Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2015.1025584

57 (2016) 7555–7561
April

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Organic matter removal and nitrification using a woven hollow fiber tube as biological media

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Received 19 November 2014; Accepted 5 January 2015

ABSTRACT

Attached growth micro-organisms are known to be beneficial to the removal of low-concentration organic matter because they can have a long retention time due to their very slow growth rate compared with the suspended growth micro-organisms suitable for high-concentration organic substance treatment. In this study, the characteristics of the treatment of organic and nitrogen pollutants in low concentrations were investigated by injecting air into the inside of the tube, using a woven-hollow fiber tube as biological media. According to the changes in the hydraulic retention time, the biochemical oxygen demand (BOD) concentrations of the influent and the treated water were 29.8–37.6 mg/L and 8.6–18.5 mg/L, respectively. The suspended solid (SS) of the influent was 33.9–36.7 mg/L, and that of the treated water was 1.6–3.6 mg/L, showing a high SS removal efficiency of more than 90%. The investigation of the BOD and the NH_4^+-N removal efficiency according to the surface loading rate revealed that the effects caused by the increase in the surface loading rate are greater in NH_4^+-N than in BOD. The attached growth micro-organisms decreased by detachment after 20 d, and increased again, securing a constant amount of growth micro-organisms.

Keywords: Organic matter removal; Nitrification; Woven-hollow fiber tube; Biological media

1. Introduction

The stream water or secondary treated water of sewage treatment plants is known to have many limiting factors (e.g. sludge bulking and organic load conditions) in removing pollutants with suspended growth micro-organisms due to its low organic matter concentration compared to general stream water [1–3]. To solve this operational problem involving suspended growth micro-organisms, the biofilm process has been developed, along with the development of filter media; but an increase in the organic load or biofilm detachment phenomenon, which occurs due to the excessive growth of the attached growth micro-organisms, can result in pollutant removal efficiency reduction [4–6].

There are various factors that affect the maintenance of a biofilm, including the dissolved oxygen (DO), hydraulic retention time (HRT), temperature, substrate loading, biofilm thickness, and filter media

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Presented at IDW 2014 — The 7th International Desalination Workshop, November 5–8, 2014, Jeju, Korea

properties. Among these, the DO in the water exerts a significant effect on the nitrification and oxidation of organic materials [7,8]. With regard to the relationship between the DO and the biofilm, if the biofilm with attached growth micro-organisms becomes thicker, the surface of the biofilm—which may come in contact with the DO in the water—can be in an aerobic condition, the intermediate layer can be in an anoxic condition, and the portion that comes in contact with the membrane can be in an anaerobic condition, according to the oxygen-transfer rate of the thickened biofilm [9,10]. The anaerobic biofilm can suffer from the membrane and micro-organism detachment phenomena due to its limitations with regard to substrate diffusivity and oxygen transfer related to the thickness of the biofilm, and if the micro-organisms do not remain for a long time and are detached, the pollutant removal efficiency becomes lower.

In addition, the surface layer of the biofilm formed by micro-organisms is dominated mainly by heterotrophic micro-organisms, which grow faster and consume organic material as a carbon source, and the micro-organisms, which are autotrophic and grow slowly, can cause nitrification inhibition and detachment of the micro-organisms because they are formed in the much inner part of the biofilm [11,12].

If utilized in wastewater-containing pollutants with a relatively low concentration of organic materials, the biofilm can maintain its microbial activity and can provide habitat conditions suitable for micro-organisms with a slow growth rate [13–15]. The use of attached growth micro-organisms boasts advantages in that it is more resistant to temperature and shock loads than suspended growth micro-organisms, and makes it possible to conduct stable treatment even when the HRT is shorter [16].

Recent studies related to hybrid biofilms, such as moving bed biofilm reactors, biologically active filters, and integrated fixed-film activated sludge, sought to develop reinforced processes against low-concentration shock loads and prevent detachment of micro-organisms in biofilm [17–19].

Accordingly, this study was designed to examine the characteristics of the attached growth micro-organisms with the aim of removing the pollutants in a low-concentration influent by getting oxygen to be supplied to the inside of the tube and to the micro-organisms attached to the biofilm using an anaerobic biofilm in the form of a woven-hollow fiber tube, to prevent the detachment of the micro-organisms from the membrane surface due to anaerobic storage.

