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SWINE WASTEWATER TREATMENT BY MEDIA FILTRATION[1]

Key Words: aeration, anaerobic lagoon, nitrification, phosphorus, solids removal, trickling filter.

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ABSTRACT

A media filter was constructed to treat swine wastewater after anaerobic lagoon treatment. The media filter consisted of a tank (1.5-m-diameter × 0.6-m-height) filled with marl gravel. The marl gravel had a carbonate content of 300 g kg^{-} Gravel particle size distributions were 85 and 14% in the 4.7- to 12.7-mm and 12.7- to 19-mm size classes,

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respectively. Pore space of the filtration unit was 57%. Wastewater flow rate was 606 L m^{-2} d^{-1}, and total Kjeldahl nitrogen (TKN) load was 198 g m^{-2} d^{-1}. The media filter removed 54% of chemical oxygen demand (COD) content after one cycle, but increased cycling did not produce additional COD reduction. Total suspended solids (TSS) removal after one cycle was 50% of initial levels, and additional cycling reduced TSS levels at a much lower rate of 7% per cycle. Removal efficiencies for total phosphorus (TP) ranged from 37% to 52% (one to four cycles), but long-term phosphorus removal would be limited by the sorption capacity of the gravel. Up to 24% of TKN was converted to nitrate-plus-nitrite-N (NO_3+NO_2-N). Effluents with high NO_3+NO_2-N levels can be treated further for denitrification with constructed wetlands or anaerobic lagoon. This is important in cases where land is limited for wastewater application.

INTRODUCTION

Wastewater from hog operations is typically treated and stored in anaerobic lagoons prior to land application. Limited land or long pumping distances between lagoons and application sites can reduce land treatment efficiency or be very expensive. Since over-application of lagoon wastewater may contaminate streams and shallow groundwater, treatment of lagoon liquid prior to land application is of major interest for the hog industry.

Lagoon liquids are rich in ammonia-N (NH_3-N) and phosphorus (P). Much ammonia-N in the lagoon is lost through volatilization and nitrification/denitrification processes. Nitrification is the most limiting factor in anaerobic lagoons and is a necessary step to convert excess NH_3-N into nitrogen gas (N_2). Nitrification is carried out by autotrophic bacteria that require adequate aeration, pH, and low levels of organic carbon. Media filters made of sand, rock fragments, or plastic material (widely known as trickling filters) have been extensively used for aeration treatment of municipal and industrial wastewater (U.S. EPA, 1971) and may provide sufficient aeration for nitrification of swine lagoon wastewater. Unlike N, P is not lost to the atmosphere; it remains in solution (organic and inorganic P) or tied to suspended matter in the wastewater. Therefore, P treatment relies on precipitation of solids or sorption to the media filter substrate.

Even though media filters have been used extensively for water treatment, limited data :xists on the use of media filters for treatment of livestock wastewaters (Loehr et al., 1973; Boiran et al., 1996). Our objective was to determine if a marl gravel media filter can provide effective treatment of anaerobic lagoon effluent. This study is part of a larger project to evaluate the sequencing of different land treatment methods (constructed wetlands, overland flow, and media filters) for renovation of swine wastewater in North Carolina (Humenik et al., 1995).

MATERIALS AND METHODS

Gravel Characterization Analyses

The marl gravel used in the media filter is a marine sediment composed of a mixture of clay, magnesium and calcium carbonates, and shell fragments. Average particle size distribution was estimated by sieving (Gee and Bauder, 1986). Bulk density and specific gravity were measured by the core and submersion methods, respectively (Blake and Hartge, 1986). Carbonate content was estimated gravimetrically by comparing the loss of weight (upon addition of hydrochloric acid) of a gravel sample with that of a standard series of analytical grade calcium carbonate (Houba et al., 1986). An equilibrium isotherm experiment was performed to determine the P sorption capacity of the gravel (Fox and Kamprath, 1970). Triplicated 10 g samples of air dried gravel weights were placed in 250 mL polyethylene bottles. One-hundred-milliliter aliquots of 0.1 M $CaCl_2$ solution containing one of six levels of phosphorus (0, 50, 200, 1000, 5000, and 10000 mg L^{-1}) were added. Bottles were capped and agitated continually for 24 hours in a horizontal position. After centrifugation (4000 × *g*, 15 minutes, 25 °C), P was determined in an aliquot of the supernatant liquid using the molybdenum blue-ascorbic acid method (Murphy and Riley, 1962). Phosphorus which disappeared from solution was considered to have been sorbed.

