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Field evaluation of wood bark-based down-flow biofilters for mitigation of odor, ammonia, and hydrogen sulfide emissions from confined swine nursery barns

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Two down-flow wood bark-based biofilters were evaluated for their effectiveness in treating odor, NH_3 and H_2S under actual swine farm conditions. The water requirement for maintaining proper media moisture contents (MC) under different ventilation rates and intervals were determined. The effect of media depth and MC on the biofilters' performance was also evaluated. The aerodynamic resistance on biofilters was studied using computational fluid dynamics (CFD) software. Water requirements for biofilters were obtained in the range of 3.8–556.0 L/m^3/d for ventilation duration of 1–24 h/d (depending on the age of the pig and environmental conditions). The highest reductions in odor, NH_3 and H_2S, obtained in this study at empty bed residence times (EBRT) of 1.6–3.1 s, were 73.5–76.9%, 95.2–97.9% and 95.8–100.0%, respectively. The pressure drop was 28.8–68.8 Pa for a media depth of 381 mm at an EBRT of 1.6–3.1 s and an MC of 64–65%. The pressure drop followed a secondary order polynomial line with both airflow rate and media MC ($R^2 = 0.927$–0.982). The results of odor, NH_3 and H_2S reduction efficiency and pressure drop suggest a media depth of ≥254 mm, MC ≥ 35–50% and EBRT of 2–3 s for successful operations of the wood bark-based biofilters. A high correlation was found between the measured and predicted pressured drops obtained using CFD software ($R^2 = 0.921$, RMSE = 0.145).

1. Introduction

The trend toward high-density, confinement swine operations has increased dramatically in recent years to satisfy higher demand for meat products. As the number and size of confinement facilities have increased, air pollution problems due to odors and gas emissions have also increased. Sources of odor and gas emissions include land application events, manure storage facilities, and exhaust air from barns. Ventilation air is typically exhausted into the ambient atmosphere without treatment. This exhaust air contains odorous gases and particulate matters that can represent a concentrated odor source (Hoff and Harmon, 2006). Besides the nuisance associated with odors, they have also been shown to have a negative impact on the public health of those living in close proximity to the swine farms, where several studies have suggested that odors from intensive swine farms may be the cause for several ailments (Schiffman et al., 1995; Merchant and Ross, 2002). Therefore, effective methods of odor control will have to be put into operation if the swine industry is to coexist with their neighbors. Any technology used to reduce emissions must be able to treat a broad spectrum of airborne compounds. Various air pollution control technologies such as activated carbon adsorption, wet scrubbing, and masking agents have been developed and applied (Ottengraf and Van Den Oever, 1983; Chung et al., 2007). These methods, however, often transfer odor causing materials from the gas phase to scrubbing liquids or solid adsorbents, and their derivatives have resulted in wastewater and solid waste concerns (Lin et al., 2001; Chung et al., 2007). Biofiltration is a green technology that uses no chemicals, thereby creating no issues of potentially hazardous media disposal (Singh et al., 2006a, b). Biofiltration has been recognized as the most promising and cost-efficient technology for treating air streams containing odorous compounds and more practical in meeting statutory emission regulations (Estrada et al., 2012; Prado et al., 2009; Wani et al., 1997).

Biofilter media selection is critical in biofilter design and performance. Media environmental and nutritional requirements

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Nomenclature

d	deviation between the measured and predicted value
F	gravity force, N
L	depth of the media, m
m	number of data sets
p	pressure, Pa
T	transpose
u	velocity in the open channel, m/s
v_s	superficial velocity of air, m/s
Y_j	predicted jth value

Greek symbols

μ	dynamic viscosity, Pa s
ρ	density, kg/m^3
ε_p	porosity
β_F	Forchheimer drag coefficient, kg/m^4
k_{br}	Permeability of the porous medium, m^2
∇	del operator

for microbial growth, i.e., moisture, temperature, and nutrients, must be considered in both selection and management of the biofilter media. 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 (Mudliar et al., 2010; Chen and Hoff, 2009). The mixture of wood chips and compost (70:30 to 50:50 on a mass basis) has been recommended for use as biofilter media (Nicolai and Janni, 2001). However, special care is needed to screen fine particles from compost/wood chip mixtures to reduce operating static pressure. To maintain reasonable efficiencies, agricultural ventilation fans should be run at pressure drops of less than 60 Pa (Nicolai and Janni, 1998). Using only wood chips or wood barks as biofilter media can reduce the pressure drop without specialty fans (Phillips et al., 1995; Chen et al., 2008; Chen and Hoff, 2012; Andres et al., 2006; Dumont et al., 2014), which results in fewer construction and operating costs. However, little is known about the performance of wood-chip/bark biofilters on reduction of malodor and VOCs emitted from swine facilities. Chen et al. (2008) have shown that the wood-chip/bark-based biofilter media is feasible in reducing odors from swine operation buildings. Meanwhile, maintaining proper moisture content is also critical to the success of wood-chip/bark-based biofilters. This factor is even more important than media depth and residence time (EBRT) for its operation (Chen et al., 2008).

