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Comparison of the biological NH_3 removal characteristics of a three stage biofilter with a one stage biofilter

[1*]H. Taghipour , [2]M. R. Shahmansoury , [2]B. Bina and [2]H. Movahdian

[1]Department of Environmental Health Engineering, Tabriz University of Medical Sciences, Tabriz, Iran

[2]Department of Environmental Health Engineering, Isfahan University of Medical Sciences, Isfahan, Iran

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ABSTRACT: A three stage and a one-stage bench-scale biofilter with effective heights of 129 cm filled with same type of packing material were operated at different influent concentrations of ammonia in order to investigate their performance in treating waste gas streams. The columns contained a mixture of municipal compost inoculated with thickened municipal activated sludge as a base material and shredded hard plastic as a bulking agent in a 3:2 v/v ratio; the porosity, density and pH were 52 %, 0.65 and 7.2 respectively. Microbial acclimation to ammonia was achieved by exposing the three stage biofilter to an average inlet loading rate of 2.15g-NH_3/m^3 h and the one-stage to an average inlet loading rate of 1.32 g NH_3/m^3 h and an empty bed residence time of 60 s, for 10 days and 17 days respectively. Under steady-state condition, maximum elimination capacity (EC) was 9.85 g-NH_3/m^3h at a loading rate of 9.86 g-NH_3/m^3h for three-stage biofilter and 8.08 g NH_3/m^3h at a loading rate of 8.13 g-NH_3/m^3h for one-stage biofilter. The average pressure drop across biofilters bed was determined 33.76 Pa/m^1 in three-stage biofilter and 180.7 Pa/m^1 in one-stage biofilter. The three stage biofilter showed superior performance and gained more elimination capacity, shorter acclimation time, longer operation in steady-state condition and less pressure drop than one-stage biofilter.

Key word: *Ammonia, three stage biofilter, one stage biofilter, compost, elimination capacity*

INTRODUCTION

Ammonia gas is a notable malodorous gas among volatile compounds. This air pollutant is irritating, toxic, reactive and corrosive (Kim, *et al.*, 2000; Ontario Ministry, 2001; Chung, *et al.*, 2000). This gas is usually emitted into atmosphere from a lot of industries and facilities like petrochemical industry, pulp and paper industry, livestock farming, wastewater treatment plants and composting plants. Exhaust gases from most of this sources are usually characterized by high flow rate and low pollutant concentrations (Davis, 2000; Busca and Piostarino 2003; Malhautier, *et al.*, 2003; Pangans, *et al.*, 2005). Ammonia control is important not only for reduction of environmental impacts but also for improving environmental conditions in animal houses and livestock waste facilities (Chung, *et al.*, 2000; Hong, *et al.*, 2005). For treatment of malodorous gases, physical and/or chemical methods have been popularly used. The disadvantages of the traditionally used air treatment technologies are high energy costs, the use of chemicals, which can be costly to purchase or dispose of and require special operational safety procedures and the production of waste products (Kim, *et al.*, 2000; Groenestijn and Kraakman, 2005). Thus biological methods have attracted attention as alternative method. Among the biological methods, a packed bed reactor system such as biofilter has been reported to be an efficient and inexpensive method especially for low concentration polluted air streams (Kim, *et al.*, 2000; Baquerizo, *et al.*, 2005). The biofiltration process involves contacting contaminated streams with microbial biofilms immobilized on porous support particles. The pollutants diffuse from the gas phase into the thin layer of biofilm attached to the support media and are metabolized. The end products of complete biodegradaton are CO_2, water and microbial biomass (Torkian, *et al.*, 2003). Hence, biofiltration is a complex process that involves several physical, chemical and biological interactions (Baquerizo, *et al.*, 2005). A large

