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EVALUATION OF NITRIFICATION PERFORMANCE OF A TRICKLING FILTER WITH NYLON POT SCRUBBER AS MEDIA

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ABSTRACT

Performance of a trickling filter with nylon pot scrubber as a media was evaluated at different inlet ammonium-nitrogen concentrations (0.5 – 3.5 g/m^3) and flow rates (3 – 10.5 L/min) in terms of its ammonium removal efficiency and nitrification rate. The ammonium removal efficiency and nitrification rates ranged between 28 – 68% and 0.11 – 1.29 g/m^2/day respectively. Further, regression models were developed for evaluating the ammonium removal efficiency and nitrification rates based on input ammonia nitrogen and flow rates.

KEYWORDS: Trickling filter, nylon pot scrubber, nitrification rate, ammonium removal efficiency

INTRODUCTION

It is a well known fact that nitrogen in the form of ammonia and nitrite needs to be removed from wastewater; potable water and water reuse systems. In fact these nitrogenous compounds add up the oxygen demand, popularly known as nitrogenous oxygen demand, which reduces the dissolved oxygen in the water body when discharged. They are found to be particularly toxic in case of aquatic organisms and may also lead to eutrophication. In case of potable water treatment, ammonia needs to be removed before water is disinfected with chlorine, as ammonia reacts with chlorine to produce chloramines which are known to be carcinogenic (Bull et al., 1990).

Nitrogenous wastes may be removed from water using chemical or biological methods. There are two well known chemical methods: adsorption using activated carbon and ion exchange using clinoptilolite. In both the methods cost of regeneration is a real issue. But it is generally agreed that biological nitrification is the most feasible method of removing ammonia from water (Tekerlekopoulou and Vayenas, 2008). In case of biological removal, living microorganisms are utilized to oxidize ammonia and nitrite to nitrate (nitrification) and subsequently nitrate is converted to nitrogen gas (denitrification). Nitrification is carried out by two different consecutive microbial processes, nitritification and nitratification. In nitritification, ammonia is converted to nitrite due to its oxidation by the bacterial genera *Nitrosomonas.* In nitratification, *Nitrobacter* converts nitrite to nitrate. *Nitrosomonas* and *Nitrobacter* are aerobic and autotrophic bacteria and are characterized by low specific growth rates. (Vayenas *et al.,* 1997). Effective nitrification depends mainly on media and the hydraulic characteristics of the biofilter. Various types of biological filters are used for nitrification (van Rijn, 1996) such as submerged filter, trickling filter, rotating biological filter, fluidized bed bioreactor etc. Potable water as well as aquaculture wastewater has a relatively low concentration of pollutants compared to domestic wastewater. Thus bacterial biomass yield in treatment of such wastes is very low. To treat this type of water, bioreactor with a high bacterial cell residence time is required. Fixed film reactor such as trickling filter shows this type of special characteristic (Bovendeur et al., 1990; Eding et al., 2006). The trickling filters are very popular in potable water and aquaculture wastewater treatment due to its following advantages (Eding *et al*., 2006): i) requirement of minimal aeration, (2) degassing removes CO_2 and thus pH is maintained; (3) water cooling in hot climate; and (4) simplicity of design, construction, operation and management.

Many research works were conducted on trickling filter for removal of nitrogenous wastes from potable as well as aquacultural wastewater. Vayenas and Lyberatos (1994) developed a mathematical model for a nitrifying trickling filter and further, Vayenas and Lyberatos (1995) presented a practical graphical method for the design of nitrifying trickling filters for potable water treatment. Nijhof (1995) developed a model describing the performance of nitrifying biofilm reactors in treating aquacultural waste. It was found that for a certain inlet ammonia concentration, the hydraulic biofilm loading rate is a key variable influencing the overall biofilter nitrification performance, within a wide range of filter dimensions. Kamstra et al. (1998) validated the Nijhof model for a range of full scale trickling filters and assessed the performance of trickling filters at 14 commercial eel farms in The Netherlands. Lekang and Kleppe (2000) studied the effect of types of media on efficiency of nitrifying trickling filters. Three sizes of crushed Leca (dried expanded clay) and three types of plastic media (Kaldnes rings, Norton rings, and a rolled mat of Finturf artificial grass) were tested in columns of 1.5 m high and 11 cm in diameter. Synthetic water containing 1.5 g/m^3 total ammonia nitrogen (TAN) and 1 g/m^3 of PO_4^{3-} was added at a rate of 0.5 L/min and a temperature of 15°C. The nitrogen removal efficiency for the Leca fraction columns, Kaldnes ring columns, Norton ring columns and artificial grass columns were found to be 100%, 80%, 60% and 40% respectively.