Media Filter

Wastewater effluent was provided by a single-stage anaerobic lagoon used to treat the manure generated by a pig nursery in Duplin Co., N.C. The media filter unit consisted of a 1.5-m-diameter × 0.6-m-height tank filled with marl gravel. The filtration unit was placed inside another tank with a slightly larger diameter that collected the effluent for recirculation. The wastewater flowed by gravity from the lagoon to a storage tank. The wastewater was pumped from the storage tank and applied onto the surface of the media filter with fixed sprinklers that provided a fine spray (Figure 1).

Lagoon wastewater was applied continuously and recirculated between the media filter and the storage tank up to four cycles or passes during six hours each day. Treated effluent was obtained with four passes through the filter. The experiment was repeated five times. The flow rate was 606 L m^{-2} d^{-1}. Mean application rates for TKN and TP were 198 and 50 g m^{-2} d^{-1}, respectively. The flow was measured with a mechanical flowmeter, and grab samples for water analysis were obtained at the end of each cycle. Water samples were packed in ice and sent to the laboratory where they were analyzed using EPA methods (U.S. EPA, 1983). Total Kjeldahl N, NO_3+NO_2-N, NH_3-N, and TP were analyzed with

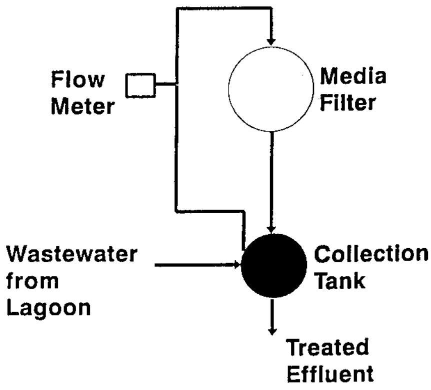

FIGURE 1

Schematic of the Marl Gravel Media Filter System.

a TRAACS 800 Auto-Analyzer using EPA methods 351.2, 350.1, 353.1, and 365.4, respectively. Total suspended solids, COD and pH were analyzed using EPA methods 160.3, 410.4, 150.1, respectively.

RESULTS AND DISCUSSION

Marl Gravel Characteristics

Although sand filters have become popular for small waste generators, especially where soil conditions are not suitable for subsurface disposal systems (Rubin et al., 1994), our filtration unit used marl gravel instead of sand to avoid clogging. The gravel size, bulk density and pore space characteristics (Table 1) allowed for very good natural aeration of the lagoon effluent, rapid vertical flow rates, and fast growth of biofilms. The marl gravel material had a 30% carbonate content (Table 1). Carbonates effectively bind with inorganic phosphorus and remove it from solution. Therefore, some phosphorus removal was expected

TABLE

Characteristics of the Marl Gravel

Parameter	Unit	
Gravel Size Distribution:		
12.7 - 19.0 mm	%	14.3
4.7 - 12.7 mm	%	85.4
< 4.7 mm	%	0.3
Bulk Density	kg m^{-3}	1167
Specific Gravity	kg m^{-3}	2716
Pore Space	%	57
Carbonate Content	g kg^{-1}	300

by sorption onto the gravel substrate since phosphorus in the wastewater was present mostly in inorganic forms (Humenik et al., 1995). The laboratory P sorption experiment indicated that marl gravel sorbed almost 100% of added soluble P up to a level of 10 mg P g^{-1} gravel but above this level the percentage of sorbed P decreased with increasing levels of added P (Figure 2).

At the highest level of 100 mg P g^{-1} gravel, about 30% of added soluble phosphorus was sorbed by the gravel material. These results demonstrate that the capacity of the marl gravel to sorb phosphorus is much larger than the sorption capacity of soil materials (Reddy et al., 1980) and similar to the sorption levels obtained when using iron rust (James et al., 1992).

Media Filter Experiment

The anaerobic conditions and organic content of the lagoon wastewater are indicated by the COD and NH_3-N concentrations (Table 2). Seventy four percent of the TKN was in NH_3-N form.

