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Biological Removal of Ammonia from Contaminated Air Streams Using Biofiltration System

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ABSTRACT

Ammonia is a colorless, toxic, reactive and corrosive gas with a sharp odor. It is irritating to the skin, eyes, nose, throat, and lungs. Ammonia gas occurs in the environment naturally and is emitted by many industries and, therefore, its control is essential. Biofiltration is a new emerging technology that is being used as a control procedure. This study evaluates the use of a mixture of compost, sludge, and pieces of PVC as biofilter media to remove ammonia gas. The study investigates the effects of parameters such as inlet concentration, accumulation time, and depth of filter media to evaluate the removal efficiency. A laboratory scale biofilter column was built and operated to investigate the removal of ammonia from a waste gas stream. The findings indicate that for inlet concentrations of 236 ppm, and ammonia loading of less than 9.86 g-NH_3/m^3.h at empty bed residence time of 1 min, an ammonia removal efficiency of more than 99.9% was obtained. The acclimation period of the bacteria was 10 days. The average pressure drop during measurement was 4.44 mm H_2O. The study also revealed that for concentration levels of 99, 211, and 236 ppmv, biofilter media depths of 40, 80, and 120 cm will be required, respectively. The results obtained in this study indicate that the biofiltration system composed of compost in the mixture of sludge and smashed polyvinyl chloride as biofilter media is an efficient method for the removal of ammonia from waste gas streams. It is also found that the optimum depth of biofilter media depends on the inlet concentration of ammonia.

Keywords: *Air pollution, Ammonia, Biofiltration, Biodegradation*

INTRODUCTION

Ammonia is a colorless, toxic, reactive and corrosive gas with a very sharp odor (Davis, 2000; Busca and Piostarino, 2003). Ammonia vapor is irritating to the eye and the respiratory tract and at high concentrations with acute overexposure, can lead to death within minutes. High concentrations of ammonia kill most or because of their odors (Boyeette, 1999). Gaseous ammonia is mainly generated by livestock farming; petrochemical industries; metal manufacturing plants; food, pulp, and paper industries; textile plants; waste treatment plants; and sludge processing and composting plants (Davis, 2000; Busca and Piostarino, 2003). Increasingly, stringent regulations for emissions have stimulated research to develop more efficient and cost effective control technologies (George et al., 2001). The traditional treatment of ammonia is based on physical and/ or chemi-

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cal processes, such as activated carbon adsorption and wet scrubbing condensers. Other methods include thermal oxidation and catalytic ammonia decomposition which are generally expensive and produce secondary pollutants (Davis, 2000; USEPA, 2002).

Air biofiltration has been practiced since the early decades of the last century and has gained much interest in recent years for controlling odorous emissions into the air, toxic compounds, and VOCs (Davis, 2000). The principle of biofiltration is relatively simple: a contaminated air stream is passed through a porous packed bed on which pollutant degrading cultures of microorganisms are immobilized, and air biotreatment relies on microbial reactions for the degradation of waste compounds (Deshusses and Cox, 2000). As the odorous and contaminated air passes through the media, the contaminants in the air stream are absorbed by the biofilm. These contaminants are then oxidized to produce biomass, CO_2, H_2O, NO_3, and SO_4. Biofiltration is an emerging technology (Sheridan et al., 2002), and in comparison with traditional methods of air pollution control, it offers a number of advantages for the treatment of low concentrations of polluted air streams. Besides its high removal efficiency, low capital and operating costs, safe operating conditions, and low energy consumption, it does not generate undesirable byproducts and converts many organic and inorganic compounds into harmless oxidation products (Deving et al., 1999).

Recently, a few studies on biofiltration utilization to remove ammonia have been reported. Kim (2000) studied the removal of high loads of ammonia using newly isolated main bacterium. In another study, the biological NH_3 removal characteristics among four inorganic packing materials were compared (Hirai et al., 2001). In yet another, an immobilized cell biofilter was utilized for the biotreatment of H_2S and NH_3 removal (Chung et al., 2000). Chung et al., (2001) used immobilized hydrotropic bacteria to eliminate ammonia and hydrogen sulfide.

