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Transient behavior of biofilter inoculated with *Thiobacillus* sp. IW to treat waste-air containing hydrogen sulfide

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Abstract–Hydrogen sulfide is heavier than air and is colorless, toxic and flammable, the gas odor threshold of which is about 0.47 ppbv, which causes nuisance odor at concentrations as low as about 8ppbv and corrosion problems in sewer systems. The transient behavior of biofilter packed with mixed media (of granular activated carbon and compost) inoculated with a pure culture of *Thiobacillus* sp. IW was observed at a height of four sampling ports to treat waste-air containing hydrogen sulfide in this investigation, which shall be used as control to be compared with the performance of a biofilter-involved integrated system for the treatment of waste-air containing hydrogen sulfide in a subsequent investigation. Unlike the previous studies of the other investigators, various process conditions were applied to successive biofilter runs in order to monitor and correlate each corresponding unsteady behavior of the biofilter at the height of each sampling port. During 10 days (20 times) after start-up of a biofilter hydrogen sulfide was continuously adsorbed on the media and that the adsorption of hydrogen sulfide was under way since the inlet loads of 1st and 2nd stage operations were very low. Afterwards it was obvious that the breakthrough curves at the 1st, 2nd, 3rd and 4th (exit) sampling ports responded rapidly to the change of operating conditions of a biofilter so that the breakthrough curve at each sampling port responded rapidly to approach a new state of saturation, which suggests that the adsorption capacity of biofilter-media may be relatively small or its affinity to hydrogen sulfide may be relatively high, compared to such volatile organic compound as ethanol. Up to the 3rd stage of operation the removal efficiency continued to be nearly 100%. However it began to decrease as inlet load increased. At the end of last stage of the biofilter-run removal efficiency was decreased and maintained at 94%. The maximum elimination capacity was observed to be ca. 95 g/m^3/h, which was higher than that of the biofiltration-work of any other previous investigator except for that of the biofiltration-work with use of each of two inorganic packing materials (porous ceramics, calcinated and formed obsidian).

Key words: Biofilter, Hydrogen Sulfide, Transient Behavior, Removal Efficiency, Elimination Capacity

INTRODUCTION

Hydrogen sulfide is frequently emitted not only in such industrial activities as petroleum refining, pulp and paper manufacturing and food processing but also from publicly owned treatment works (POTWs). Hydrogen sulfide is heavier than air and is colorless, toxic and flammable, the gas odor threshold of which is about 0.47 ppbv [Oyarzun et al., 2003], which causes nuisance odor at concentrations as low as about 8 ppbv and corrosion problems in sewer systems [Cox and Deshusses, 2002]. It is treated in most cases by use of caustic/hypochlorite or caustic/peroxide scrubbers. However, such physicochemical methods as chemical scrubbers are expensive to operate since those for its removal from gas emissions in use today have relatively high energy requirements or high chemical and disposal cost. Biological treatment by use of biofilter has been suggested as a convenient alternative for treating waste air containing hydrogen sulfide [Oyarzun et al., 2003]. In general, biofilters have been reported to excel in the removal of odoriferous compounds from waste air [Oyarzun et al., 2003; Cox and Deshusses, 2002; Hirai et al., 1990; Eckhart, 1987; Lee et al., 2000; Islander et al., 1990; Hirai et al., 2001; Cho et al., 2000; Wani et al., 1998; Chung et al., 1996a, b, 2001; Elias et al., 2002]. Bioreactors are reactors in which a humid polluted airstreams are passed through a porous packed bed on which pollutant-degrading microbial cultures are naturally immobilized. The technology consists of exploring the contaminated air to a moist film of microbes attached to a stationary synthetic or natural support medium. Biological waste air treatment processes offer a cost-effective solution for the treatment of large volumetric air-streams containing low levels of pollutants [Ottengraf, 1986; Sorial et al., 1995; Lim and Lee, 2003; Lim and Park, 2004; Lim, 2005]. Hydrogen sulfide can be removed by various microbes largely divided into aerobic and anaerobic microbes. For aerobic microbes HS^- and S^0 may be oxidized in hydrogen sulfide removal system to produce S^0 and SO_4^{-2}, respectively, to supply energy to the cell and produce odorless compounds. Among hydrogen sulfide-degrading aerobic-microbes bacteria from the genus Thiobacillus exhibit less nutritional requirement, shorter initial lag phase and higher removal efficiency of hydrogen sulfide in biofiltration system than chemoheterotrophic bacterias [Oyarzun et al., 2003; Buisman et al., 1990].