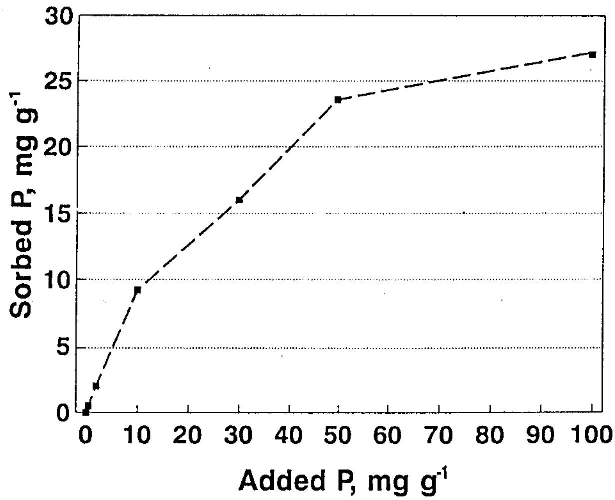

FIGURE 2

Sorbed Phosphorus versus Added Phosphorus per Gram of Marl Gravel (laboratory experiment). Data Points Represent Means (n=3), and Vertical Bars ± 1 Standard Error of the Mean (SEM).

TABLE 2

Characteristics of the Anaerobic Lagoon Wastewater.

Parameter	**Unit**	**Mean**	**SD***
Total Suspended Solids	mg L^{-1}	521	274
Chemical Oxygen Demand	mg L^{-1}	869	262
Total Kjeldahl Nitrogen	mg L^{-1}	327	36
Organic Nitrogen	mg L^{-1}	91	23
Ammonia-Nitrogen	mg L^{-1}	236	43
Nitrate-Nitrite-Nitrogen	mg L^{-1}	6	3
Total Phosphorus	mg L^{-1}	82	22
pH		8.2	0.4

* SD = Standard deviation (n = 5).

The media filter removed 54% of COD content after one cycle, but increased cycling did not produce additional COD reduction (Figure 3). Total suspended solids removal after one cycle was similar to COD at 50% of initial levels, and additional cycles reduced TSS levels at a much lower rate of 7% per cycle (Figure 3). A significant linear correlation between COD and TSS ($r^2 = 0.40$, $P < 0.01$) indicated that a substantial portion of COD is removed by sedimentation. Similar linear relationships between COD and TSS were reported by Tebbutt (1979); his data also show that substantial COD levels were removed from wastewater after primary sedimentation.

Data in Figure 4 indicate that wastewater with very high NH_3-N concentrations can be treated by media filtration to obtain significant reduction in TKN and NH_3-N. Nitrate-plus-nitrite-N concentration increased and NH_3-N and TKN decreased with increasing number of cycles through the media filter. The nitrification ratio (fraction of initial TKN converted to NO_3+NO_2-N) after four cycles was 24%. Organic nitrogen, which is shown in Figure 4 as the difference between the TKN and NH_3-N, was also reduced with increased number of cycles. Process conditions such as pH, temperature, and organic loadings were favorable for nitrifying bacteria to transform NH_3-N into NO_2+NO_3-N. Mean NO_2+NO_3-N concentration was 88 mg L^{-1} after four cycles a day. Water pH, an important parameter for nitrification, did not change significantly and remained buffered in the range of 8.0 to 8.5 units. The decrease in organic loading necessary for nitrification is further explained by the COD and TSS results in Figure 3.

Figure 5 shows that total P decreased with increasing number of cycles, and the trend was similar to the TSS and COD reduction curves (Figure 3). Although significant linear correlation was found between TP and TSS ($r^2 = 0.27$, $P < 0.05$), a stronger correlation was

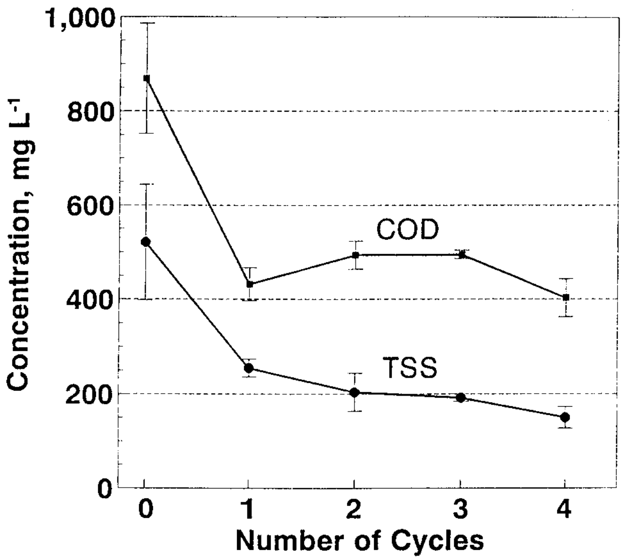

FIGURE 3

Changes in Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) Concentration with Number of Cycles. Data Points Represent Means (n=5), and Vertical Bars ± 1 SEM.

found between TP and COD ($r^2 = 0.88$, $P < 0.01$). These results indicate that a portion of TP and the suspended solids precipitated. Removal efficiencies for TP ranged from 37% to 52% with one to four cycles, respectively.

