Journal of Zhejiang University SCIENCE
ISSN 1009-3095
http://www.zju.edu.cn/jzus
E-mail: jzus@zju.edu.cn

Biomass and microbial activity in a biofilter during backwashing*

BAI Yu (白 宇)†[1,2], ZHANG Jie (张 杰)[2], LI Yi-fan (李一凡)[2], GAO Yu-nan (郜玉楠)[2], LI Yong (李 泳)[3]

(*[1]Beijing Drainage Group Limited Company, Beijing 100061, China*)

(*[2]School of Municipal and Environmental Engineering, Harbin Institute of Technology, Harbin 150090, China*)

(*[3]School of Environmental Engineering, Nanyang Technological University, 639798, Singapore*)

†E-mail: Baiyu75322@163.com

Received Aug. 13, 2004; revision accepted Nov. 10, 2004

Abstract: Biomass and microbial activity in backwashing processes of a biofilter for tertiary treatment were investigated. The microbial groups revealed new distribution along the biofilter depth after low flow rate backwashing for a short time. Then the start-up process was accelerated by backwashing. The biomass profile and microbial activity profile both varying with depth before and after backwashing, can be mathematically described by quadratic equations. Using the profiles, the difference of oxygen demand can be calculated to determine the airflow rate during backwashing. Combined with the difference between biofilters and rapid gravity filters, analysis of biomass and microbial activity can determine more accurately the required airflow rate during backwashing.

Key words: Biofilter, Backwashing, Biomass, Microbial activity, Oxygen demand
doi:10.1631/jzus.2005.B0427 **Document code:** A **CLC number:** Q93

INTRODUCTION

The technique of biofiltration has been successfully used in water and wastewater treatment for over a century. The biofiltration process used in tertiary treatment before the early 1980s for application to water pollution and reuse, however, were focused on the design, parameters and operations (Viotti *et al.*, 2002; Tauno *et al.*, 2001; Payraudeau *et al.*, 2001), and the biomass and microbial activity did not receive enough attention. Biomass and microbial activity in a biofilter are two critical parameters, which determine the reactor's performance in water treatment (Liu *et al.*, 2001), and have become the focus of interest in the scientific community due to the development of modern analytical techniques. Boifilms are of two types: active biofilms and inactive ones. Different from inactive biofilms, active ones have direct influence on the substrate degradation rate, which is proportional to the surface areas of supports (Liu and Capdeville, 1996). Biofilm spatial structures can be studied by using a 3-D image technology as a bridge between light microscopy and electron microscopy (Lazarova and Manen, 1995).

Biofilters are different from conventional gravity filters and can be used to treat water in a fine porous medium where the purification occurs, and can not only filter suspended solids, but also increase the degradation of organic matter using the fixed film biomass. These two mechanisms ultimately result in the progressive clogging of the biofilter, which must then be washed clean (Hozaiski and Bouwer, 1998). Biomass and biofilm activity changed after backwashing in the experiment. The objective of the research is to study the changes of biomass and biofilm activity in start-up and running operations and their relations with backwashing parameters.

MATERIALS AND METHODS

Experimental set-up

The pilot plant tested in this study was in Wen

* Project (No. 2002BA806B04) supported by the National Technological Research Program of China

Chang Sewage Treatment Plant, Harbin, China. The schematic diagram of all the reactors for the present study is shown in Fig.1. The biofilter is a 3.0 m tall, 0.3 m inside diameter cylinder with volume of 212 L. The filter was filled up to 2.1 m height with argil particles of 2–4 mm diameter, density 1832 kg/m^3, 0.46 porosity, and there were eight taps located at height of 0, 30, 60, 90, 120, 150, 180, 210 cm respectively (from bottom to top of biofilter), allowing for biomass and biofilm activity sampling.