Oyarzun et al. [2003] previously investigated the biofiltration of high concentration of hydrogen sulfide above 1,000 ppmv using *Thiobacillus thioparus* where the maximum elimination capacity of 55 g S/m^3/h was reached. Cox and Deshusses [2002] investigated the use of biotrickling filters for the co-treatment of high loadings of H_2S and toluene at different pH. In their experiment the concen-

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trations of H_2S and toluene were up to 170 ppmv and upto 2.2 g/m^3, respectively, and the H_2S maximum elimination capacity of 20 g/m^3/h was observed. Hirai et al. [2001] compared the biological H_2S removal characteristics among four inorganic packing materials (porous ceramics, calcinated cristobalite, calcinated and formed obsidian and granulated and calcinated soil) inoculated with the sludge taken from a reservoir tank for UF film separation of a soil treatment plant. In their investigation the maximum elimination capacities of biofilter with use of inorganic packing materials of porous ceramics and calcinated and formed obsidian were 146 g S/m^3/h and 142 g S/m^3/h, respectively, while those with use of calcinated cristobalite and granulated and calcinated soil were 50 g S/m^3/h and 67 g S/m^3/h, respectively. Thus the maximum elimination biofilter capacities with use of inorganic packing materials of porous ceramics and calcinated and formed obsidian were superior over those with use of calcinated cristobalite and granulated and calcinated soil. Wani et al. [1998] researched the effects of periods of starvation and fluctuating hydrogen sulfide concentration on biofilters packed with compost/perlite (4 : 1), hog fuel/perlite (4 : 1), and compost/hog fuel/perlite (2 : 2 : 1), where it was observed that the maximum elimination capacity of biofilter under its given operating conditions was ca. 27 g S/m^3/h, and the extended periods of starvation resulted in longer re-acclimation periods. Chung et al. [1996a] performed biodegradation of hydrogen sulfide by laboratory-scale immobilized *Pseudomonas putida* CH11 biofilter. The maximum removal rate was calculated to be 1.36 g S/day/kg dry-bead, which may be converted into the equivalent form of 20 g S/m^3/h with the bead dry weight of 0.25 kg and the packed volume of 0.7 L from their experiments. Chung et al. [1996b] optimized the operation of biofilter inoculated with *Thiobacillus thioparas* CH11 for hydrogen sulfide removal. In their experiments the concentration of hydrogen sulfide was kept up to 60 ppmv and the maximum elimination capacity turned out to be below 25 g/m^3/h. Chung et al. [2001] showed that hydrogen sulfide removal of biofilter packed with immobilized heterotrophic bacteria of *Pseudomonas putida* CH11 was significantly affected by high inlet concentrations of hydrogen sulfide since high hydrogen sulfide concentration was an inhibitory substrate for the growth of heterotrophic sulfur-oxidizing bacteria. In their investigation the maximum elimination capacity of hydrogen sulfide under its applied operating conditions was 8 g/m^3/h. Elias et al. [2002] evaluated a packing material based on pig manure and sawdust in the experiments of biofiltration of waste air containing hydrogen sulfide, in which the maximum inlet load of hydrogen sulfide applied was 45 g/m^3/h and its corresponding removal efficiency was ca. 90% so that the maximum elimination capacity was reached at ca. 40 g/m^3/h.