2. Materials and methods

2.1. Characteristics of hollow fiber tubes

The hollow fiber tube that was used in the experiment was fabricated in the form of a tube by weaving together several strands of yarn made of polypropylene (PP). It was designed in such a way as to induce micro-organisms to attach to its surface, and to ensure that the inside of the tube and the attached growth micro-organisms would not become anaerobic by injecting air into it, and that oxygen could be delivered to the attached growth micro-organisms by diffusing the DO injected into the tube (Fig. 1). Table 1 shows the physical properties of the hollow fiber tube with a 3 mm diameter and a 60 cm length fabricated to ensure the diffusion of air through the tube surface by the injected air.

2.2. Pilot plant operation and analysis

The pilot plant with a scale of 20 m^3 per day was used in the experiment, where a hollow fiber tube was

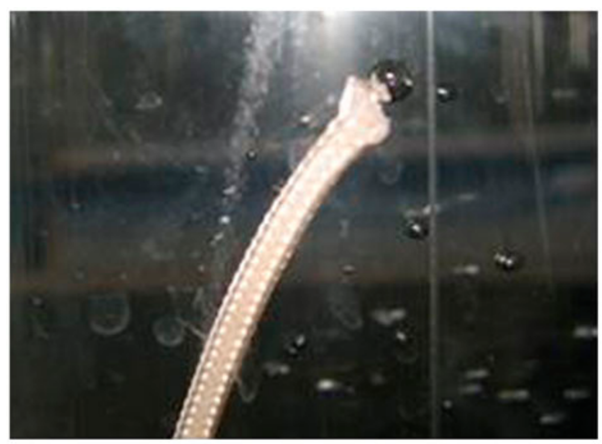

Fig. 1. Hollow fiber tube.

Table 1
Properties of the reactor with a hollow fiber tube

Items	Properties
Hollow fiber tube diameter (Ø, mm)	3
Hollow fiber tube length (cm)	60
Number of hollow fiber tubes (ea.)	6,560
Hollow fiber tube volume (cm^3)	27,807
Hollow fiber tube surface area (cm^2)	370,771
Reactor volume without a hollow fiber tube (L)	812.2
Reactor size (L × W × H, cm)	200 × 70 × 120

fixed onto the bottom of a reactor (Fig. 2). It was designed in such a way as to have the influent introduced into the bottom of the reactor and to have the treated water discharged into the top of the reactor by placing a partition in the middle of the reactor so that the influent could be in full contact with the micro-organisms attached to the tube. In addition, it was designed in such a way as to ensure that the air volume could be adjusted within the maximum amount of air in the reactor (160 L/min per partition), and to ensure that enough air could be supplied into the tube.

The influent that was used in the experiment was made by mixing the primary clarifier effluent from the sewage treatment plant with tap water. The experiment was performed in the environment affairs agency facility located in Ilsan domestic wastewater treatment plant, South Korea. In the experiment, the sample was analyzed according to the change in HRT after stabilizing it so that micro-organisms could attach to the hollow fiber tube at HRT 3 h during the initial 15 d, and the DO in the water was kept at 3–4 mg/L to maintain the thickness of the micro-organisms, and to optimize the organic matter removal and nitrification.

The operation conditions from pilot plant are shown in Table 2. The experiment was designed to gradually increase the pollution loads of the influent by reducing the HRT from 3 to 1 h. The analysis for biochemical oxygen demand (BOD), chemical oxygen demand (COD_{cr}), and suspended solid (SS) was done by following the standard methods [20]. Total nitrogen (T-N), NH_4^+-N, and NO_3^--N were determined by HACH spectrometer (DR/4000). The hollow fiber tube containing micro-organisms has been cut into similar lengths in such a way that the micro-organisms do not detach from hollow tube in the four reactors. The amount of micro-organisms in the reactor has been filtered with the GF/C filtering paper after washing the micro-organisms in the cut tube. The difference before and after drying was calculated in terms of weight.

3. Results and discussion

3.1. Removal of organic matter

Fig. 3 shows the organic matter concentration and removal efficiency according to the changes in HRT. With regard to the average values with various HRTs (from HRT 3 to 1 h), the BOD concentration of the influent was 29.8–37.6 mg/L and that of the treated water was 8.6–18.4 mg/L. The BOD removal efficiency had a tendency to gradually decrease from 70.4 to 50.3%. The COD_{cr} concentration of the influent was 44.9–53.6 mg/L and that of the treated water increased from 13.1 to 31.2 mg/L with a decrease in HRT. The COD_{cr} removal efficiency was similarly reduced from 70.6 to 41.0%, showing a similar tendency as BOD. In both BOD and COD_{cr}, the removal efficiency was found to decrease depending on the HRT reduction. The treated water