Vayenas et al. (1997) developed a dynamic model describing nitritification and nitratification in trickling filters. Tekerlekopoulou and Vayenas (2007) evaluated the performance of pilot scale trickling filters in terms of simultaneous removal of ammonia, iron and manganese from potable water. Akker et al. (2008) investigated the efficacy of high rate, plastic-packed trickling filters as a pre-treatment process to remove low concentrations of ammonia from polluted surface water.

The available literatures show that nitrification efficiency of trickling filters primarily depends on filter media type, inlet ammonium–nitrogen concentration and hydraulic loading rate. In the present study nitrification performance of a pilot scale trickling filter with nylon pot scrubber as the media was studied. Nylon pot scrubber was selected as the media due to its high specific surface area (1213 m^2/m^3), cost effectiveness and easy availability (http://www. wernersponds.com/biofiltermedia.htm).

MATERIALS AND METHODS

Three cylindrical acrylic columns of diameter 90 mm and height 1800 mm were fabricated and filled up with nylon pot scrubber media to a height of 160 cm with a freeboard of 20 cm to act as trickling filters (Vayenas and Lyberatos, 1994). The filter columns were also covered with black paper to prevent algal growth. A provision for diffused-air aeration was made at the bottom of the columns to supply air with a flow rate of 6 L/min. A water spraying mechanism was used for uniform distribution of effluent over the top surface of the columns. Initially these columns were inoculated with a synthetic substrate containing ammonium chloride, sodium bicarbonate and other necessary nutrients (Zhu and Chen, 2001) and run in batch mode for around two months for optimum growth of nitrifiers.

To evaluate the nitrification performance of the filters, ammonia solutions of various concentrations were prepared in a tank ($0.7 \times 0.5 \times 0.45\ m^3$) located beside the filters. The ammonia solution was fed at the top of the filter columns through a 0.5 HP pump. It was found that the support material was not flooded for flow rates up to 10.5 L/min. Thus the filters were tested for their nitrification performance at different inlet ammonia concentrations (0.5 – 3.5 g/m^3) operated at different flow rates (3 – 10.5 L/min.). Samples were collected from the outlets of the filters for measurement of ammonium-, nitrite- and nitrate-nitrogen concentrations using a HACH spectrophotometer (Model DR2500) following Standard Methods (APHA et al., 1985). Dissolved oxygen measurements were made using three YSI 55 DO meters. The dissolved oxygen concentration in the bulk liquid was always maintained above 6 g/m^3. Occasionally, sodium bicarbonate was added to the filter columns to maintain the pH within 7.5 – 8.5. A schematic diagram showing all the components of the experimental setup is shown in Fig. 1.

Determination of ammonium removal efficiency and nitrification rates

The performance of the trickling filters in triplicate was evaluated at various flow rates (3 – 10.5 L/min.) and inlet NH_4^+-N concentrations (0.5 – 3.5 g/m^3) in terms of their nitrification rates and removal efficiency. The nitrification rate and NH_4^+-N removal efficiency can be expressed in the following forms:

Nitrification rate = $[(NH_4^+\text{-}N)_i - (NH_4^+\text{-}N)_o] \times$ flow rate/surface area of filter media …(1)

Surface area of filter media (S) = effective volume of tickling filter (VF) × specific surface area of filter media (SSA) … (2)

The nitrification rate was corrected for temperature using the following equation (Bovendeur et al., 1987):