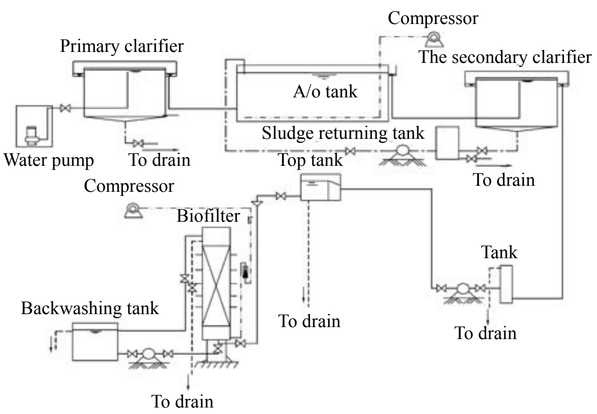

Fig.1 Pilot apparatus

Analytical methods

The amount of biomass was quantified by measuring the organically bound phosphorous (phospholipids) according to a method described by Yu *et al*.(2002). Phosphorous is an important part of biofilm and decomposed after death. The organically bound phosphorous was extracted and then digested into inorganic phosphate. In the colorimetric quantification, the units of measurement are nmoles of PO_4^{3-} (1 nmol P) per gram of dried medium. 1 nmol P corresponds to 10^8 coliform. The biofilm activity measured by biomass respiration potential (BRP) method (Urfer and Huck, 2001).

The measurement of chemical oxygen demand (COD) followed that in Standard Methods (APHA, 1992).

Start-up operation of the biofilter

During active sludge cultivation in the aerated tank, biofilter also was inoculated by feeding the sewage water to the first filter at increasing flow rate of 1 m^3/m^2 to 5 m^3/m^2 to save time. Superficial velocity of 4 m^3/(m^2·h) for the air was maintained throughout the experiment. The filter operated at ambient temperature of (20±2) °C. Temperature, pH, dissolved oxygen concentration of the biofilter reactor were monitored online.

RESULTS AND DISCUSSION

Backwashing in start-up operation

Microorganisms grow in the start-up of biofilter. Researchers suggested that no backwashing is needed in this phase for biomass accumulation (Chandravathanam and Murthy, 1999). Fig.2 shows the change of COD removal efficiency of a backwashed biofilter in start-up operation. For the first 5 days, the COD removal rates of two biofilters (1$^\#$ and 2$^\#$) were similar and then the performance of 1$^\#$ was heightened by the backwashing. To the eighth day, the COD removal reached to 30%. As observed in Fig.2, one third of start-up time of the biofilter can be saved through a backwashing.

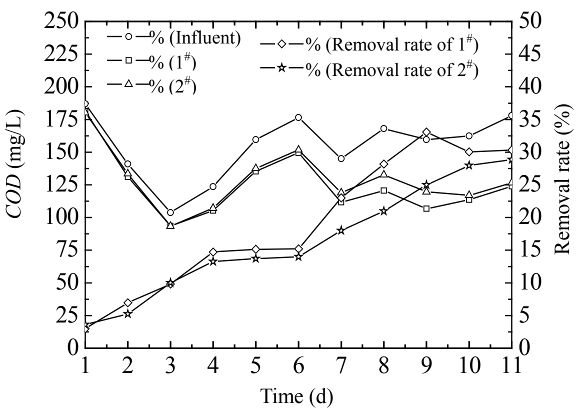

Fig.2 Effect of backwashing on the start-up of biofilter

However, the parameters of backwashing in start-up operation were different from those in periodic backwashing. Low rate flow backwashing that occurred a short time caused microbial redistribution along the biofilter. A plot of biomass versus layer depth (Fig.3) showed that the biomass concentration on the filter asymptotically decreased along the biofilter, and was less than 30 nmol P/(cm^3 medium) on the top layer. The major portion of biomass was in the 60 cm layers for the influent mass flow of organic matter and caused clogging of the biofilter. It appeared that as the organic loadings decreased and less biomass was in the top layer of the biofilter, the biofilms became thinner. Fig.3 suggests that more space inside the top layer medium can be utilized for the growth of microorganisms.