In the present work, the transient behavior of biofilter packed with mixed media (of granular activated carbon and compost) inoculated with a pure culture of *Thiobacillus* sp. IW was observed at the height of four sampling ports to treat waste-air containing hydrogen sulfide. Unlike the previous studies of the other investigators various process conditions are applied to successive biofilter runs in order to monitor and correlate each corresponding unsteady behavior of the biofilter at the height of each sampling port. It will be used as control to be compared with the performance of the biofilter-involved integrated system for the treatment of waste-air containing hydrogen sulfide in subsequent investigation.

MATERIALS AND METHOD

1. Biofilter Design and Its Apparatus

The experiment to treat waste-air containing hydrogen sulfide was performed to observe transient behavior of biofilter. Biofilter reactor was manufactured in a way that feed gas entered from the top of the biofilter composed of two acryl tubes (diameter: 5 cm, length: 25 cm) connected in series. Upper and lower reactor tubes were packed up to 22 cm and 22 cm from their bottom with media, respectively, so that total effective height of the biofilter was adjusted to 44 cm. Among four sampling ports of the biofilter the 1st one, 2nd one and 3rd one were positioned at 12 cm below top surface of the upper media, 2 cm below top surface of the lower media and 12 cm below top surface of the lower media, respectively. Fourth sampling port was positioned at the exit of the biofilter. Therefore, the ratios of effective height to total were 0.27, 0.55, 0.77 and 1.0 for 1st one, 2nd one, 3rd one and 4th one, respectively.

In the biofilter mixture of equal volume of granular activated carbon and compost with an average radius of 3 mm and 0.6 mm, respectively, was used as the packing media of the biofilter. Granular activated carbon chosen as supporting material of the packing media has shortcomings of frequent channeling and short circuiting with increased pressure drop resulting from microsomal growth while it has the advantage of high buffer capacity against sudden shock loading owing to high adsorption capacity. Nutrition necessary for the growth of microorganisms was provided by organic packing media, i.e., compost. Buffer solution was intermittently provided, to the extent that there was no drainage of buffer solution from the bottom of the biofilter, to the top of the biofilter in order to maintain the optimum pH and moisture condition.

Air provided by blower (Young Nam Yasunnaga, outlet pressure; 0.12 kg/cm^2, maximim flow rate; 43 L/min) passed through series of three humidifier columns maintained at 40-50 °C by thermostat (Jeil Science, J-PW B2) and its relative humidity was maintained at 95-99%. Then humidified air was provided to the mixing chamber where it was mixed with the adjusted amount of concentrated hydrogen sulfide gas to determine the concentration of hydrogen sulfide in the feed gas to the top of a biofilter. Variously concentrated hydrogen sulfide gases (1,000, 4,000 and 8,000 ppmv, 1,500 psia) were purchased from RiGas in the form of the stainless steel or aluminium cylinder of 10 L. The concentrated hydrogen sulfide gas was passed through a regulator, metering valve (Swagelok, S series: viton sealing) and mass flow controller (Bronkhorst, F-201D) where the amount of the concentrated hydrogen sulfide was adjusted and was fed to the mixing chamber. Stainless steel tubing of 1/8 inch I.D. was used to supply it from the concentrated hydrogen sulfide gas cylinder to the mixing chamber. Tygon tube was used to convey pure air from blower and viton tube was used to transport feed gas of manufactured waste-air containing hydrogen sulfide from the mixing chamber to the biofilter. Temperature of biofilter column was maintained at 30 °C by heating band and swagelok fitting was used for all fittings. Schematic diagram of biofilter-process is shown as Fig. 1.