*Corresponding author, Email: hteir@yahoo.com
Tel.: +98411 335 7580; Fax: +98411 334 0634

number of experimental studies have demonstrated that biofiltration is an effective biological process to remove air polluted emissions (Baquerizo, *et al.*, 2005). However studies regarding to the comparing of performance of multi-stage and one-stage biofilter are relatively limited. Also a lot of different packing materials have been used like inorganic packing material inoculated with a newly isolated marine bacteriumin, Vibrio alginolytius (Kim, *et al.*, 2000), peat and peat seeded with nitrifying bacteria and mixture of compost and activated carbon (Liang, *et al.*, 2000), ceramic, granulated and calcinated soil (Hirai, *et al.*, 2001), woodchips (Sheridan, *et al.*, 2002), coconut fiber (Baquerizo, *et al.*, 2005) zeolite and oyster shells, (Mac Newin and Barford, 2000). But mixture of compost cultivated with thickened municipal activated sludge and shredded hard plastics as the bulking agent has rarely been used as packing material for biofiltration of ammonia. So in this study a three-stage biofilter and a one-stage biofilter filled with mixture of inoculated compost and pieces of hard plastic were operated in same condition to (a) investigation of microbial acclimation time, elimination capacity, removal efficiency and pressure drop of biofilters, (b) determination of effectiveness of a new packing material in the biodegradation of ammonia, (c) comparing of performance of three-stage biofilter and one-stage biofilter in ammonia biodegradation.

This study has been done in Isfahan University of Medical Sciences, in 2004 -2005.

MATERIALS AND METHODS

Biofilters set-up

In the first phase a three-stage bench-scale downward biofilter constructed from a cylindrical metal container with height of 40cm, 40 cm and 49cm, respectively first, second and third stage, and internal diameter of 8 cm and was used for study (Fig.1). The column stages were separated by perforated plates acted as a support for the packing material as well as for gas redistribution. Provision of sampling ports at the top, midpoint and the end of each section allowed bed media access. A 7 cm space in between the sections allowed for representative gas sampling from the inlet and outlet of each layer. The three stage biofilter was operated for 83 days. Then in the second phase of study by removing the perforated plates of column of three stage biofilter, that was changed to one stage biofilter in effective overall height of 129 cm and was operated 66 days (flow diagram of one-stage biofilter was same as Fig.1, only without the perforated plates of column). In the both of biofilters, the compressed air was passed through a granular activated carbon column to retain residual oil and particles and then was sparged through a 16 l water container equipped with heated element for adjusting gas stream temperature and humidification. Changing water temperature in the humidifier allowed humidity control of influent gas stream and biofilter material. The synthetic polluted gas stream was prepared by injecting controlled amount of pure ammonia from a gas cylinder equipped with a precision gas regulator (Herice Co.). Overall air stream flow through the column was measured using a gas flow meter (Platon, Co.). A digital thermometer was applied to keep of the bed material temperature in 30±1 ºC by using a heated tape wrapped around the exterior of the reactor wall. This condition resulted avoiding environmental temperature effects and prevented any disorder of the steady state condition of the biofilter. Bed water content was maintained at 40-65 % during the study period. Monitoring of bed pressure drop along the column was conducted with a U type glass water manometer. Packing material for both of three-stage and one stage-biofilter was prepared by mixing municipal compost (Isfahan compost co.) with shredded high density plastics (1.0×0.5 cm) as bulking agent to increase bed porosity and thickened activated sludge to produce a 3:2:1 v/v ratio with the porosity, density and pH of 52%, 0.65 and 7.2 respectively. In preparing the packing medium, thickened activated sludge obtained from municipal wastewater treatment plant (Isfahan Water and Wastewater Co.).

Analytical methods

Concentration of ammonia in the gas samples was determined by colorimetric indophenols method (Lodge and James, 1990). Gas sampling ports were connected to impingers containing sulfuric acid solution to trap ammonia gas. Moisture content was determined by drying 5 g of the bed medium at 104 °C for 24 h., cooling in desiccators at room temperature, and measuring the final weight (Torkian, *et al.*, 2003). To determine the pH value of the media, 50ml distilled water was added to a 5g sample then the mixture was blended and used for measurement (Liang, *et al.*, 2000). Pressure drop was measured with a U type glass water manometer.