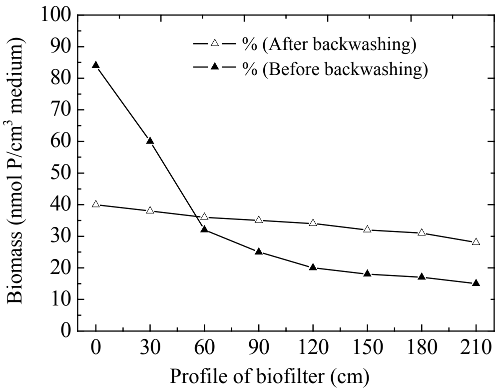

Fig.3 Biomass along the profile of biofilter

Biofilms detachment from the medium in start-up process through backwashing redistributed the biomass and microorganisms profile along the filter. As presented in Fig.3, the curve of the biomass versus layer depth after backwashing is a smooth line. Additionally, low flow rate backwashing for a short time partially restratified the medium, further contributing to reducing the clogging in the biofilter and shortening the start-up time.

Biofilm activity was not proportional to the quantity of fixed biomass, but increased with the depth of biofilter. The biofilm on the top layer became less thick, and then the microbial oxidation and COD removal efficiency were improved which accelerated the start-up operation. A significant fact observed in this test was that the biofilter without backwashing ($2^{\#}$) became hardened in the start-up operation due to clogging of a large amount of biomass and solids in the bottom layer, and then made the running and backwashing of the filter difficult. As shown in the previous example, backwashing is necessary in the start-up operation of biofilter. However, the mode, flow rate and time of backwashing should be selected for different medium. Low backwashing flow rate and shorter backwashing time than those in regular backwashing were used for maintaining the biomass accumulation. Only water backwashing was selected in the start-up process of this experiment and the water velocity was maintained at 7.5 L/(m^2·s) for 120 s.

Expanding of biofilter during backwashing

Combined air/water backwashing has been adopted in the process (Stevenson, 1995), since water backwashing alone seemed not to have a favorable effect on the biofilter. It appears that the air velocity is important to the backwashing and dependent on the expanding of biofilter in most cases (Kraft and Seyried, 1990).

Fig.4 shows expanding rate of biofilter (after start-up) and filter (before start-up) in backwashing at different air velocity. When the water flow rate is fixed, the expanding rate of biofilter increases with the increasing airflow rate. Fig.4 indicates that the expanding rates of biofilter are larger than those for non-biological filters in the range of air flow rate of 5−20 L/(m^2·s). Unlike the rapid gravity filter, surface on the medium and space in the medium are full of biofilm, which is organic matter with density smaller than water among the filter before start-up operation. Considering the difference between biofilter and rapid gravity filter, using expanding rate only to choose the air velocity during backwashing is not realistic.

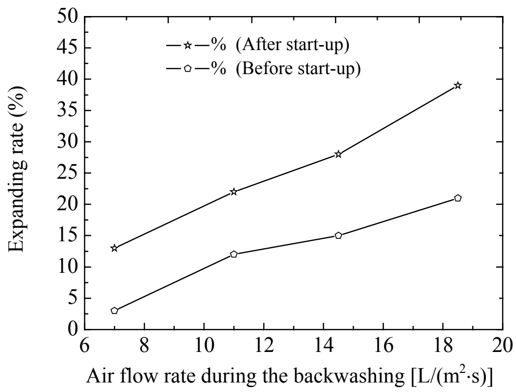

Fig.4 Change of expanding rate of filter with different air flow rate during backwashing

Change in oxygen demand

Aerobic microbes and the oxygen demand of icroorganisms which can cause removal of contamination complete in biofilter degradation (Ellis *et al.*, 2000) complete in biofilter degradation. The units of biomass and microbial activity are nmol P/(cm^3 medium) and mg O_2/(L·nmol P) respectively, and is the oxygen demand [mg O_2/(L·cm^3 medium)] of one unit medium. The biomass loss in the effluent worsened during backwashing. But the oxygen demand loss ceased when microbial activity increased. The removal rate of COD recovered to 80% of normal operation after 3 h of backwashing.

The oxygen demand (OD) changes with different air flow rate (AFR) (Fig.5). Conversely, the relationship between OD and AFR shown in Fig.5 can also be used to decide the air velocity in backwashing. Three grams of medium was removed for each test, a mount that was in the periodic running and after 3 h of backwashing in the 80 cm layer. It can be observed in Fig.5 that the oxygen demand after backwashing was about 1.4 mg O_2/(L·cm^3 medium) or so but less than that in the periodic running, which suggestes recovery occurring in the backwashed biofilter.