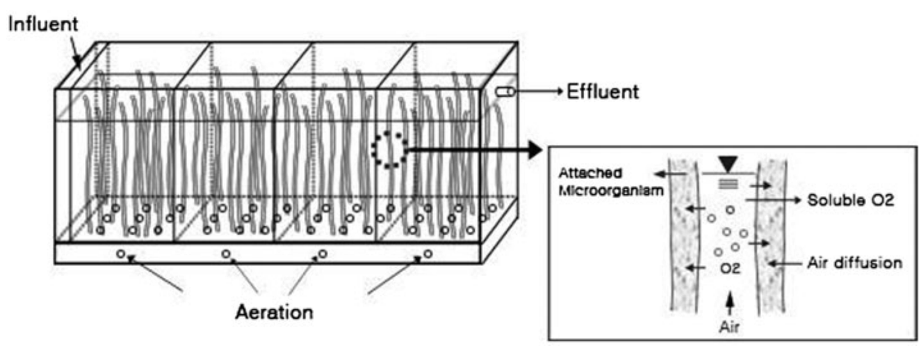

Fig. 2. Pilot plant equipped with woven-hollow fiber tubes.

Table 2
Operation conditions of the reactor

HRT (h)	BOD (mg/L)	BOD loading rate (kgBOD/d)	COD_{cr} (mg/L)	COD_{cr} loading rate (kgCOD/d)	NH_4^+-N (mg/L)	NH_4^+-N loading rate (kgNH_4^+-N/d)
3	29.9	0.20	44.9	0.30	6.18	0.04
2	35.8	0.36	51.1	0.51	6.98	0.07
1	37.6	0.76	53.6	1.08	6.86	0.14

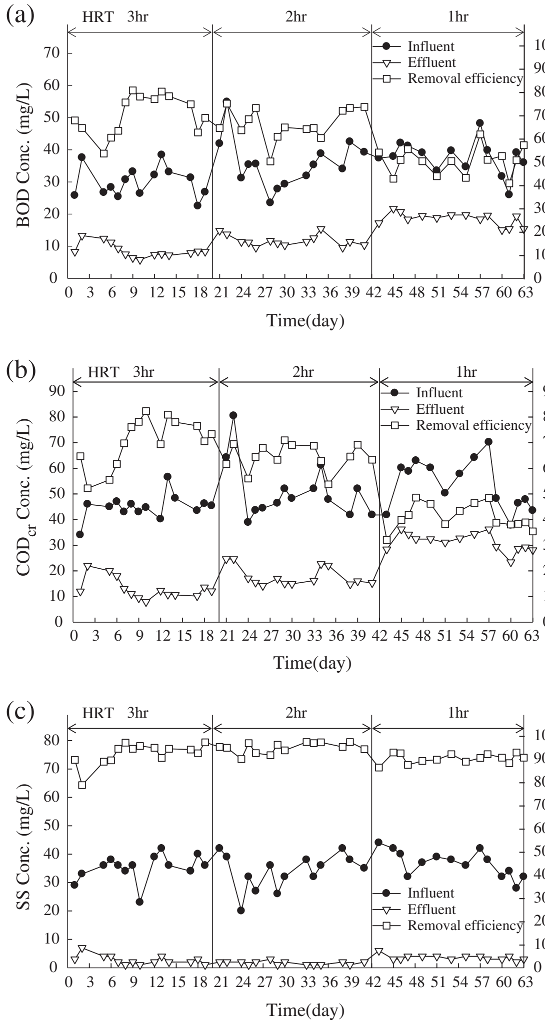

Fig. 3. Organic matter concentration and removal efficiency with various HRTs.