2. Microorganism, Inoculum Preparation, Bacteria Count

Thiobacillus sp. IW was provided from Pusan University and was incubated in the following way in order to inoculate the media of a biofilter. The medium was prepared according to the composi-

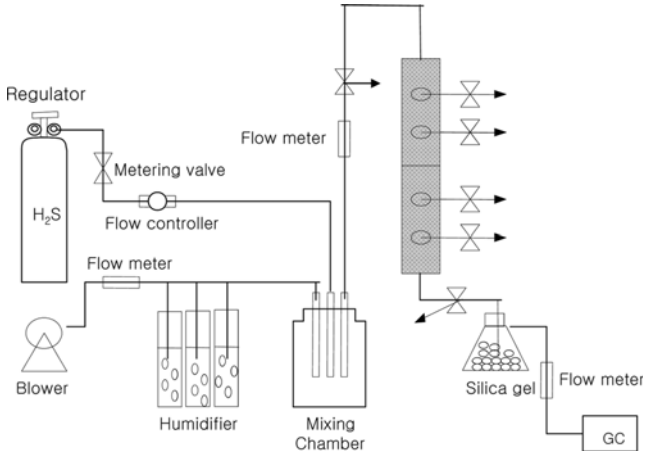

Fig. 1. Schematic diagram of the biofilter process.

Table 1. Compositions of the medium to incubate *Thiobacillus* sp. IW

Medium component		Medium component	
NH_4Cl	0.5 g/L	$MnCl_2 \cdot 4H_2O$	0.01 g/L
K_2HPO_4	4.0 g/L	$FeSO_4$	0.05 g/L
KH_2PO_4	4.0 g/L	$(NH_4)_6Mo_7O_{24}$	0.01 g/L
$MgSO_4$	0.8 g/L	$CuSO_4$	0.01 g/L
$Na_2 \cdot EDTA$	0.5 g/L	CoCl2	0.01 g/L
$ZnSO_4$	0.22 g/L	$Na_2S_2O_3$	8 g/L
$CaCl_2$	0.05 g/L	yeast extract	2 g/L

tions as shown in Table 1. Microorganism on the petri-dish was taken by loop transfer needles, was dropped into a prepared medium in the flask and was incubated under the condition of 30 °C and 200 rpm set by shaking incubator. Microorganism was inoculated, when the absorbance of the medium representing optical density measured in every 3 hr at a wave length of 660 nm by UV-Visible spectrophotometer exceeded 0.8, on the packing media of biofilter by recycling the incubated microorganism with the medium into a biofilter for 72 hrs.

Microbial count fixed on packing media was determined in the following way. One gram of packing media was vortexed with 5 ml of sterilized demineralized water and it was ground in 5% paraformaldehyde solution for 48 hrs. The ground sample was 10 times diluted and was filtered with polycarbonate membrane filter (pore size 0.2 μm, ø25 mm) by 1 ml at a time and the filter was dried. The dried filter was placed on slide glass and was stained by 10 μl of DAPI (4'-6-diamidino-2-phenylindole, 0.33 mg/ml) for 1 hr in dark box. After the stained filter was washed and was dried, each drop of fluoroguard-antifade-reagent was dropped on each side of the stained filter. It was coved with cover glasses and was observed by fluorescence microscope (Axiolab, Xeiss, Germany) UV filter (G365, LP395, FT420). The total bacterial number (TBN) was calculated by formula as below:

$$\text{TBN (total bacterial number)} = \frac{A_0 \times F_1}{F_2 \times F_3}$$

A_0 : Average cell number in field
F_1 : Filter area
F_2 : Field area
F_3 : Filter sample volume

3. Analytical Methods

The concentrations of hydrogen sulfide were measured in the following way at the positions of feed and four sampling ports. A gas chromatograph (Shimazu, GC-2010AF) equipped with flame photometric detector (FPD) and silica capillary column (30 m×0.32 mm×4.0 μm) was calibrated with hydrogen sulfide standard gas (1 ppmv) purchased from RIGAS. The flow rates of air, helium and hydrogen were 82, 4 and 85 ml/min, respectively. The operating temperatures of injector, oven (column) and detector were 100 °C, 50-230 °C and 225 °C, respectively. Alternatively, gas detector tubes (Gastec, 4LK-4LT and 4L-4LL) were purchased from Gastec and were used to measure the concentration of hydrogen sulfide.