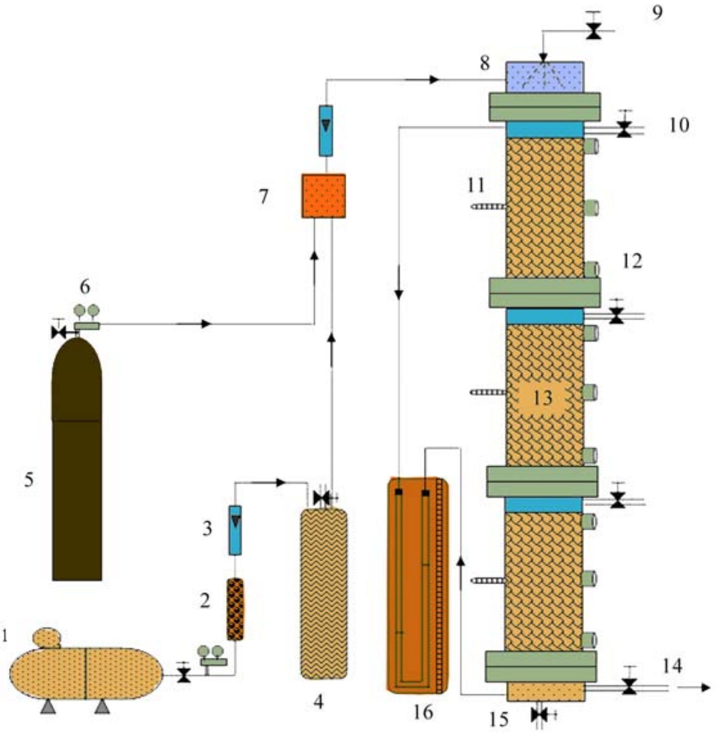

Fig. 1: Schematics of three stage biofilter system:1- compressor, 2- carbon filter, 3- flow meter, 4- humidifier, 5- ammonia gas cylinder, 6- regulator, 7- mixing chamber, 8- inlet, 9- water inlet, 10- gas sampling port, 11- thermometer, 12- media sampling port, 13- biofilter bed, 14- outlet, 15- leachate, 16- manometer

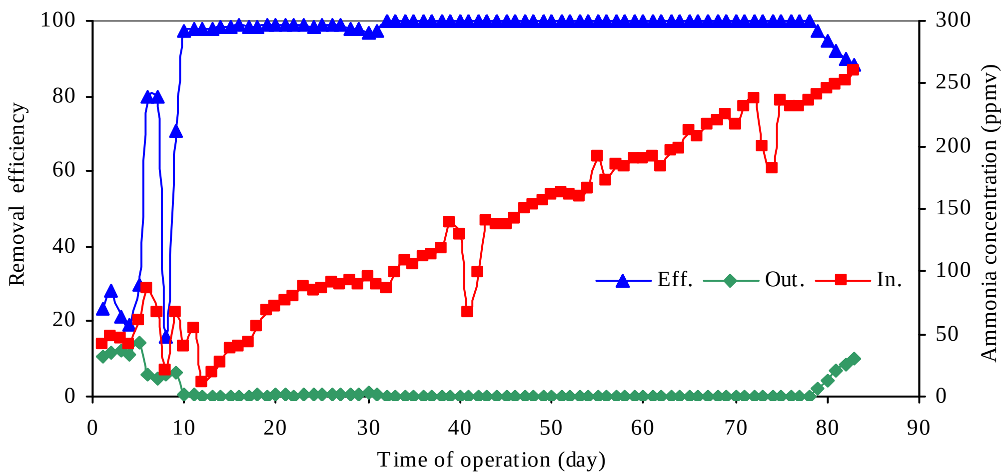

Fig. 2: Overall performance of compost bed three stage biofilter in removal of ammonia

