The Society for engineering in agricultural, food, and biological systems

Paper Number: 01-2286
An ASAE Meeting Presentation

Comparison of Plastic Trickling Filter Media for the Treatment of Swine Lagoon Effluent

A. Morton, E.I.T.

Texas A&M Research & Extension Center, Amarillo, Texas; anissa97@excite.com

B. Auvermann, Ph.D.

Texas A&M Research & Extension Center, Amarillo, Texas; b-auvermann@tamu.edu

Written for presentation at the
2001 ASAE Annual International Meeting
Sponsored by ASAE
Sacramento Convention Center
Sacramento, California, USA
July 30-August 1, 2001

Abstract. *Plastic media trickling biofilter technology is being used on a pilot-scale to treat swine lagoon wastewater for use in a hydroponic greenhouse system. Two treatments of 9 filters each were installed to compare the treatment performance of commercially available Bioballs™ and recycled soda six-pack rings and to verify a mathematical description of nitrification in a trickling filter. Determining the effectiveness of trickling filters for nitrification of swine wastewater will allow producers to decide what level of treatment is most economical for their operation. A comparison of trickling filter media will help determine which of the media to be tested will provide the highest level of nitrification for the money. Sampling data under the initial design indicated that no detectable performance difference existed between the two treatments using a combined recycle stream. The system was redesigned to isolate the treatments, which will preserve the difference in performance between the Bioballs™ and six-pack rings. Other changes in system operation and in analytical methods will be implemented to ensure consistent and reportable results. Data collection will continue in an effort to correlate actual biofilter performance to model parameters.*

Keywords. swine lagoon; effluent; trickling filter; nitrification; hydroponics.

Introduction

The trickling filter was one of the first biochemical operations developed to treat municipal and industrial wastewater. Because trickling filter technology has historically been used for municipal wastewater treatment, the design parameters found in the literature are based on typical municipal wastewater characteristics. Since trickling filters have not often been used to treat high-strength animal wastewater, the development of design parameters for trickling filters to treat swine wastewater must start with the basics of attached growth processes and biofilm modeling.

The design goal for this project is to convert the ammonia present in the wastewater to an optimum level of nitrate for use as fertilizer in a hydroponic greenhouse. To accomplish this, we will determine operating parameters for swine wastewater for two different types of plastic filter media using pilot-scale trickling filters. These parameters will be used to optimize a mathematical model describing the process. Monitoring the system during operation will show how well the model describes actual filter operation.

Objectives

The purpose of the project is to compare types of plastic trickling filter media for use in treating third-stage swine lagoon effluent for use in a hydroponic greenhouse system. Specifically, the media to be compared are commercially produced Bioballs™ and recycled soda six-pack rings. The objectives are:

1. To mathematically describe nitrification in a trickling filter.
2. To compare the nitrification efficiency of Bioballs™ and six-pack rings.

Significance

As wastewater regulations become more stringent on confined animal feeding operations and land application of wastewater, producers need more alternatives for economical onsite animal waste treatment. Determining the effectiveness of trickling filters for nitrification of swine wastewater will allow producers to decide what level of treatment is most economical for their operation. For this project specifically, a fairly high level of treatment is needed to use the effluent in a hydroponic greenhouse. A comparison of trickling filter media will help determine which of the media to be tested will provide the highest level of nitrification for the money.

Background

Because trickling filter technology has historically been used for municipal wastewater treatment, design parameters found in the literature are based on typical municipal wastewater characteristics. Trickling filter design criteria for applied design are based on the assumption that the filter will be used in a full-scale municipal treatment plant (Grady, 1999, Metcalf & Eddy, 1991). Hobby aquarium owners have used trickling filters on a small scale, but no data exists to support word-of-mouth claims as to what media type gives the best treatment performance.

Theoretical models for trickling filter performance have not correlated well with actual plant scale performance (Metcalf & Eddy, 1991). Most wastewater treatment plants rely on pilot-scale tests to determine operating parameters, which then are enlarged to full plant scale operation. This essentially is empirical design. There are several widely used empirical trickling filter models, but each is specific to wastewater type, media type or filter depth. Because swine lagoon effluent has a vastly different composition than municipal wastewater, the empirical design parameters for plastic media found in literature could not be used to design the filters for this project.