4. pH, Density, Moisture

The optimum control of pH and moisture of the packing media in the biofilter reactor is definitely necessary for adequate operation of the biofilter. Buffer solution was intermittently supplied at a rate of 0.4 ml/min by peristaltic pump (Masflex) to maintain the optimum pH of packing media. For the measurement of pH each ten grams of media sample was taken from each sampling port. After it was placed in a beaker and was shaken with 50 ml of de-mineralized water, its supernatant was taken to measure the pH of the media with a pH meter (Isteck 720P).

Each twenty grams of media sample was taken from each sampling port to place in vacuum dry oven (Sam Heung) for 24 hrs at 105 °C and to measure dried weight of the sample. The moisture content of the media was calculated by the difference of its weight between before and after drying. Density of the media was measured on basis of equal volume mixture of granular activated carbon (25 ml) and compost (25 ml).

5. Biofilter Experiment

5-1. Process Condition

For 5 days (10 times) of biofilter operation (i.e., 1st stage of operation) air was supplied to a mixing chamber at the rate of 0.5 L/min, and concentrated hydrogen sulfide of 1,000 ppmv was provided at the rate of 0.015 L/min set by mass controller from the pressurized cylinder of 1,500 psi to the mixing chamber. Therefore, the theoretical hydrogen sulfide feed-concentration of manufactured waste-air from the mixing chamber was 30 ppmv assuming it was ideal gas. At the 2nd stage of biofilter operation (11-20 times) the same hydrogen sulfide concentration was maintained as that of 1st stage of operation. However, the air supply rate and the rate of concentrated hydrogen sulfide of 1,000 ppmv to the mixing chamber were increased by factor of two to be 1 L/min and 0.03 L/min, respectively, so that hydrogen sulfide inlet load was doubled. During 3rd stage (21-30 times) the air-supply rate was kept the same as 1 L/min and the feeding rate of concentrated hydrogen sulfide of 1,000 ppmv was increased, by factor of two, up to 0.06 L/min. Therefore, theoretical hydrogen sulfide feed-concentration was increased by a factor of two to be 60 ppmv in the same way as inlet load was. At 4th stage of operation (31-40 times), the air-supply rate and the rate of concentrated hydrogen sulfide of 4,000 ppmv were adjusted to be 2 L/min and 0.03 L/min, respectively. Thus, theoretical hydrogen sulfide feed-concentration was maintained to be as same as 60 ppmv and inlet load was doubled. At 5th stage of operation (41-50 times), the air-supply rate was kept the same and the feeding rate

Table 2. Operating condition of each stage of biofilter-process

Stage (times) / Theoretical value	I (1-10)	II (11-20)	III (21-30)	IV (31-40)	V (41-50)	VI (51-55)	VII (56-60)
Q (L/min)	0.5	1			2		
C_{go} (ppmv)	30		60		100	250	500
τ (min)	1.72	0.86			0.43		
Inlet load (g/m^3/h)	1.5	3	6	12	20	50	100
Feeding rate (L/min)	0.015 (1000)	0.031 (1000)	0.064 (1000)	0.0305 (4000)	0.0513 (4000)	0.1333 (4000)	0.1333 (8000)

Q : air flow rate

C_{go}: feed concentration

τ : retention time (effective height: 0.44 m)

Feeding rate : feeding rate of concentrated hydrogen sulfide gas (In the parenthesis the concentrations of concentrated hydrogen sulfide gas are shown in the unit of ppmv)