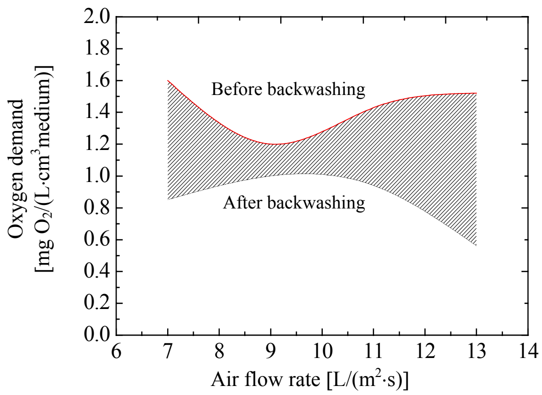

Fig.5 Oxygen demand before and after backwashing

The hatched area in Fig.5 represents the differences of the oxygen demand before and after backwashing. The figure indicates that the hatched area has a bottleneck shape, and that the OD differences minimized when AFR (X_0) is equal to 9.4 L/(m^2·s). The differences increase when AFR deviated from the values of X_0. The result indicates that the backwashing in halfway and microbial activity changed little when the air velocity was less than 9.4 L/(m^2·s); on the contrary, too high values of air flow rate can also result in large biomass loss. But too low or too high values of AFR can decrease the oxygen demand, and shorten the running time or lengthen recovery time after backwashing.

Change of biomass and microbial activity

The general patterns of the biofilter biomass in relation to biofilter depth are presented in Fig.6 showing that the biomass decreased progressively along the biofilter depth for decreasing organic matter concentration.

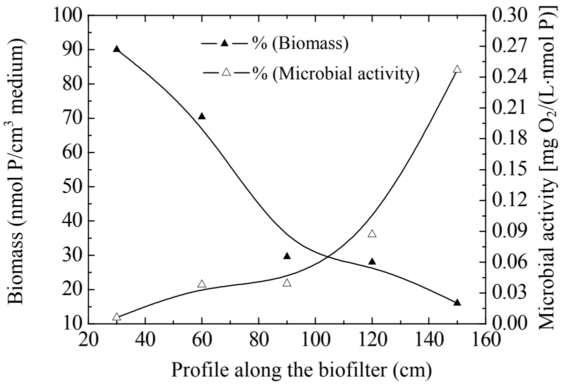

Fig.6 Biomass and microbial activity along the biofilter

Biofilm reaction-diffusion kinetics and modelling were used to establish a general model describing the thickness of film and substrate concentration of the influent (Liu *et al.*, 2000):

$$Th_{\mathrm{a}} = \frac{1}{\beta}\left(\frac{2D_{\mathrm{e}}}{k_{0v}}\right)^{\frac{1}{2}} S^{\frac{1}{2}} \qquad (\beta = 1) \qquad (1)$$

where Th_{a} is the thickness of active biofilm (L); D_{e} is the diffusion coefficient of substrate (L^2/t); S is concentration of liquid substrate (M/L^3); β is the penetration coefficient; and k_{ov} is the dynamical constant of biofilm [$M/(L^3 \cdot t)$].

According to Eq.(1), the activity in the top layer is less than that in the low layer for decreasing organic matters concentration, which is different from the results that we observed in the experiment. The reason for this discrepancy is that Eq.(1) was derived on the basis of the symmetrical distribution of microbial activity along the film thickness (Wimpenny *et al.*, 2000), which means the specific growth rate of inactive and active microbes is the same and that it is impossible to restrain indecomposable, toxic, metabolized matter. The gradually decreasing organic matters stimulated microbial activity in the top layer and increased the biofilter oxygen demand (Servais *et al.*, 1991). As shown in Fig.6, the microbial activity increased along the biofilter depth.

Figs.7−8 are plots of the change of biomass and microbial activity along the biofilter depth after backwashing respectively. The profiles in Fig.7 show that the 50% of biomass is lost due to backwashing in the low layer, partly due to the air flow rate. After backwashing, and that the biofilm becomes thinner, which favor diffusion of the oxygen (Hwang and Matsumoto, 1978). The microbial activity after backwashing is higher than the values shown in Fig.6. Increasing the air velocity during backwashing can also increase the microbial activity. However, the improvement was limited when air velocity was more than 9 L/(m^2·s).