Wastewater Composition

The wastewater stream in this project is from a third-stage treatment lagoon treating swine wastewater. The wastewater averages about 130 mg/L BOD_5, 823mg/L COD, 530 mg/L NH_3-N, and 621 mg/L TKN. An estimate of the BOD_5/COD ratio of this wastewater is 0.158, whereas typical untreated domestic wastes range from 0.4 to 0.8 BOD_5/COD (Metcalf & Eddy, 1991).

Nitrification

Nitrification in trickling filters has been found to follow typical saturation kinetics. It is a two-step aerobic process, which first oxidizes ammonia to nitrite. According to Metcalf & Eddy (1991), this reaction seems to control the overall conversion process, since nitrite does not build up in the system. Initial sampling data from this study indicates that nitrite peaks in the system in the fourth week of operation. In the second step of nitrification, nitrite is converted to nitrate by *Nitrobacter*. The nitrification process does not remove nitrogen from the system, but fully satisfies its oxygen demand (Metcalf & Eddy, 1991).

Denitrification

The process of denitrification is accomplished by several types of heterotrophic bacteria under anoxic conditions. These bacteria are capable of dissimilatory nitrate reduction, which is a two-step process. In the first reaction, nitrate is converted to nitrite and the second reaction produces nitrogen gas (Rudiger & Sekoulov, 1994). The enzymes that catalyze denitrification are suppressed by the presence of dissolved oxygen. It may be difficult to maintain a high denitrification rate in the biofilters because of the presence of oxygen (Metcalf & Eddy, 1991). Preliminary data shows the average filter effluent DO concentration to be approximately 4.5 mg/L. (Metcalf & Eddy, 1991).

Methodology

To size the experimental trickling filters, the Schultz-Germain equation (Metcalf & Eddy, 1991) for trickling filter design was used:

$$\frac{S_e}{S_i} = e^{(-k_{20} D (Q_v)^{-n})} \qquad (1)$$

where: S_e = effluent BOD (mg/L)

S_i = influent BOD (mg/L)

k_{20} = reaction constant at 20 °C (day^{-1})

D = filter depth (m)

Q_V = flow rate per unit cross-sectional area (m^3/day per m^2)

n = experimental constant (0.5 for plastic media)

The reaction constant depends on the specific surface area of the filter media. Six-pack rings have an estimated specific surface area of 557.5 m^2/m^3 (170 ft^2/ft^3) compared to 321.5 m^2/m^3 (98 ft^2/ft^3) for 1.5-in Bioballs™.

The following equation governs the reaction constant:

$$k_{20} = K_T A_S \qquad (2)$$

where: K_T = reaction rate constant (m/day)

A_S = specific surface area (m^2/m^3)

Due to space constraints, the experimental trickling filters were constructed from 30.5-cm (12-in) diameter PVC pipe with a maximum length of 1.98 m (6.5 ft). The Bioballs™ reach a height of 1.52 m (5 ft) inside the pipe. The pipe was stood on end and arranged in two sets of nine columns each. To achieve a similar effective surface area for both treatments, 6.35 kg (14 lbs) of six pack rings were used in each biofilter.

Using an average influent BOD concentration of 130 mg/L, a target effluent BOD concentration of 15 mg/L and a flow rate of 74.9 $m^3/day*m^2$ (1 gpm), the expected BOD reaction rate constant for Bioballs™ is 0.038 m/day and for six pack rings is 0.022 m/day.

Lagoon effluent is pumped into a recycling reservoir beneath each treatment, and then pumped up through the distribution system to the trickling filters as shown in Figure 1.