The objective of the present study was to employ biofiltration for the treatment of gas streams polluted by ammonia. This study evaluated the use of the mixture of compost, sludge, and pieces of PVC as biofilter media for the removal of ammonia gas. Along these lines, the effects of such parameters as inlet concentrations, accumulation time, and depth of filter media on the removal efficiency were investigated.

MATERIALS AND METHODS

Biofiltration system A three-bed layer biofilter was designed, manufactured, and used in this study (Fig.1). The biofilter was constructed from a cylindrical metal container with a height of 1.5 m and a diameter of 80 mm. The column of biofilter was packed with the mixture of compost (A), municipal sewage sludge (B), and smashed PVC (C). The compost was supplied from Isfahan Compost Facility and sewage sludge was supplied from South Isfahan Wastewater Treatment Plant. The compost was mixed with sludge and PVC at a ratio of 3-2-1.

The packed biofilter material in each layer (A, B, and C) was supported by a metal sieve plate. Four gas-sampling ports were installed at the inlet and outlet of each layer. In addition, three media sampling ports were fitted in each layer for taking samples from the packing material. Temperature was measured daily by three thermometers located at the mid level of each section of the filter bed. To maintain a constant temperature in the biofilter, the system was equipped with a digital thermostat and a thermocouple. The humidified air stream was prepared by passing pressurized air through a water-containing tower equipped with a thermostat, called the humidification tower.

Measurement methods Ammonia concentration was determined by the indophenols method (Lodge and James, 1990). Temperature was measured using an alcoholic glass thermometer graduated from zero to 100 and a scale division of 1 ºC. The gas flow rate was measured using

flow meters in l/min that was calibrated with the Wet Gas Meter. The pressure drop was determined by a water manometer (with a minimum division length reading of 1-mm water column (H_2O). Moisture of media was measured by weight loss after the medium sample was dried at 103-105 ºC for 24 h to constant weight (APHA, 1992).

RESULTS

Acclimation time One of the major objectives of the study was to determine the time that bacteria need to acclimate to ammonia gas. In this experiment, the first phase lasted for 83 days. As shown (Fig. 2), the removal efficiency was low in the first few days during which stage bacteria were acclimated to ammonia over approximately 10 days. After that, removal efficiency increased by up to 99.9% and the system became stable.

The effect of inlet ammonia concentrations on removal efficiency The other two major objectives of this research included (1) investigation of the removal efficiency of ammonia by the biofiltration system, and (2) determination of the maximum concentration that the biofilter can remove. In order to achieve these objectives, the system in this phase was operated for 83 days (Fig. 2) at a gas flow rate of 6.48 l/min yielding an empty bed residence time (EBRT) for the contaminated air stream of 1 min in the biofilter column. At the beginning of the operation, the inlet concentration was 10 ppmv, and then it increased gradually to about 236 ppmv. During the first few days, the removal efficiency was low but after the acclimation period, the removal efficiency increased rapidly. The maximum concentration that the system was capable of removing was observed to be as high as 236 ppmv. Also, the maximum ammonia removal efficiency was measured at above 99.9%. When the influent ammonia concentration was between 10 to -236 ppmv, the effluent ammonia concentration was found to be less than 0.1 ppmv. However, by increasing the influent concentration to above 236 ppmv, removal efficiency decreased and the system became unstable. Fig. 3 shows the ammonia loading and ammonia removal rate in the biofilter at influent concentrations of 10 - 236 ppmv and maximum ammonia load at 9.86 g-NH_3 /m^3h.

Column pressure drop Resistance to gas flow is the major factor that determines the amount of energy needed by the blowers to force the contaminated gas through the filter (Abumaizar et al., 1998). In the course of the experiment, the pressure drop was continuously monitored by a water manometer and the readings were plotted as a function of time and ammonia loading. As shown in Fig. 4, the system had a high-pressure drop in the first day and after some time there were other pressure drops that were related to the moisture of the medium in the system. The average pressure drop was 4.44 mm H_2O or 43.55 Pa. No clear relation was found between influent ammonia loads and pressure drop.

Moisture content of the biofilter material

The moisture of the biofilter media is an important operational parameter since it directly influences the efficiency of the biofilter and pressure drop across the filter medium. The optimum moisture content in the biofilter was between 40% and 60% (Deving et al., 1999). In order to maintain moisture content of the packing material in the optimum range, in addition to humidifying the polluted air stream in the humidifying tower, it was sometimes necessary to spray water on top of the filter before air introduction into the biofilter (Fig. 5).