Table 3. Compositions of buffer and mineral medium

Salt stock solution		Mineral solution	
$NaHPO_4$	70 g/L	$CaCl_2 \cdot 2H_2O$	0.37 g/250 ml
KH_2PO_4	30 g/L	$MgSO_4 \cdot 7H_2O$	6.16 g/250 ml
NaCl	50 g/L		
NH_4Cl	10 g/L		

of concentrated hydrogen sulfide of 4,000 ppmv was increased to be 0.05 L/min so that theoretical hydrogen sulfide feed-concentration was raised to 100 ppmv and the corresponding inlet load was increased by 67%. At 6th (51-55 times) and 7th (56-60 times) stages of operation, air-supply rates were kept as same as 5th stage of operation. The feeding rates of concentrated hydrogen sulfide of 6th and 7th stages of operation were increased to be 0.13 L/min of 4,000 ppmv and 0.13 L/min of 8,000 ppmv, respectively, so that their theoretical hydrogen sulfide feed-concentrations were raised to 250 ppmv and 500 ppmv, and their inlet loads were increased by 150% and 100%, respectively. The operating conditions of a biofilter are shown in Table 2.

5-2. Buffer Solution

The solutions, as shown in Table 3, were mixed in such a fixed proportion as [salt stock solution (100 ml)+$CaCl_2 \cdot 2H_2O$ (10 ml)+$MgSO_4 \cdot 7H_2O$ (10 ml)+sterilized distilled water (880 ml)] to make 1 liter of the buffer and mineral medium. Ten milliliters of buffer solution was intermittently provided to the top of a biofilter by peristaltic pump (Masterflex).

RESULTS AND DISCUSSION

1. Time Evolutions of Hydrogen Sulfide Concentrations at Four Sampling Ports

Transient behavior of hydrogen sulfide concentrations measured at the position of feed inlet and four sampling ports of a biofilter, is shown in Fig. 2 when the biofilter was run at 30 °C under various operating conditions as shown in Table 2 for 30 days (total 60 times with measuring frequency of two times per day). The concentrations of hydrogen sulfide measured at the position of feed inlet, 1st, 2nd and 3rd sampling ports, and 4th sampling port (exit) are shown as in Figs. 3 and 4, respectively.

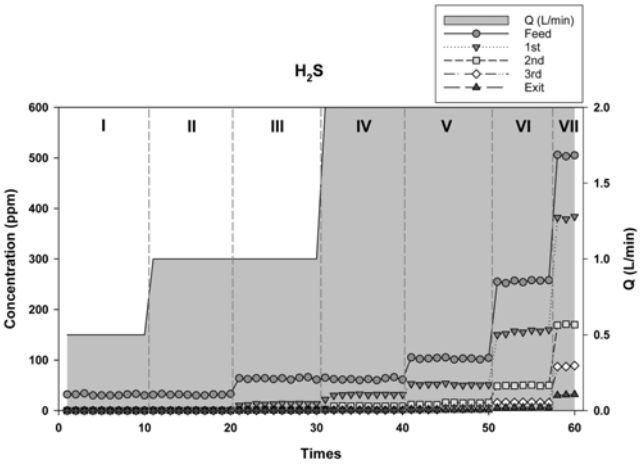

Fig. 2. Various hydrogen sulfide concentrations of biofilter process at each sampling port (1st, 2nd, 3rd and exit) versus experimental times.

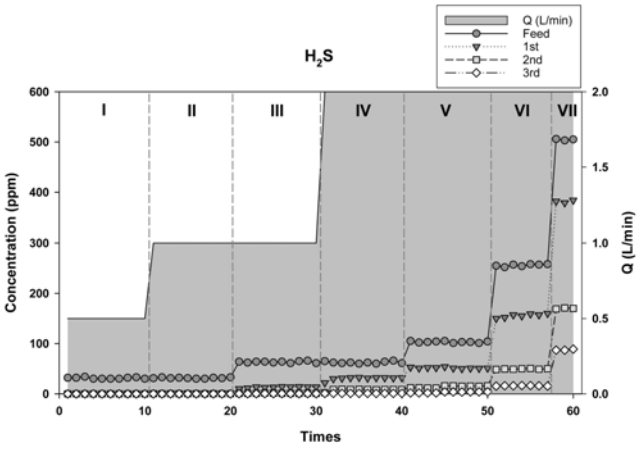

Fig. 3. Various hydrogen sulfide concentrations of biofilter process at feed inlet, 1st, 2nd and 3rd sampling ports.