Results show that functioning of this media filter is analogous to recirculating sand filters that provide excellent biochemical oxygen demand (BOD) and suspended solids removal as well as an acceptable degree of nitrification (Hines and Favreau, 1975; Mote et al., 1991). Total P concentration only decreased rapidly with one cycle. This indicated that the media filter substrate had a limited P treatment capacity under field conditions.

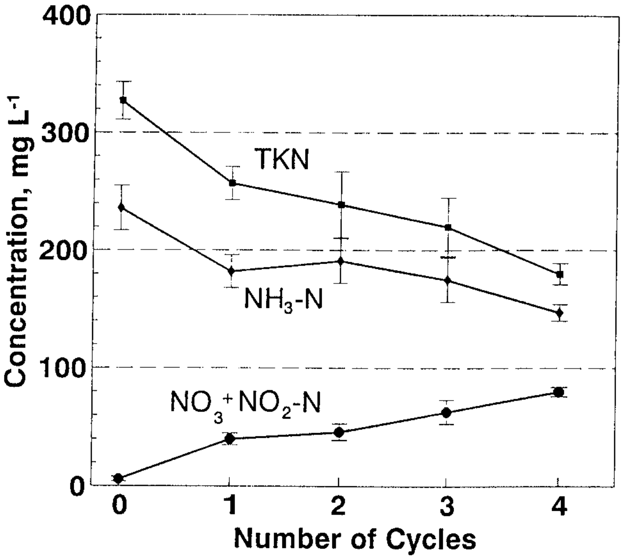

FIGURE 4

Changes in Total Kjeldahl N (TKN), Ammonia-N (NH_3-N) and nitrate+nitrite-N (NO_3+NO_2-N) Concentration with Number of Cycles. Data Points Represent Means (n=5), and Vertical Bars ± 1 SEM.

CONCLUSIONS

The media filter removed 54% of COD content after one cycle, but increased cycling did not produce additional COD reduction. Total suspended solids removal after one cycle was 50% of initial levels, and additional cycling reduced TSS levels at a much lower rate of 7% per cycle.

Conditions for nitrification were good with up to 24% of TKN converted to NO_3+NO_2-N and consequent reduction of NH_3-N when wastewater was recycled four times a day. Mean NO_3+NO_2-N concentration after four cycles was 88 mg L^{-1}.

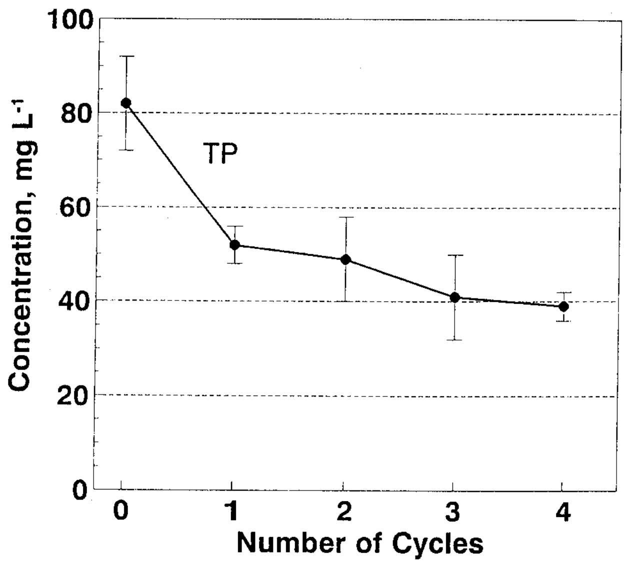

FIGURE 5

Changes in Total Phosphorus (TP) Concentration with Number of Cycles. Data Points Represent Means (n=5), and Vertical Bars ± 1 SEM.

Removal efficiencies for TP ranged from 37% to 52% (one to four cycles), but long-term P removal would be limited by the sorption capacity of the gravel.

Media filtration can be an acceptable method to treat lagoon wastewater if land is limited for nutrient application. This method may provide effluents with NO_3+NO_2-N levels that can be treated further in constructed wetlands or be returned to the anaerobic lagoon for denitrification.

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