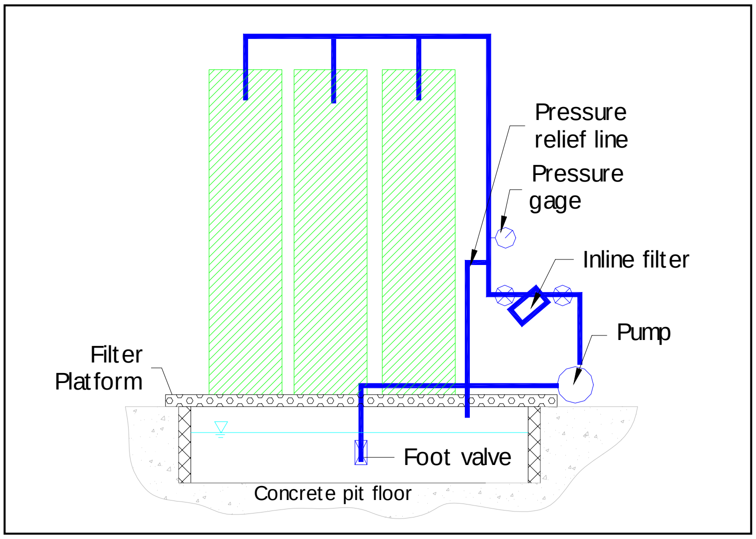

Figure 1: Treatment schematic

Senninger sprinkler heads with No. 7 emitters calibrated to deliver 3.8 L/min (1 gpm) at 16 psi distribute water onto the media surface in each filter.

Two 9-µm inline filters (Figure 1) remove larger particles to help prevent the sprinkler emitters from clogging. Because of the high solids concentration of in the lagoon effluent, the inline filters must be rinsed out every other day to ensure consistent flow rates.

Grab samples are collected from the recycle reservoirs and the outlet of each filter on a weekly basis to monitor filter performance. Samples are analyzed for ammonia-N, nitrite-N, and COD using a Hach DR/4000 Spectrophotometer and for nitrate-N using a Hach DR/2000 Spectrophotometer. After problems were encountered with the DR/2000, nitrate-N samples were reanalyzed using the DR/4000, as discussed in the Analysis section below. BOD_5 analysis is done using Standard Methods. Temperature, pH and dissolved oxygen readings are taken at the time of sample collection using portable units.

System analysis

Sampling data from the first five weeks of system operation were statistically analyzed to determine whether a significant difference existed between the performances of the two treatments. The system was initially constructed with a common recycle reservoir supplying influent to both treatments through a common distribution system (Figure 2). It was hypothesized that with continuous system operation, any difference between the two treatments would be washed out because the effluent from both treatments was mixed together before being recycled. Effluent ammonia concentrations from the nine filters in each treatment were averaged to obtain a single effluent ammonia concentration for each treatment. These values were then compared using the Student-T test at a 95% confidence level.

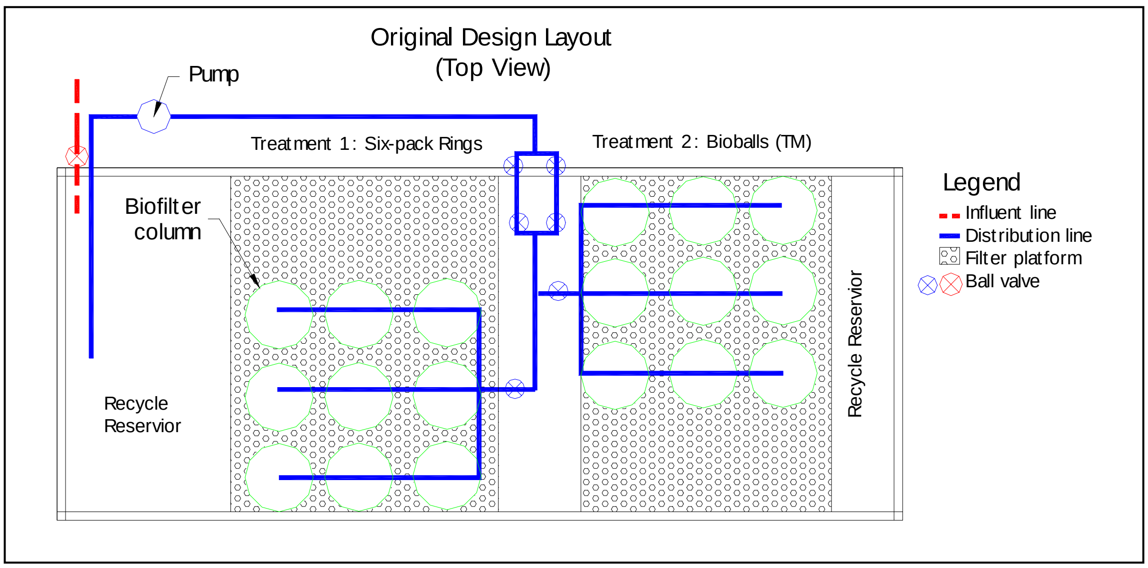

Figure 2: Original Design Layout

The results from the Student-T test at $\alpha = 0.5$ showed that after the fourth week of operation, no significant difference existed between the performance of the two treatments. After the fifth week of operation, the system was shut down due to cold weather and the system was redesigned (Figure 3).

