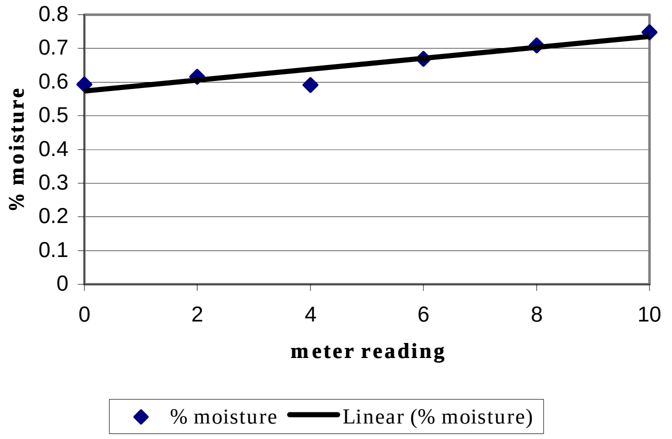

Figure 2. Lincoln Irrigation Soil Moisture meter test in biomedium.

Biomedia saturated in this way were tested with all three soil moisture meters. Again, each meter did not appear to read the moisture content properly. After saturation the media was found to have 60% moisture content. The Lincoln Irrigation Soil Meter registered a reading of 2 for the saturated media. To ascertain whether this was due to a faulty meter, the meter was tested in the wet soil outside just after a rain and registered 10, indicating a properly working meter.

Similarly, the digital hay meter on the default settings gave very inconsistent readings for the saturated media. On average, these readings were only 1% above those obtained from exposing the sensor to the dry media. Trials of various other settings resulted in comparable readings.

Finally, the Hydrosense meter also read erratically. Completely saturated biomedium registered a mean reading of 8% and completely dried media a mean reading of 3%.

The data obtained from the second experiment are presented in Figs. 3 and 4. The calibration curve (Fig. 3) indicates the response of the instrument over the range of interest of biomedium moisture content.

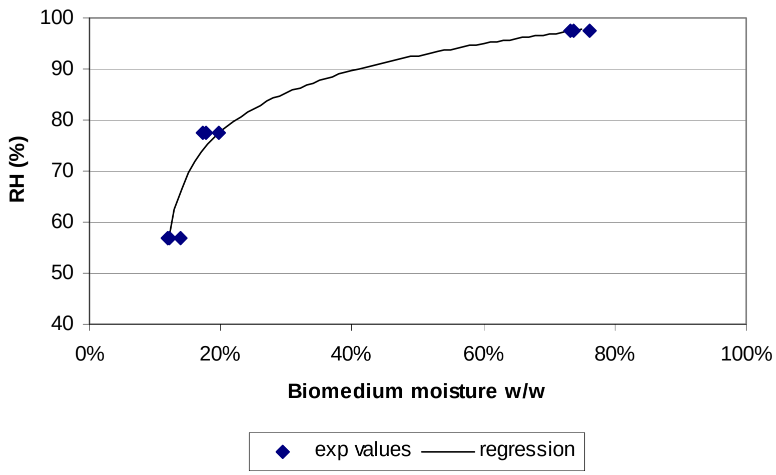

Figure 3. Calibration response of relative humidity sensor, air in equilibrium with biomedium.

Over the course of two days the apparatus dried the soaked media to equilibrium with the surrounding air and relative humidity measurements correspondingly decreased to equal that of the ambient air (47%). The plot shows that the drying took place in three apparent stages.