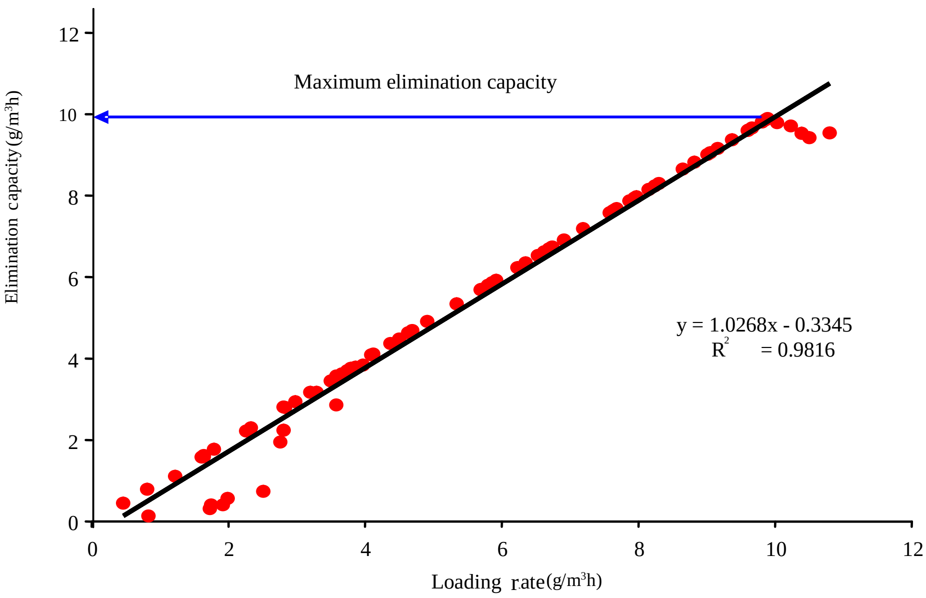

Fig. 3: Relationship between elimination capacity and loading rate of ammonia in three stage biofilter

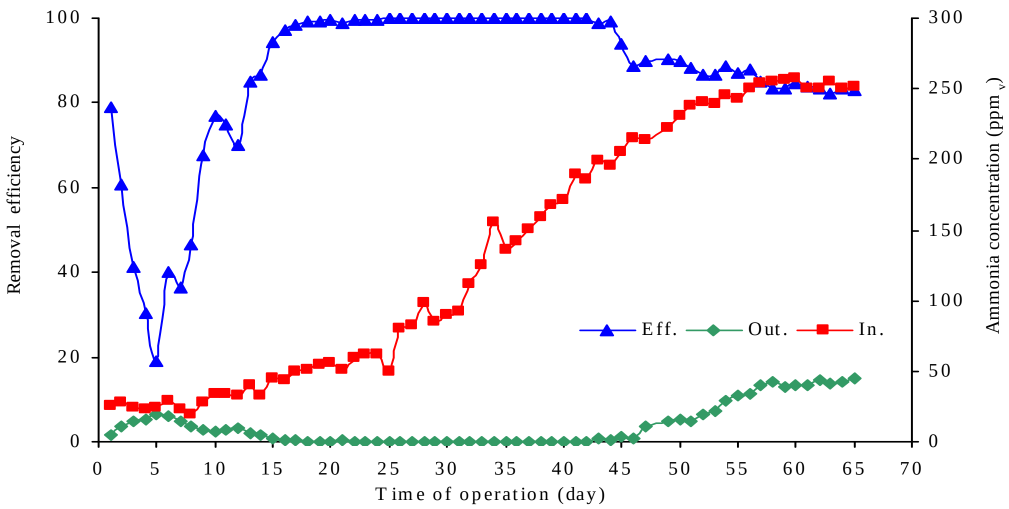

Fig. 4: Overal performance compost bed one stage biofilter in removal of ammonia

RESULTS

Microbial acclimation time, Elimination capacity and removal efficiency of three-stage biofilter

In the beginning of study of three stage biofilter after inoculation of the biofilter with thickened municipal activated sludge, the system was operated with airflow rate (Q) of 0.388 m^3/h corresponding to an empty bed residence time (EBRT) of 60 seconds with an average inlet load of 2.15g NH_3/m^3h. The microbial acclimation achieved for 10 days. Then the inlet concentration and loading rate of ammonia was increased gradually. According to Fig. 2 and Fig. 3, the maximum elimination capacity of 9.85 g NH_3/m^3h (removal efficiency of 99.9 %) was obtained at loading rate of 9.86 g NH_3/m^3h corresponding to inlet concentration of about 236 ppm_v. The effluent ammonia concentration was less than 1 ppm_v. At higher inlet concentration of ammonia the system started to be unstable and became completely unstable on the day of 83 of operation. On the day of 83 of operation the removal efficiency of three-sage biofilter reached to 88.3% and the effluent ammonia concentration increased to about 30 ppm_v.