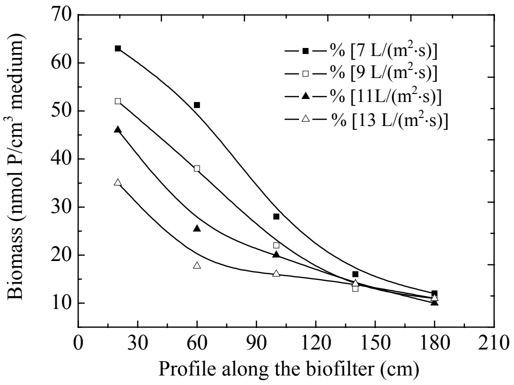

Fig.7 Change of biomass along the biofilter with different air velocity during backwashing

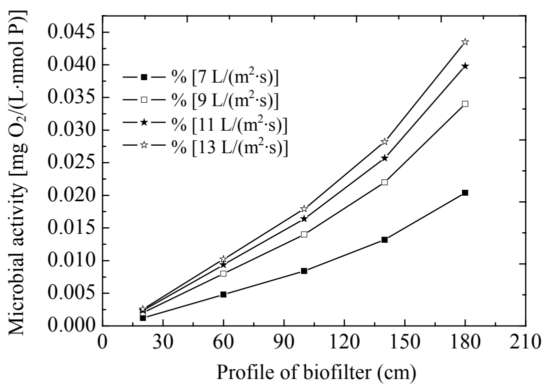

Fig.8 Change of microbial activity along the biofilter with different air velocity during backwashing

Air velocity in backwashing based on oxygen demand

Examination of the results for biomass and microbial activity along the biofilter depth shows that the oxygen demand can be determined not only in a layer profile (Fig.5) but also in the profile of the whole biofilter. The biomass and microbial activity for any layer, which decreases or increases with depth exponentially, can mathematically be described by the quadratic Eq.(2) and Eq.(3):

$$m(x)=a_1x^2+b_1x+c_1 \quad (2)$$

$$n(x)=a_2x^2+b_2x+c_2 \quad (3)$$

where a_1, b_1, c_1, a_2, b_2, c_2 are coefficients found from the regression analysis and change with the air velocity during backwashing, and x is the biofilter depth (cm). The average oxygen demand at any layer, $q(x)$, is thus given by:

$$q(x)=\frac{\int_0^x m(x)\cdot n(x)\mathrm{d}x}{x}=\frac{\int_0^x (a_1x^2+b_1x+c_1)(a_2x^2+b_2x+c_2)\mathrm{d}x}{x} \quad (4)$$

Assuming the biomass and microbial activity along the biofilter depth at different air velocity are $m_7(x)$, $m_9(x)$, $m_{11}(x)$, $m_{13}(x)$ and $n_7(x)$, $n_9(x)$, $n_{11}(x)$, $n_{13}(x)$ respectively, according to Eq.(4), the average oxygen demand of the whole biofilter can be decided not only during running operation but also after backwashing.

Fig.9 presents the change of the average oxygen demand in the whole biofilter before and after backwashing according to Eq.(4), which is close to the curves of the 80 cm layer in Fig.5. So the best air velocity value of backwashing is that of the 80 cm top layer. Fig.9 shows that the oxygen demand before and after backwashing has the minimum value when the air velocity is approximately 9 L/(m^2·s), close to 9.4 L/(m^2·s) in Fig.5.

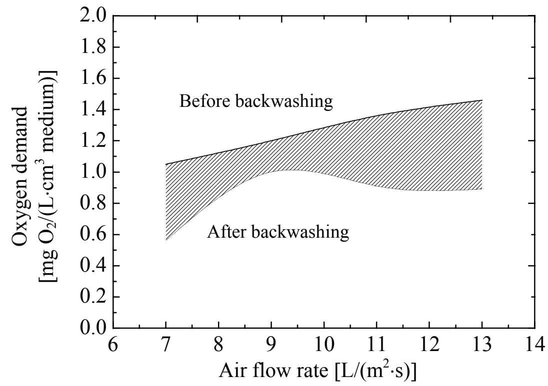

Fig.9 The average oxygen demand of biofilter before and after backwashing

CONCLUSIONS

1. The low flow rate backwashing for a short time can alleviate biofilter clogging and accelerate the start-up operation.