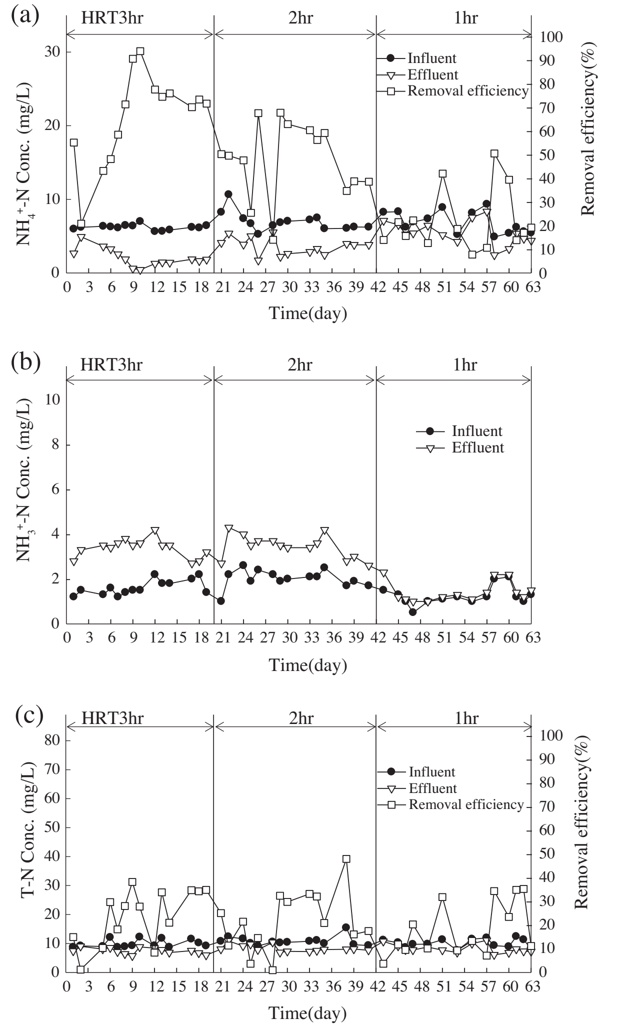

Fig. 4. Nitrogen concentration and removal efficiency with various HRTs.

remained stable, however, compared with the load variations of the influent and showed the highest removal efficiency at HRT 3 h (Fig. 3(a) and (b)).

From HRT 3 to 1 h, the average SS of the influent was introduced at 33.9–36.7 mg/L, and that of the treated water was found to be 1.6–3.6 mg/L, when the average SS removal efficiency was 90.2–94.9%, showing a very high SS removal efficiency. SS showed a high removal efficiency of 90% or more regardless of the HRT. This is because as SS is introduced, its moving particles are attached to the hollow fiber tube, and some of them are stably attached to the fixed biofilm due to a tube that serves as a filter (Fig. 3(c)).

3.2. Nitrogen removal

Fig. 4 shows the nitrogen concentration and removal efficiency according to the changes in HRT. From HRT 3 to 1 h, the NH_4^+-N concentration of the influent was introduced at 6.6–7.2 mg/L and that of the treated water ranged from 2.0 to 4.9 mg/L. The removal efficiency of NH_4^+-N was 31.5–68.8% (Fig. 4(a)). With the nitrification tendency of NO_3^--N, the NO_3^--N concentration of the influent was introduced at 1.2–1.7 mg/L and that of the treated water turned out to be 1.6–4.1 mg/L from HRT 3 to 1 h (Fig. 4(b)). Due to the decrease in HRT, the nitrogen load increased. The nitrification phenomenon was highest at HRT 3 h and it was found that nitrification has a close correlation with the nitrogen loads on the surface of the media [21].

The average T-N of the influent was 9.9–10.8 mg/L and the T-N concentration of the treated water was 7.5–8.3 mg/L. The T-N removal efficiency was found to be 21.6–23.3% from HRT 3 to 1 h. At each retention

Table 3
F/M ratio and organic matter loading with various HRTs

HRT (h)	F/M ratio (kgBOD/kgMLSS d)	BOD loading per surface area ($gBOD/m^2$ d)	BOD removal per surface area ($gBOD/m^2$ d)	NH_4^+-N loading per surface area (gNH_4^+-N/m^2 d)	NH_4^+-N removal per surface area (gNH_4^+-N/m^2 d)
3	0.076	5.42	3.85	1.12	0.74
2	0.089	9.74	6.55	1.90	0.92
1	0.099	20.45	10.40	3.73	0.78

time, the T-N removal efficiency was approximately more than 20% (Fig. 4(c)). As shown in Fig. 7, an anoxic condition was created by the thickened biofilm formed in the hollow fiber tube and nitrate nitrogen was reduced to the nitrogen gas, thereby removing the nitrogen.

3.3. *Organic matter and nitrogen removal characteristics according to the surface load*

BOD and NH_4^+-N load characteristics according to the changes in HRT are shown in Table 3. Both BOD and NH_4^+-N showed increased removal per tube surface area with an increase in the loading rate per tube surface area. As the loads per surface area of the tube became greater, however, due to an increase in HRT, the BOD and NH_4^+-N removal rates were reduced compared with the loads, showing a tendency for a shorter retention time that lead to a further decrease in organic matter removal and nitrification efficiency.