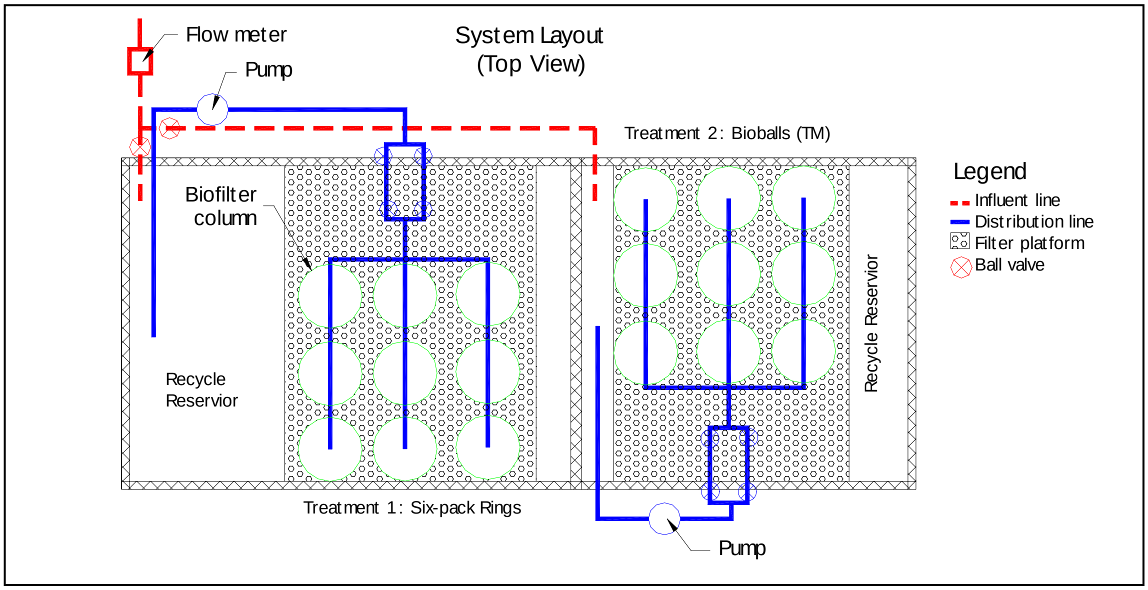

Figure 3: Redesigned distribution system

The recycling reservoir was split into two separate tanks with separate distribution systems for each treatment. It is anticipated that by keeping the effluent flows separate, a performance difference between the Bioballs™ and six-pack rings will be more apparent after continuous operation.

Model development

To develop a general mathematical description for nitrification in the trickling filter system, mass balances were performed on water, ammonia-N, nitrate-N and nitrite-N for a single isolated treatment. To arrive at an initial model, several assumptions were made:

- The filters have reached a steady operating state.
- The nitrogen concentration profile from top to bottom inside the biofilters is linear.
- The BOD concentration has been reduced to 15 to 20 mg/L.

An analysis of the sample results should reveal the true nitrogen concentration profile, which would add another degree of difficulty to the model.

Water balance

The water balance equation is:

$$-\frac{dV_B}{dt} = E \qquad (3)$$

where: V_B = volume of liquid in biofilter (m^3)

E = evaporation rate from the reservoir surface (m^3/s)

t = time (s)

Nitrogen balance

The system mass balance for the three forms of nitrogen is represented by the following equation, accounting for the assumption stated above:

$$R_V = -\frac{d}{dt}\left[V_R(t)\left(C_{RA}(t)+C_{RN2}(t)+C_{RN3}(t)\right)+\frac{V_B m}{2}\left(C_{iA}(t)+C_{eA}(t)+C_{iN2}(t)+C_{eN2}(t)+C_{iN3}(t)+C_{eN3}(t)\right)\right]$$
$$-S_R(t)\mathrm{X}_{RN}(t) \tag{4}$$

where: R_V = mass transfer rate (g/s)

$V_R(t)$ = volume of liquid in recycle reservoir (m^3)