Temperature control The temperature of the system was controlled daily, because it played a very important role in microorganisms' life. The optimum temperature for nitrifying bacteria including nitrobacteria and Nitrosomonas is 30 °C (Biton, 1994). Therefore, the average temperature was maintained at 30 °C during the operation of the system.

Effect of biofilter's height in ammonia removal In order to find out the effect of the height of the biofilter in the removal of ammo-

nia, samples were taken from each gas-sampling port installed at the inlet and at the outlet of each layer at depths of 40, 80, and 120 cm in the biofilter column at different inlet concentrations and at different times. The results are shown in Fig. 6.

Guide table

1	Humidification tower	9	First layer of bioflter
2	Air distributor	10	Second layer of bioflter
3	Warmer and Thermostat	11	Third layer of bioflter
4	Ammonia gas cylinder	12	Leachate outlet
5	Inlet of nutrients	13	Gas outlet
6	Gas flow meter	14	Regulator
7	Gas sampling port	15	Air Compressor
8	Media sampling port	16	Separating Plate

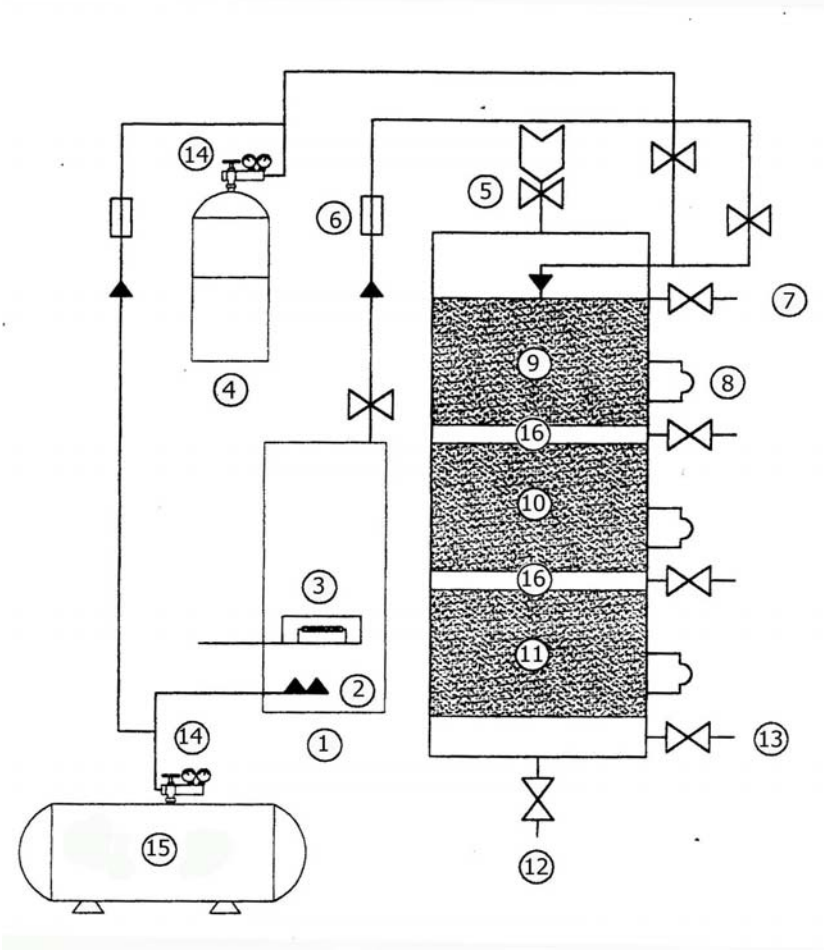

Fig. 1: Flow diagram of biofiltration pilot

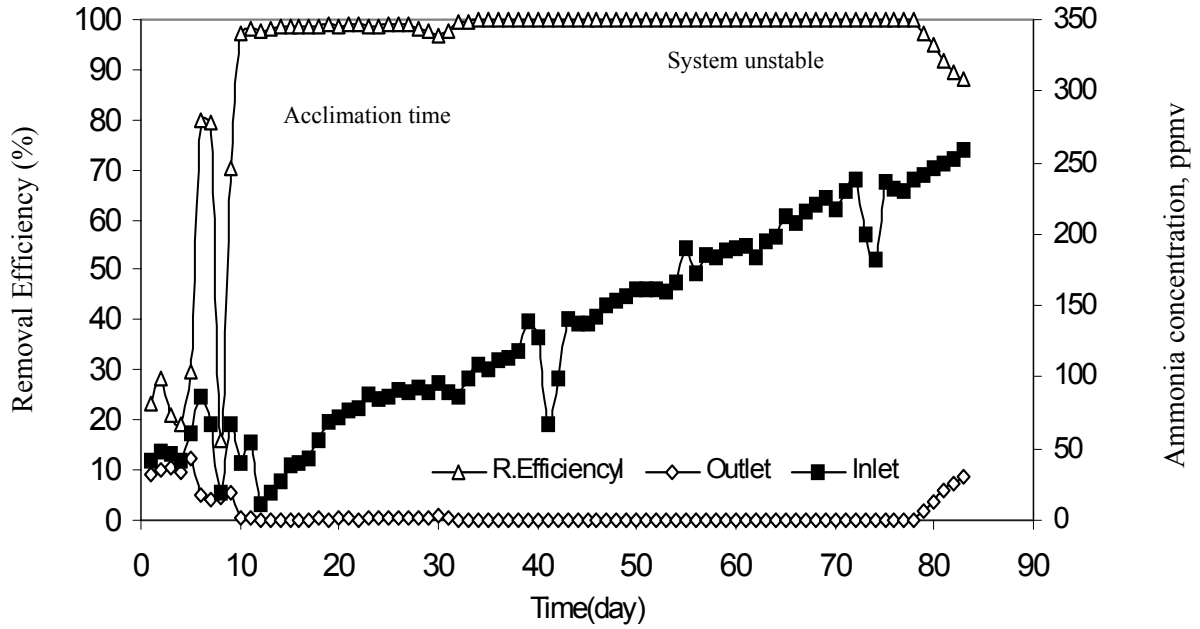

Fig. 2: Performance of bioflilter during 83 days with EBRT of 1 Minute

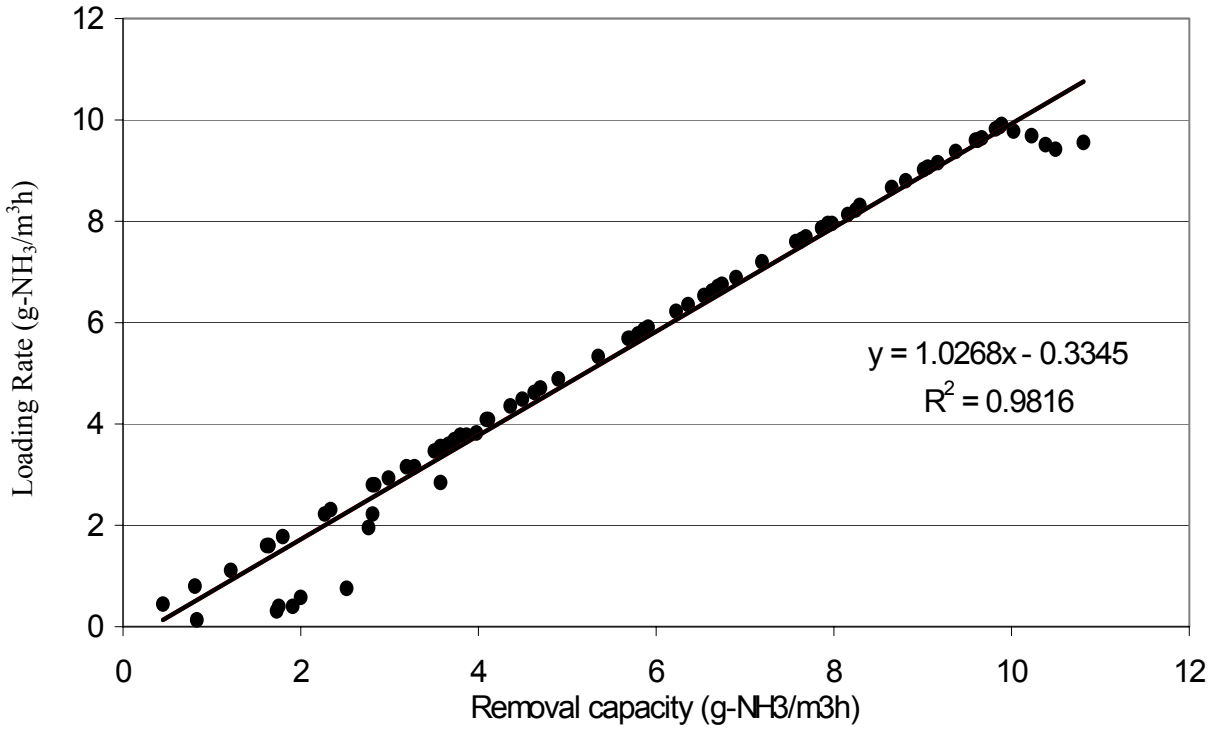

Fig. 3: Relation between removal capacity and loading rate

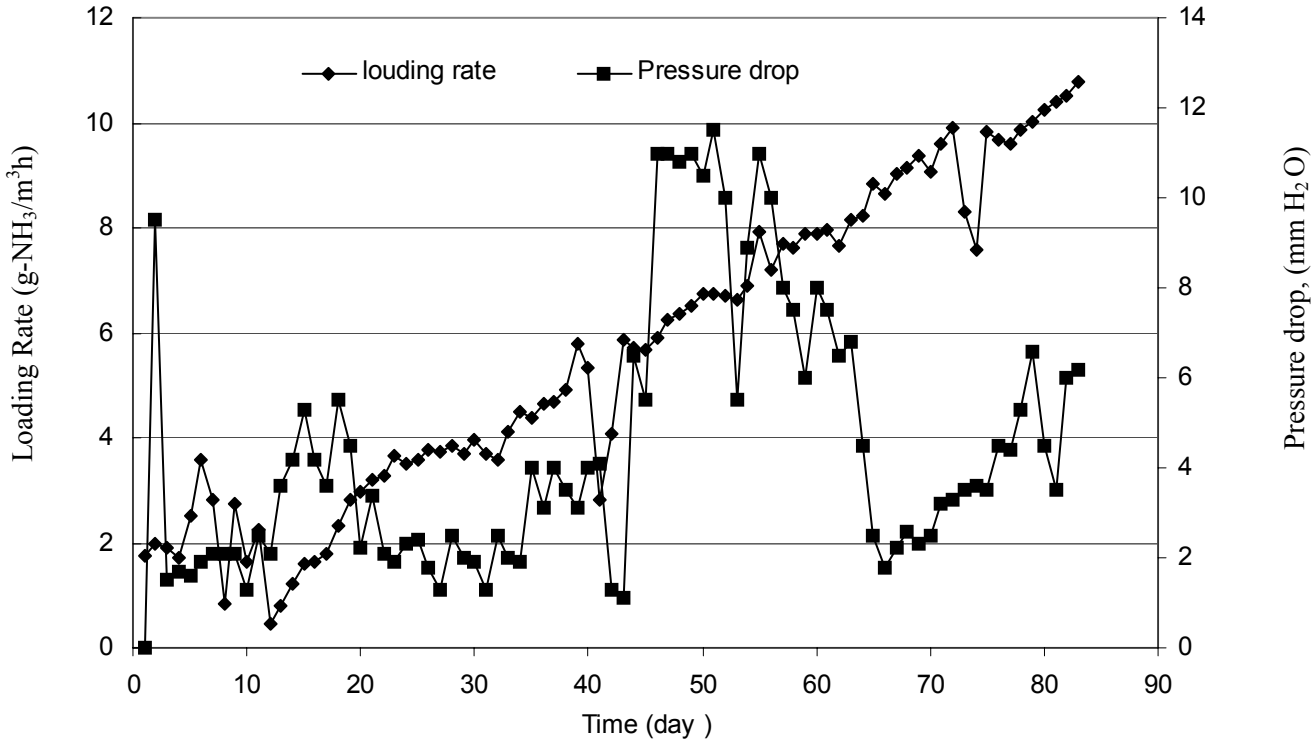

Fig. 4: Relation between pressure drop and loading rate of ammonia

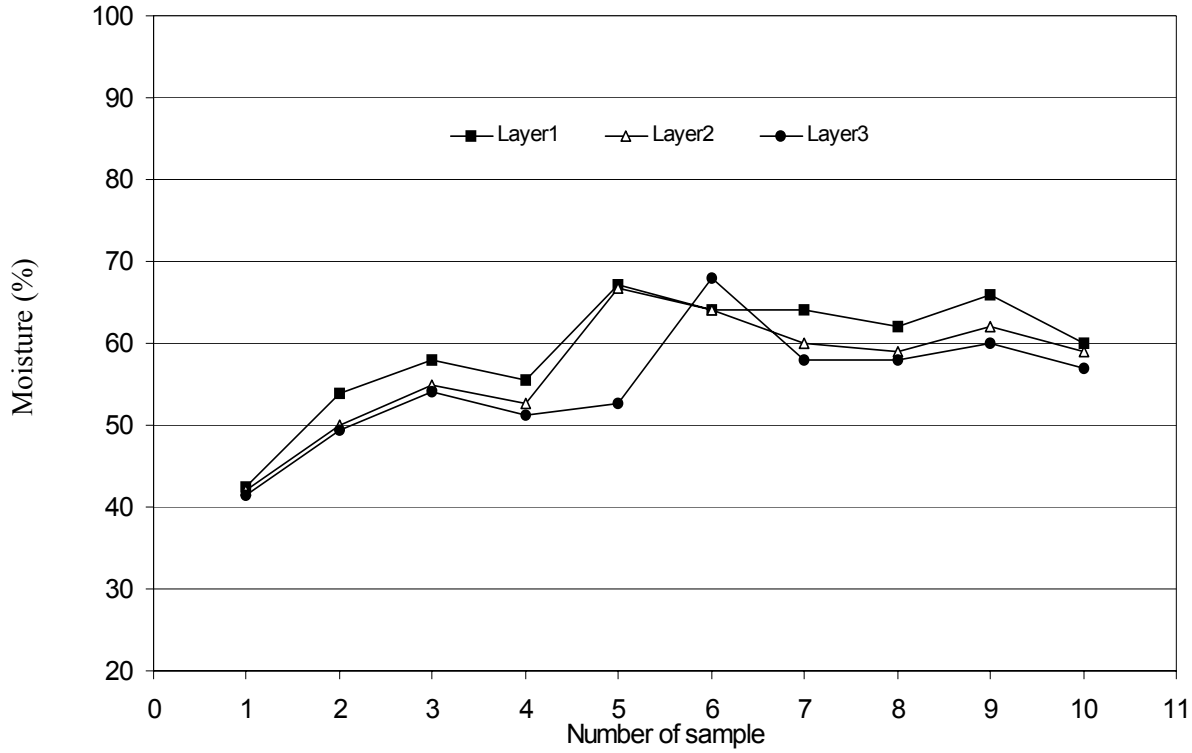

Fig. 5: Moisture content profile in biofilter media during of experiment

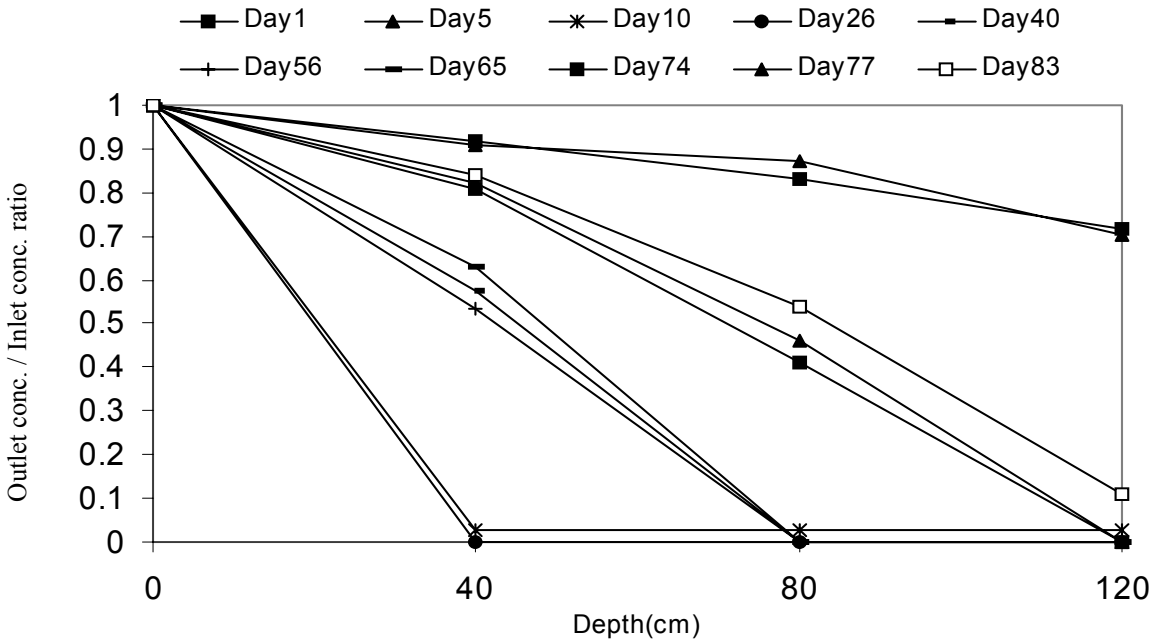

Fig. 6: Ratio of outlet to inlet ammonia concentration in different depth of biofilter

DISCUSSION

In the process of ammonia biofiltration, microorganisms convert ammonia to nitrate. This process is carried out by two categories of chemioautotroph and aerobic microorganisms. Conversion of NH_4^+ to NO_2^- is accomplished by nitrosomonas and nitrobacteria that convert NO_2^- to NO_3^-. The microbial population in the packing material is relatively inactive before contact with the ammonia