Table 1: Comparing of three stage biofilter and one stage biofilter

Biofilter	Three-stage biofilter	One-stage biofilter
Microbial acclimation time	10 dyes	17 dyes
Removal efficiency	99.9% (C_{in} =236 ppm_v)	99.4 %(C_{in} =195 ppm_v)
Maximum elimination capacity	9.85 g-NH_3/m^3h	8.08 g-NH_3/m^3h
Average pressure drop	33.76 Pa m^{-1}	180.7 Pa m^{-1}

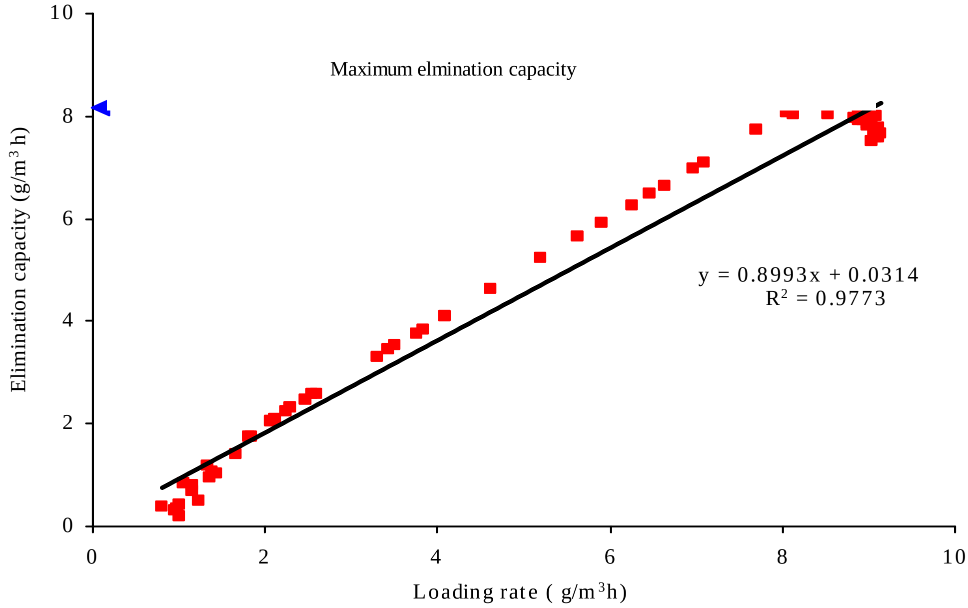

Fig. 5: Relationship between elimination capacity and loading rate of ammonia in one stage biofilter