2. It is not appropriate to determine the air velocity of backwashing by expanding which is used in rapid gravity filter for biofilms cultivated in it. The biomass and microbial activity are important biofilter parameters, which depend on the layer depth. The oxygen demand can be used to determine the airflow rate in backwashing. The difference of the oxygen demand before and after backwashing has the lowest value at the most desired air flow rate, which is approximately 9.4 L/(m^2·s) according to this experiment.

References

APHA (American Public Health Association), 1992. Standard Methods for the Examination of Water and Wastewater, 17th Ed. American Public Health Association, Washington D.C.

Chandravathanam, S., Murthy, D.V.S., 1999. Studies in nitrification of municipal sewage in an upflow biofilter. *Bioprocess Engineering*, **21**:117-122.

Ellis, T.G., Barbeau, D.S., Smets, B.F., Grady, C.P.L., 2000. Resperometric technique for determination of extant kinetic parameters describing biodegradation. *Water Environment Research*, **68**(5):917-925.

Hozaiski, R.M., Bouwer, E.J., 1998. Deposition and retention of bacteria in backwashed filters. *Journal AWWA*, **90**(1):71-76.

Hwang, S.L., Matsumoto, J., 1978. Kinetics of attached microbial growth in a continuous stirred tank reactor. *Wat Res*, **12**:243-249.

Kraft, A., Seyried, C.F., 1990. Bioligically intensified filtration (dual-medium dry bed filter) for advanced waste water treatment. *Water science and technology*, **22**(1/2): 317-328.

Lazarova, V., Manen, J., 1995. Biofilm characterization and activity analysis in water and wastewater treatment. *Wat. Res.*, **29**(10):2227-2245.

Liu, Y., Capdeville, B., 1996. Specific activity of nitrifying biofilm in water nitrification process. *Wat Res*, **30**(7):1645-1650.

Liu, Y., Zhao, Q.L., Zheng, X.C., 2000. Biofilm Technology for Wastewater Treatment. Beijing, China, p.50-60 (in Chinese).

Liu, X.B., Huck, P.M., Slawson, R.M., 2001. Factors affecting drinking water biofiltration. *Journal AWWA*, **12**:90-101.

Payraudeau, M., Pearce, A.R., Goldsmith, R., Bigot, B., 2001. Experience with an up-flow biological aerated filter (BAF) for tertiary treatment: from pilot trials to full scale implementation. *Water Science and Technology*, **44**(2-3): 63-68.

Servais, P., Billen, G., Ventresque, C., Bablon, G.P., 1991. Microbial activity in GAC filter at the choisy-le-roi treatment plant. *Journal AWWA*, **2**:62-67.

Stevenson, D.G., 1995. Process conditions for the backwashing of filters with simultaneous air and water. *Wat Res*, **29**(11):2594-2597.

Tauno, H., Soniya, I., Kanjo, Y., Hidaka, T., 2001. Advanced treatment of sewage by pre-coagulation and biofilm process. *Water Science and Technology*, **1**:327-334.

Urfer, D., Huck, P.M., 2001. Measurement of biomass activity in drinking water biofilters using a respirometric method. *Wat Res*, **35**(6):1469-1477.

Viotti, P., Eramo, B., Boni, M.R., Carucci, A., Leccese, M., Sbaffoni, S., 2002. Development and calibration of a mathematical model for the stimulation of the biofiltration process. *Advances in Environmental Research*, **7**:11-33.

Wimpenny, J., Manz, W., Szewzyk, U., 2000. Heterogeneity in biofilms. *FEMS Microbiology Reviews*, **24**:661-671.

Yu, X., Zhang, X.J., Wang, Z.S., 2002. Meassurement of biomass in drinking water biofilters using phospholipids method. *Water and Wastewater*, **5**:24-27.