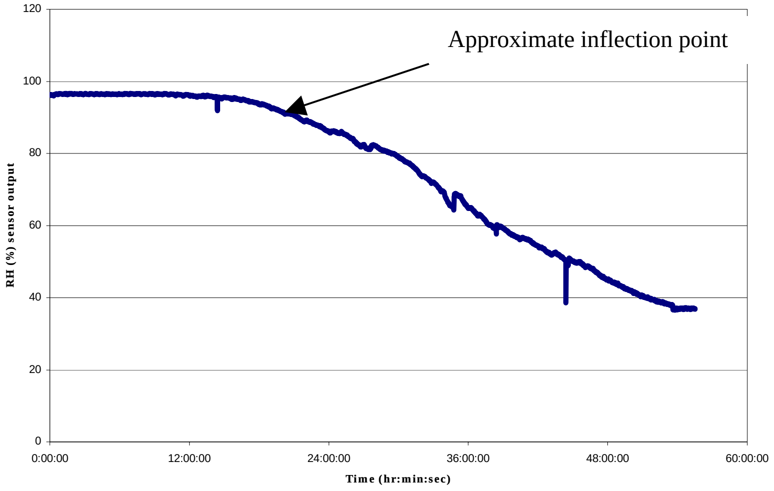

Figure 4. Response of relative humidity sensor in simulated biofilter showing passage of drying front over time.

First, there was a period lasting approximately 18 hours in which relative humidity measurement is nearly constant. The second was a stage of sustained drying, followed by a third period during which the sensor reading leveled off at ambient humidity. All three stages have approximately constant slope (drying rate). Biofilter moisture content should be generally kept higher that 50% (Devinny, 1999, 59). Because the drying rate must increase or decrease between stages (pass through an inflection point), it should be possible to control the moisture content of the biomedia by using this inflection point as a trigger for automated wetting systems.

The field trial period for the relative humidity sensor lasted approximately three months (June-September 2004). During that period the readings from the sensor were used to indicate the need for biofilter irrigation, the irrigation water control being done manually. The only equipment maintenance needed during that time was a battery exchange in the display meter. Otherwise the sensor output followed a predictable pattern reflecting short-term water additions to the biofilter (approximately weekly schedule) and long-term slow drying of the biofilter between irrigation cycles.

The large-format embedded moisture sensor showed a marked response over a relatively narrow range of tested moisture conditions, indicating the possibility of simple calibration and an advantage over probe-type sensors for automated biofilter irrigation systems. At the time of this paper, licensing rights for the sensor concept and further development are being discussed within University administration.

CONCLUSION

Three resistance moisture meters, a relative humidity meter, and a large-format embedded sensor were tested for their ability to measure the moisture content of debark biofilter media. A small climate chamber was developed to measure the media moisture at saturation, and an apparatus was built to mimic biofilter operation conditions during drying. It was found that conventional soil and hay moisture meters are unsuitable for measuring the moisture content of biofilter media due to the variability and limited range of their response. It is suggested that these problems are due to a lack of reliable contact between the probe and the biomedium.

Relative humidity sensors were shown to be a more promising method of biofilter moisture content measurement. A logarithmic calibration was constructed for relative humidity measurement with one sensor, and it was found to be suitable over a useful range of moisture contents. Relative humidity for a drying biofilter was found to proceed in three stages of essentially constant drying rate, suggesting a method for controlling an autonomous irrigation system based upon relative humidity measurements. Further research should focus on reproducibility of the calibration curve through measurements for different biomedia at different ambient conditions and on testing the efficacy of the automated system suggested.

A large-format moisture sensor was developed and limited calibration tests in the laboratory indicated the concept could be more useful than any of the probe methods for automatically monitoring biofilter moisture.

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REFERENCES

Classen, J. J., J. S. Young, R. W. Bottcher, P. W. Westerman, 2000. Design and Analysis of a Pilot Scale Biofiltration System for Odorous Air. *Transactions of the ASAE* 43(1): 111-118.

Devinny, J. S., M. A. Deshusses, T. S. Webster, 1999. *Biofiltration for Air Pollution Control*. Boca Raton, Fla.: Lewis Publishers.

Haug, R. T., 1993. *The Practical Handbook of Compost Engineering*, 586. Boca Raton, Fla.: Lewis Publishers.

MWPS. 2002. Outdoor air quality – Manure management series MWP-18 Section 3. MidWest Plan Service, Ames, IA.

Nicolai, R., K. Janni, D. Schmidt. Biofilter Design Information. University of Minnesota Extension Program. www.bae.umn.edu/extens/aeu/baeu18.html