Fig. 5 illustrates the BOD and NH_4^+-N removal efficiency according to the surface loading rate. The increase in the surface loading rate showed a tendency to lower both the BOD and NH_4^+-N removal efficiency. Compared to BOD, NH_4^+-N had a further decrease in removal efficiency due to an increase in the surface loading rate, and was significantly affected by the load per surface area of the hollow fiber tube. In nitrification, the loading rate according to the specific surface area of the media is a major design factor [21,22]. For the estimation of the nitrification rate by the micro-organisms attached to the hollow fiber tube, the specific nitrification rate (SNR) according to the surface load was calculated. According to the calculation results, the SNRs were 0.021, 0.018, and 0.008 $mgNH_4^+$-N/mgMLVSS d, respectively, at HRT 3, 2, and 1 h. The nitrification rate was highest at HRT 3 h.

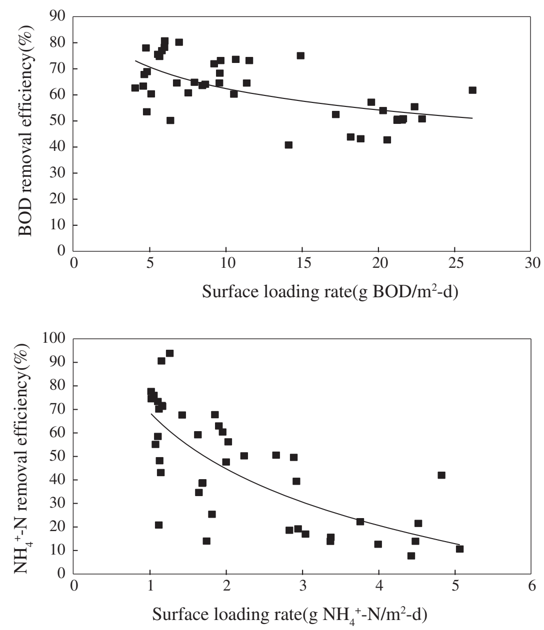

Fig. 5. BOD and NH_4^+-N removal efficiency with various surface loading rates.

3.4. *Biofilm growth characteristics*

Fig. 6 shows the changes in the number of attached growth micro-organisms over time. The biofilm showed a tendency to increase steadily after the attachment of growth micro-organisms and was found to have maintained a constant amount of micro-organisms after its reduction through detachment after about 20 d, and to have increased again thereafter. In a previous

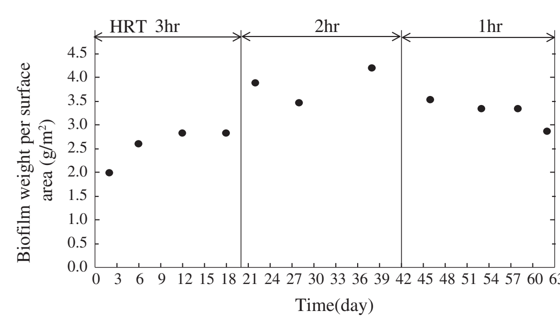

Fig. 6. Variation of the net biofilm growth in the reactor.

Fig. 7. Micro-organisms attached to the reactor.

experiment conducted by other researchers [2,23–25], its growth rate was reduced after 20 d, showing a detachment phenomenon. In this experiment, the attachment of micro-organisms was maintained well with an increase in biofilm due to its re-growth, and the micro-organisms were also found to have been kept stable even after the detachment of the biofilm. The inflow of air within the woven-hollow fiber tube is deemed to have maintained a certain amount of the micro-organisms by enhancing the oxygen transfer rate.

4. Conclusions

The results of the experiment on organic matter and nitrogen removal efficiency when low-concentration pollutants were treated by injecting air into the inside of the woven-hollow fiber tube are summarized below.

(1) For both BOD and COD_{cr}, the removal efficiency decreased due to the increased loads resulting from the HRT reduction, and the highest removal efficiency was shown at HRT 3 h. The concentration of the treated water was stably maintained. In the treated water, the SS concentration was found to have been very stably treated, with an average of 3.5 mg/L or less, regardless of the load variation of the influent.

(2) The results of the BOD and NH_4^+-N removal efficiency according to the biofilm surface loading rate showed that the NH_4^+-N removal efficiency according to the surface loading rate had a tendency to decrease more sharply compared with the BOD removal efficiency according to the surface loading rate, indicating that NH_4^+-N was affected more by the load per surface area of the hollow fiber tube compared to BOD.

(3) The investigation of the aerobic biofilm growth characteristics in this study confirmed that the number of micro-organisms was reduced by the detachment from the biofilm, but that the attached growth micro-organisms were stably maintained after the regeneration.

Acknowledgement

This work was supported by Korea Institute of Civil Engineering and Building Technology [2014-0074].

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