substrate. After the acclimation period has passed, the microorganisms grow in mass and number in the thin layer of water surrounding the support media of the biofilter forming a biofilm. The pollutants diffuse from the gas phase into the biofilm where the microorganisms are immobilized and in which oxidation of ammonia into harmless by-products of NO_2^-, NO_3^- occur. As shown in Fig. 2, the ammonia removal efficiency of the biofilter system was high and was found to be more than 99.9% at empty bed residence time (EBRT) of 1 min. This result complied with removal efficiencies of 54% to 93% and 95% obtained by Sheridan et al.(2002) and Yangkun et al.(2000), respectively. According to the results from the present study, the influent ammonia concentration should be less than 236 ppmv (Fig. 2) and the load of ammonia must be less than 9.86 g-NH_3 /m^3h. However the results from similar studies meet the maximum influent concentration of 200 ppmv (Yangkun et al., 2000; Hirai et al., 2001). According to Fig. 2, the effluent concentration of ammonia was less than 0.1 ppmv that meets air emission standards (Yongkun et al., 2000). As shown in Fig. 4, the pressure drop was very low and the average pressure drop was less than 4.44 mm H_2O (43.55 Pa); therefore, if the system is to be used at full scale, power costs will be acceptably low.

No clear relation was found between ammonia load and pressure drop. Pressure drop generally depends on moisture of the medium in the system. To maintain optimum moisture content (40-60%), in addition to humidifying the influent gas in the humidifying tower, it was sometimes necessary to spray water on top of the

biofilter media. It was also found (Fig. 6) that at inlet ammonia concentrations of less than 99, 211, and 230 ppmv, the required bed depths would be 40, 80, and 120 cm, respectively. This is important because the biofilter height should be designed with respect to ammonia concentration level. If the biofilter is designed excessively high, only the first part of the system will be used for the treatment of pollutants. Under such conditions, it will not be cost-effective while operational problems may also arise (Abumaizart et al., 1998). Thus, the height of the biofilter system can be designed on the basis of inlet concentration at the pollution source. The mixture of compost with sludge and smashed PVC was found in the present study to be a suitable biofilter media for the removal of ammonia from waste gas streams with high removal efficiency and low-pressure drops. The advantages of mixing sludge and PVC with compost included increasing the population of nitrifying bacteria to decrease acclimation time and to reducing chances for compaction and channeling in the filter media (Hirai et al., 2001). As an air pollution control technology, the use of microbial biofilters for the treatment of air streams contaminated with ammonia is reliable, highly efficient, and easy to operate and maintain. In addition to the high removal efficiency and low capital requirements and operating costs, it does not generate undesirable byproducts and converts ammonia into harmless nitrate.

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