$C_{RA}(t)$ = ammonia-N concentration in the reservoir (mg/L)

$C_{RN2}(t)$ = nitrite-N concentration in the reservoir (mg/L)

$C_{RN3}(t)$ = nitrate-N concentration in the reservoir (mg/L)

m = number of filters per treatment

$C_A(t)$ = biofilter ammonia-N concentration (mg/L)

$C_{N2}(t)$ = biofilter nitrite-N concentration (mg/L)

$C_{N3}(t)$ = biofilter nitrate-N concentration (mg/L)

i = influent at top of biofilter

e = effluent at bottom of biofilter

$S_R(t)$ = mass sludge in recycle reservoir (g)

$X_{RN}(t)$ = nitrogen concentration in sludge (mg/g)

The biofilter mass balance for nitrogen is presented by the following equation:

$$R_V = \frac{q}{2}\left(C_{eN} - C_{iN}\right)+V_R(t)\left(K_{VA}C_{RA}(t)+K_{VN2}C_{RN2}(t)+K_{VN3}C_{RN3}(t)\right) \tag{5}$$

where: q = flow rate through biofilter (m^3/s)

C_N = biofilter nitrogen concentration (mg/L)

K_{VA} = ammonia-N mass transfer coefficient (s^{-1})

K_{VN2} = nitrite-N mass transfer coefficient (s^{-1})

K_{VN3} = nitrate-N mass transfer coefficient (s^{-1})

Recognizing that:

$$C_{iN} = C_{RN} \tag{6}$$

and

$V_B = A_{eff}{*}z$ (7)

where: A_{eff} = effective surface area of biofilter media (m^2)

z = thickness of liquid film in biofilter (m)

Setting (4) equal to (5), substituting in (6) and (7), collecting terms and integrating over time, gives:

$$\frac{q}{2}\int_0^t C_{eN}(t)dt - V_E(t)C_{susN}(t) = -V_R(t)C_{RN}(t) + K_{VA}\int_0^t V_R(t)C_{RA}(t)dt + K_{VN2}\int_0^t V_R(t)C_{RN2}(t)dt$$

$$+ K_{VN3}\int_0^t V_R(t)C_{RN3}(t)dt + \int_0^t S_R(t)\mathrm{X}_{RN}(t)dt + \frac{q}{2}\int_0^t C_{RN}(t)dt - \frac{A_{eff}zm}{2}(C_{RN} + C_{eN}) \quad (8)$$

Most of the variables in the model can be measured and book values can be used for the mass transfer coefficients, leaving two equations, (3) and (8), and two unknowns: A_{eff}, effective surface area of the biofilter media and z, the thickness of the liquid film in the biofilter.

Analysis

The original system with combined treatments was operated for five weeks starting in November 2000. At system start, influent from the lagoon was diluted with fresh water, but no other fresh water was added to the system after that. Lagoon water was added periodically on an as-needed basis during operation. Four complete sample sets were collected. Table 1 shows the percent change in concentrations from the top to the bottom of the filter and Table 2 shows the average effluent concentrations for pH, BOD_5, COD, NH_3-N, NO_3-N and NO_2-N for each treatment.

Table 1: Percent change in concentration from top to bottom of filter

Table 2: Average effluent concentrations at the bottom of filter

Bioballs			**Concentration (mg/L)**			
Date	**pH**	**BOD5**	**COD**	**NH3-N**	**NO3-N**	**NO2-N**
2-Nov-00	9.46	72.82	1309.93	18.62	2.14	0.02
16-Nov-00	9.86	19.92	2726.59	1.50	1087.15	150.00
30-Nov-00	9.70	92.36	2335.11	2.25	923.81	299.38
9-Dec-00	--	52.99	2221.85	1.30	926.78	79.45

Six pack rings				**Concentration (mg/L)**		
Date	**pH**	**BOD5**	**COD**	**NH3-N**	**NO3-N**	**NO2-N**
2-Nov-00	9.53	73.00	1361.21	20.57	2.81	0.07
16-Nov-00	9.85	39.52	2651.42	2.08	1033.58	175.00
30-Nov-00	9.70	76.24	2352.50	2.17	925.04	309.20
9-Dec-00	--	49.49	2234.25	1.97	945.25	78.62

The absence of any observable trends in the data is due to several factors inherent in the original design of the system and to problems with laboratory analysis. Metcalf & Eddy (1991) report that trickling filters usually take about four weeks of continuous operation to reach a steady operating state. The system was shut down once during operation for three days for repairs and then was shut down for the winter after the fifth week of operation. It is likely that the filters were just beginning to reach a steady operating state at this point.