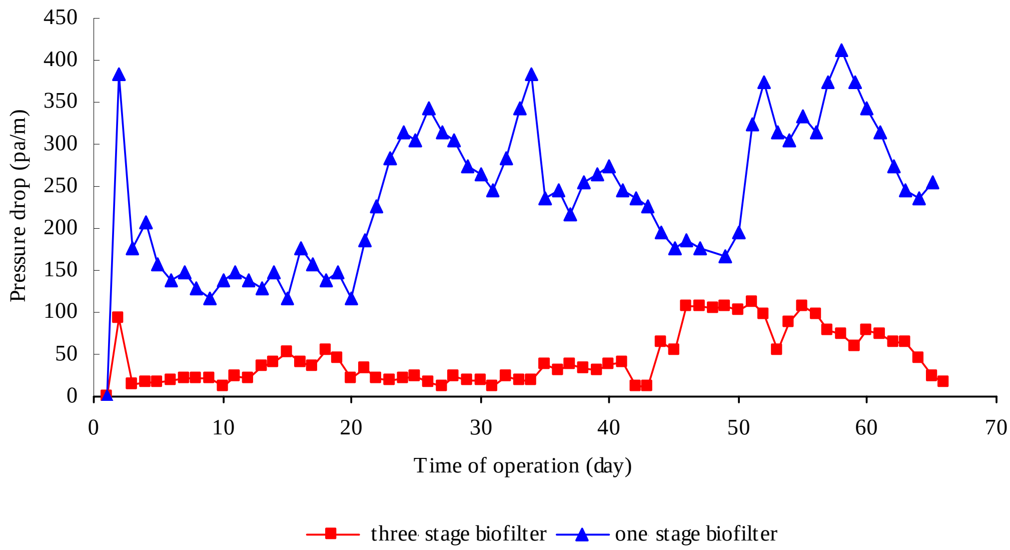

Fig. 6: Pressure drop as function of operation time in three stage biofilter and one stage biofilter columns with an effective height of 129 cm

DISCUSSION AND CONCLUSION

In this study the microbial acclimation was achieved for 10 days and 17 days for three-stage and one stage-biofilter respectively. While Malhautier, *et al.* (2003) used granulated sludge as packing material in biofiltration air loaded with ammonia and hydrogen sulfide mixture and reported 7 weeks acclimation period for ammonia oxidizing microorganisms and Liang, *et al.* (2000) reported 2 weeks as acclimation time for ammonia biotreatment with a compost based biofilter and activated carbon as an added material. Comparison of results indicates that the microbial acclimation period in the three-stage biofilter was less than repotted time by other researcher and also in the same condition of operation and with same packing material the acclimation time for three- stage biofilter was about one week less than microbial acclimation time of one-stage biofilter. It was concluded that compaction of packing material in one-stage biofilter due to weight of media of biofilter column caused the acclimation time in one stage-biofilter delay in comparing with three-stage biofilter. Also the inoculation of the biofilter media with adapted aggregates like thickened municipal activated sludge reduced the acclimation time especially in the three-stage biofilter in regarding to the reported acclimation time in the other studies. This subject is consistent with the results which obtained by other experimental works in biofiltration of other pollutants (Dehghanzadeh, *et al.*, 2005; Jorio, *et al.*, 2000). After acclimation period and reaching to steady state condition in three-stage biofilter, according to Fig.2 and Fig.3, the maximum EC of 9.85 g-$NH_3/m^3/h$ (RE=99.9 %) was achieved at loading rate of 9.86 g-NH_3/m^3h corresponding to inlet concentration of about 236 ppm_v. The three-stage biofilter became unstable on the day of 83th. But under steady-state the maximum elimination capacity obtained 8.08 g-NH_3/m^3h for one stage-biofilter at an inlet loading rate of 8.13 g-$NH_3/m^3/h$ (RE=99.4%) corresponding inlet concentration of 195 ppm_v, then the system became unstable for higher loading rates on the day of 47 due to reaching ammonia concentration and loading rates above the inhibition limit. According Fig.4 and Fig.5, there was a liner relationship between elimination capacity and organic loading rate for both of biofilters in the loading rates of less than maximum elimination capacity. The removal efficiency in the both of reactors was almost equal (99.9% and 99.4% for three-stage and one-stage respectively), but in the evaluation and comparing of biofilters performance the removal efficiency alone is not acceptable parameter and same removal efficiency in two different systems doesn't indicate that both of them have same performance . The removal efficiency (RE) and elimination capacity (EC) were determined using the relationships between influent and effluent contaminant concentration, waste air flow rate, and effective volume of biofilter column as follows:

$$RE = \left(\frac{C_{Gi} - C_{Go}}{C_{Gi}}\right) \times 100 \quad (1)$$

$$EC = \frac{(C_{Gi} - C_{Go}) \times Q}{V_f}\left[\frac{M \times 10^{-3}}{24.86}\right] \quad (2)$$