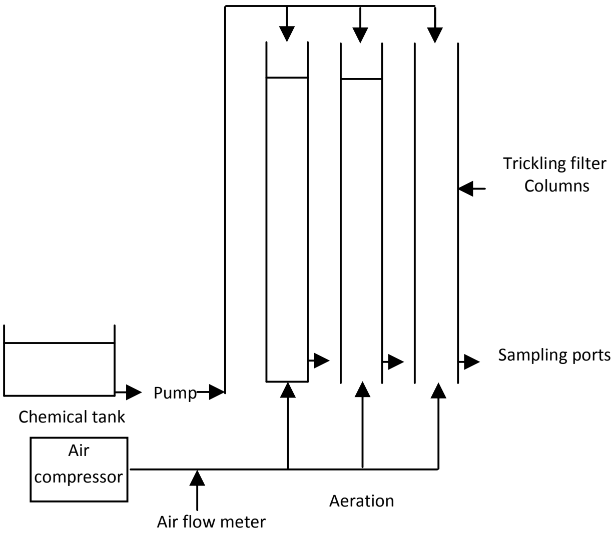
$(\text{Nitrification rate})_{20} = (\text{Nitrification rate})_T \times \theta^{(20-T)}$ …(3)

where, subscript 20 and T denote temperature in °C and θ = temperature activity coefficient = 1.08.

NH_4^+-N removal efficiency (%) = $100 \times [(NH_4^+\text{-}N)_i - (NH_4^+\text{-}N)_o] / (NH_4^+\text{-}N)_i$ ...(4)

where the subscripts 'i' and 'o' denote inlet and outlet respectively.

FIGURE 1. Schematic diagram of the experimental setup for testing the performance of trickling filter



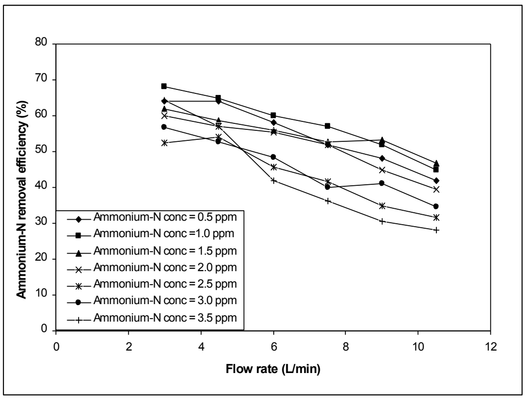
RESULTS AND DISCUSSION

Performance evaluation of trickling filter

Batch operation of trickling filter consisted of a substrate solution containing ammonium chloride, sodium bicarbonate and other necessary nutrients (Zhu and Chen, 2001) in the filter column operated in batch mode for optimum growth of nitrifiers. In the present study, the batch operation took almost 2 months, after which the filters were ready for continuous operation.

After completion of the batch culture, performance of the trickling filters was evaluated in triplicate at various flow rates (3 – 10.5 L/min) and inlet ammonium-nitrogen concentrations (0.5 – 3.5 g/m^3). The temperature ranged between 22 and 25°C. The variations of ammonium removal efficiencies with flow rates at different inlet NH_4^+-N concentrations are shown in Fig. 2.

FIGURE 2. Variation of ammonium-nitrogen removal efficiency with flow rates at different inlet ammonium-nitrogen concentrations

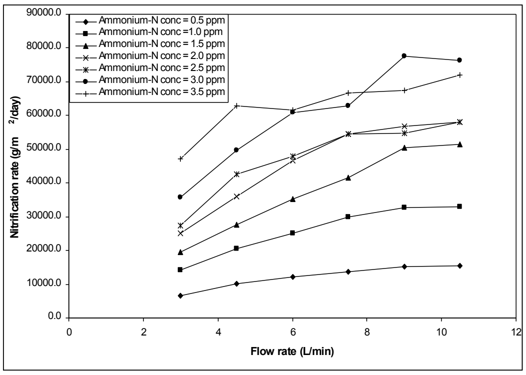


It can be seen from the figure that the ammonium removal efficiency decreases with increase in flow rate. It is due to the fact that at high flow rates, detention time of the effluent decreases leading to lesser removal efficiency. The ammonium removal efficiency ranged from 28% to 68%, the average being 50%, which is generally considered to be very high (Lekang and Kleppe, 2000). A regression model was developed to evaluate the ammonium removal efficiency (E) as a function of input ammonium-nitrogen concentration (NH_4^+-N_{in}) and flow rate (FR) as follows:

$$E = 0.0415/NH_4^+\text{-}N_{in} + 59.8 \times \exp(-5659 \times FR) - 0.15 \times 10^{-4}/ NH_4^+\text{-}N_{in}^2 \qquad (R^2 = 0.88) \qquad ...(5)$$

The nitrification rate generally decides the size of a biofilter. The more the value, the less will be the size required. The variations of nitrification rates with flow rates at different inlet NH_4^+-N concentrations are presented in Fig. 3.

FIGURE 3. Variation of nitrification rate with flow rate at different inlet ammonium-nitrogen concentrations



It shows that the nitrification rate increases with increase in flow rate and inlet NH_4^+-N concentrations. At high NH_4^+-N concentrations and flow rates, mass inflow per unit time increases and hence nitrification rate also increases. The nitrification rates ranged between 0.11 and 1.29 g/m^2/day, the average being 0.7 g/m^2/day. Further, another regression model was developed to evaluate the nitrification rate (NR) as a function of NH_4^+-N_{in} and FR as follows:

$$12.17 \times NH_4^+\text{-}N_{in}^{(0.0138 \times FR^{-0.35})} - 6418 \times FR \qquad (R^2 = 0.96) \qquad ...(6)$$

Comparative nitrification performance of the present filter medium with other filter media

Nijhof (1995) studied the performance of a trickling filter filled with a random plastic filter medium (Filterpack CR50, Mass Transfer, England, specific surface area of 200 m^2/m^3) by varying the flow rates between 48.6 and 239.6 L/min. The nitrification rate ranged between 0.1 and 0.8 g/m^2/day. Greiner and Timmons (1998) tested 5.1 cm Norpak media (NSW Corporation, Roanoke, VA) of specific surface area 164 m^2/m^3 in pilot sized trickling biofilters. The nitrification rates ranged from 0.94 to 3.92 0.8 g/m^2/day for influent TAN concentrations between 0.81 and 4.63 g/m^3. Lekang and Kleppe (2000) used three sizes of crushed Leca (dried expanded clay) and three types of plastic media (Kaldnes rings, Norton rings, and a rolled mat of Finturf artificial grass) to determine the relative performance of these media in trickling filter. The nitrification rates were found to vary between 0.1 and 0.2 g/m^2/day. Thus, it can be observed that the nitrification rate offered by the nylon pot scrubber media is very much comparable with the other ones used in literature. The nylon pot scrubber media used in the study did not require any backwashing during the study period of around 3 months. Moreover, its cost effectiveness and easy availability makes it a lucrative one as a bio-media.

SUMMARY AND CONCLUSIONS

The objective of this study was to evaluate the performance of a trickling filter with nylon pot scrubber as a media. Initially batch operation was carried out for a period of 2 months introducing a substrate solution containing ammonium chloride, sodium bicarbonate and other necessary nutrients for supporting the growth of the bacteria. After the batch operation, performance evaluation of the trickling filters in triplicate was carried out at various flow rates (3 – 10.5 L/min) and inlet NH_4^+-N concentrations (0.5 – 3.5 g/m^3) for the determination of ammonium removal efficiency and nitrification rates. The results showed that the ammonium removal efficiency decreases with increase in flow rate, whereas the nitrification rate increases with increase in flow rate. The ammonium removal efficiency and nitrification rates were found to vary between 28 – 68% and 0.11 – 1.29 g/m^2/day respectively. Regression models were developed for evaluating the ammonium-nitrogen removal efficiency and nitrification rate. The nylon pot scrubber used in the present study did not require any backwashing during the study period of around 3 months. It also yielded reasonable ammonium removal efficiency and nitrification rates. Moreover, its cost effectiveness and easy availability makes it a lucrative one as a bio-media.

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