Although a number of laboratory scale studies have shown that biofilters could be a promising technology for mitigating aerosol emissions from confined swine production facilities, the use of on-farm biofilters continues to be low in the United States. This is due in part to the lack of information pertaining to on-farm biofilter performance. Thus, this study aimed to investigate the effects of biofilter media and MC on the efficiencies of two on-farm down-flow biofilters: biofilter one (BF1) and biofilter two (BF2). The objectives of this research were: (1) to determine the optimum water supply rate at different airflow rate conditions; (2) to evaluate the performance of the biofilters in odor, ammonia (NH_3), and hydrogen sulfide (H_2S) reduction; (3) to evaluate the effect of media MC and media depth on NH_3 and H_2S reductions; (4) to investigate the pressure drop characteristics; and (5) to study aerodynamic resistance on biofilters.

2. Materials and methods

2.1. Description of experimental site

This study was conducted at a commercial swine nursery facility, which consisted of four 4.3 m × 12.8 m, 120-head nursing rooms, near Kimberly, Idaho, USA (Fig. 1). Each room had an independent tunnel ventilation system. Air entered the rooms through an inlet located on the south wall of each room. There were two variable speed exhaust fans (primary and secondary) in the north wall of each room. During this study, only primary fans were in operations. A shallow pit with a depth of 0.6 m was constructed below the slatted floor to collect manure and washing water. Around 60–70% of total volume in the shallow pit was drained to the lagoons every 5 days. Small pigs were moved in at about 5–7 kg and were raised to approximate 64–68 kg at the nursery facility. After the pigs moving out, the room was completely flushed with well water before new small pigs were moved in. The two biofilters were installed in the front of rooms 7 and 8 (N7 and N8) to treat the exhaust air from the first stage fans (Multifan, 4E40Q, Schuyler, NE, USA).

2.2. Biofilter construction details

Two vertical down-flow biofilters were designed to treat exhaust air from two of the four nursing rooms in Fig. 1. The contaminated air passed through the media in a down-flow direction, which allowed easier application of water to the air entrance surface, where dry zones were reported for vertical up-flow biofilters. This arrangement was found to be more efficient than upward flow in terms of water distribution and filtration efficiency (Arnold et al., 1997).

The biofilters were 2.15 m × 2.26 m in cross-section and 1.22 m in height. Both of the biofilters had the media depth of 381 mm. BF1 (single stage biofilter) was installed in the front of room N7 and BF2 (two-stage biofilter) was installed in the front of room N8 (Fig. 1). Biofilters were connected to the primary exhaust fan of their respective rooms using a rectangular duct made of plywood (Fig. 1). Both biofilters were constructed with 20 mm thick plywood boards. Biofilter plywood room areas were covered with thin metal sheets to protect them from rainfall (Fig. 1). Metal mesh (10 mm diameter holes) with support on the ground was built to support the biofilter media. In BF2, two horizontal metal mesh surfaces were constructed with a vertical spacing of 381 mm. The interior walls and roof of the biofilters were covered with plastic sheets to protect the plywood from sprinkled water. On the bottom of each biofilter, a rectangular metal pan was provided to collect the leachate from the biofilter, which was drained to the manure collecting lagoon by PVC pipes.

Tap water was supplied to the biofilter media via four customized sprinkler heads in each biofilter. Each sprinkler head used a dual spray nozzle (Half circle, Model # 12DSH, Rain Bird Corporation, Azusa, CA 91702, USA) to evenly distribute water to the biofilter media. The water system was controlled using a battery operated propagation timer (Model# 6020P/61512, Drip inc. Concho, AZ 85924, USA). The water supply pressure was controlled within a range of 262–283 kPa by a pressure gauge (Pro Plumber, PP100G, Mansfield, OH 44907, USA). Water was supplied for 20–30 s every 15–240 min, depending upon the duration of the exhaust fan operations and environmental conditions. The watering time of 20–30 s was based on laboratory tests which showed it took 20–30 s for water to travel through 381 mm thick wood bark biofilter media from the top to the bottom. Thus, sprinkling time was fixed at 20–30 s to minimize biofilter leachate.