Where C_{Gi} and C_{Go} are the concentration of contaminant in the influent and effluent waste gas stream (ppm_v), Q is the gas flow rate (m/h^3), V_f is the volume of filter bed (m^3), M is the molecular weight of contaminant. In the evolution of biofilters performance parameters like pollutant concentration (C_{Gi}), flow of polluted air (Q) and effective volume of biofilter (V_F) have decisive effect. As shown in the relationship of 1, all of those parameters enter in the calculation of elimination capacity but they don't participate in the removal efficiency equation. So in the comparing biofilters the elimination capacity used directly. It was concluded that in spite of reaching to the same removal efficiency in the both of biofilters the performance of three-stage biofilter was superior than one stage biofilter in ammonia biodegradaton, due to gaining more elimination capacity, shorter acclimation time, and also working longer time in steady-sate condition. Liang , *et al.* (2000) in a compost based biofilter and activated carbon as an added material at influent ammonia concentrations of 100 and 200 ppmv achieved the EC of 0.0779 g- NH_3/kg-media per day and 0.1562 g-NH_3/ kg media per day , Mc Nevin and Barford (2000) reported that in a biofilter with mixture of compost, bark mulch and wood chips as packing material reached 1 g $NH_3/m_3/h$ and Kapahi and Gross (1995) by using mixture of compost, oyster and perlite as biofilter medium reported the EC equivalent to 10.6 g $NH_3/m^3/h$. Monitoring of pressure drop in biofilter column is one of important operational parameters. Any increase in pressure drop adds the operating cost of the biofilter as the odorous air must be supplied at greater pressure to achieve the same flow rate (Mc Nevine, *et al.*, 2000). As shown in Fig. 6, there was a gradual pressure building up with time in the both of biofilters due to generation an acclimation of biomass and the accompanying reduction in the bed void fraction as a result of surface oxidation reactions. The average pressure drop and maximum pressure drop of three stage biofilter was less than one-stage biofilter. It was ascribed to probably more compaction of packing material in one-stage biofilter. Also in comparison with other reported pressure drop of 28-128 Pa/m for a biofilter with wood chips as media (Sheridan, *et al.*, 2002) and 218 Pa/m for compost based biofilter (Devinny, *et al.*, 1999) the pressure drop of the three-stage biofilter in this study was less. These results imply that using compost in mixture with thickened municipal activated sludge and pieces of hard plastics is suitable biofilter media for removal of ammonia from waste gas streams with low-pressure drop. According to the results of the study in Table 1, it was concluded that the performance of one-stage biofilter in ammonia biotreatment due to less elimination capacity, longer acclimation time, shorter time working in steady state condition and more pursuer drop was less than three-stage biofilter because of compaction and reduction porosity of packing material in column of one stage biofilter. So design of multi-stage biofilters are advised due to superior performance than one-stage biofilter, because of reaching to higher elimination capacity, longer operation in steady state condition and also avoiding operational problems like high pressure drop, high energy consumption for blowers. Using of mixture of inoculated compost with pieces of hard plastic as packing material showed suitable performance with low pressure drop.

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AUTHOR (S) BIOSKETCHES

Taghipour, H., Ph.D. of environmental health engineering, assistant professor of Department of Environmental Health Engineering, School of Public Health, Golgasht Street, Tabriz University of Medical Sciences, Tabriz, Iran. Email: *hteir@yahoo.com*

Shahmansoury, M. R., Ph.D. of environmental health engineering, associate professor, Department of Environmental Health Engineering, School of Public Health , Isfahan University of Medical Sciences, Isfahan, Iran. Email: *mshamansouri@yahoo.com*

Bina, B., Ph.D. of environmental health engineering, associate professor, Department of Environmental Health Engineering, School of Public Health, Isfahan University of Medical Sciences, Isfahan, Iran. Email: *bbina123@yahoo.com*,

Movahdian, H., Ph.D. of environmental health engineering, associate professor, Department of Environmental Health Engineering, School of Public Health, Isfahan University of Medical Sciences, Isfahan, Iran. Email: *movahedian34@yahoo.com*

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