Besides supplying influent for the trickling filter system, the lagoon pump supplies flush water to all of the swine buildings on the property on a continuous basis, resulting in inconsistent flow rates. This made it necessary to add lagoon water to the system as needed, rather than using a continuous influent stream. It is likely that these periodic additions of lagoon water acted as shock loads to the system, contributing to the sharp percent increases in NH_3-N and BOD_5 shown in Table 1. Converting over to scheduled additions of lagoon water may reduce the impact of these shock loads on filter performance.

Bioballs				**% Change**		
Date	**pH**	**BOD5**	**COD**	**NH3-N**	**NO3-N**	**NO2-N**
2-Nov-00	-0.47%	4.40%	-6.41%	-10.09%	8.66%	-45.22%
16-Nov-00	0.57%	3.85%	-2.55%	-16.87%	12.00%	-11.99%
30-Nov-00	-1.02%	55.49%	-0.58%	40.63%	-4.00%	-2.17%
9-Dec-00	--	4.84%	2.48%	-23.31%	-9.05%	4.23%

Six pack rings				**% Change**		
Date	**pH**	**BOD5**	**COD**	**NH3-N**	**NO3-N**	**NO2-N**
2-Nov-00	0.26%	4.65%	-2.75%	-0.72%	42.80%	0.00%
16-Nov-00	0.51%	105.95%	-5.24%	15.28%	6.48%	4.15%
30-Nov-00	-1.02%	28.36%	0.16%	35.42%	-3.88%	1.04%
9-Dec-00	--	-2.07%	3.06%	15.93%	-7.24%	3.13%

Several problems were encountered with analytical methods and equipment. After running several NO_3-N standards and developing quality control charts using the Hach DR/2000 spectrophotometer, it was determined that the machine was out of calibration and giving abnormally high readings. All four sample sets were reanalyzed for NO_3-N and NO_2-N in May 2001 using a Hach DR/4000 spectrophotometer, after several months in storage at 4°C. These results are reported in Table 2. All other tests were originally performed using the DR/4000, so no reanalysis was required. It is unknown how much the samples degraded while in storage, so the data gained from the reanalysis is for illustrative purposes only.

The high concentration values for NO_3-N also may be attributed to a high solids concentration in the effluent samples. Although no data on solids is reported here, it is likely that the biomass sloughed off of the filter media contains significant amounts of NO_3-N. More representative results for all constituents may be obtained by settling the solids out of solution using an Imhoff cone and only analyzing the supernatant.

Conclusion

Plastic media trickling biofilter technology is being used on a pilot-scale to treat swine lagoon wastewater for use in a hydroponic greenhouse system. Two treatments of 9 filters each were installed to compare the treatment performance of commercially available Bioballs™ and recycled soda six-pack rings. Sampling data under the initial design indicated that no detectable performance difference existed between the two treatments using a combined recycle stream. The system was redesigned to isolate the treatments, which will preserve the difference in performance between the Bioballs™ and six-pack rings. Other changes in system operation will include scheduled lagoon water additions and minimized shut downs for maintenance and repair. Changes in analytical methods will include settling solids out using an Imhoff cone prior to sample analysis and performing regular calibration checks on all equipment to ensure data quality. Data collection will continue in an effort to correlate actual biofilter performance to model parameters.

Acknowledgements

Thanks to Higley Farms, Inc., for their cooperation on this project.

References

Grady, C. P. L., et al. 1999. Biological Wastewater Treatment. 2nd Ed. Marcel Dekker, Inc.: New York.

Metcalf & Eddy, Inc. 1991. Wastewater Engineering: Treatment, Disposal and Reuse. Edited by G. Tchobanoglous and F. L. Burton. 3rd Ed. McGraw-Hill, Inc.: New York.

Rudiger, A., and I. Sekoulov. 1994. Denitrification in trickling filters. Nutrient removal from wastewaters. Edited by N.J. Horan, P. Lowe, and E.I. Stentiford. Technomic Publishing Co.: Lancaster, Pa.