During 10 days (20 times) after start-up of a biofilter the transient behavior of all breakthrough curves for all sampling ports showed that hydrogen sulfide was continuously adsorbed on the media and

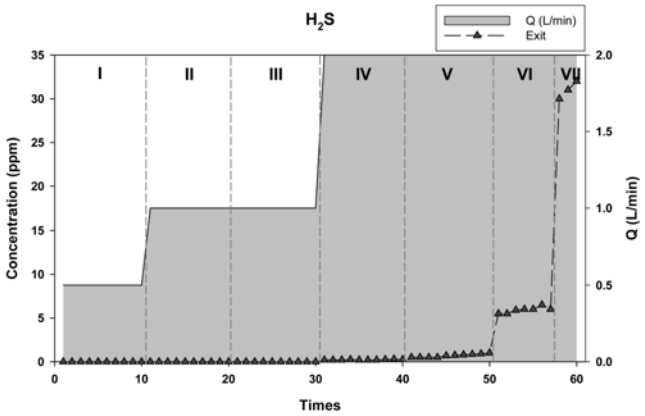

Fig. 4. Various hydrogen sulfide concentrations of biofilter process at 4th sampling port (exit).

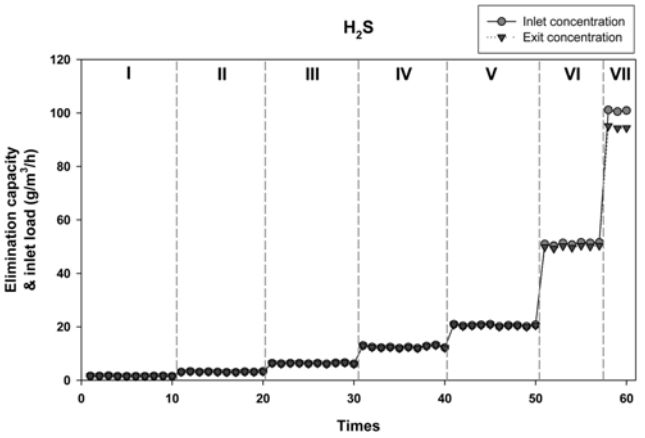

Fig. 6. Elimination capacity and inlet load of hydrogen sulfide versus times.

that the adsorption of hydrogen sulfide was under way since theoretical inlet loads of 1st and 2nd stage operations were very low. At 3rd stage of biofilter-operation (21-30 times), the feeding rate of concentrated hydrogen sulfide was increased by a factor of two so that the breakthrough curve at the 1st sampling port responded rapidly to approach a new state of saturation, which suggested that the adsorption capacity of biofilter-media may be relatively small or its affinity to hydrogen sulfide may be relatively high compared with such a volatile organic compound as ethanol. Therefore, it was shown after the 4th stage of operation in Figs. 2, 3 and 4 that the saturation by adsorption from each unsteady behavior of breakthrough curve took place almost simultaneously at each sampling port even though its order should be observed in such way as 1st, 2nd, 3rd and 4th (exit) sampling ports were in the 1st, 2nd, 3rd and 4th place, respectively. At the former sampling port a breakthrough curve reached the status of saturation by adsorption, the higher its hydrogen sulfide concentration of waste-air passing through the position of its sampling port was. At 4th stage of operation (31-40 times), the breakthrough curves at the 1st and 2nd sampling ports responded rapidly to approach a new state of saturation since the inlet load of hydrogen sulfide was doubled even though theoretical hydrogen sulfide feed-concentration was maintained as same as 60 ppmv. Furthermore, it was obvious that the breakthrough curves at the 1st, 2nd, 3rd and 4th (exit) sampling ports responded rapidly in 7th (last) stage of operation as shown in Figs. 2, 3 and 4. Thus, the buffer capacity of the biofilter-media (i.e., mixture of granular activated carbon and compost) to hydrogen sulfide was expected to be too small to maintain stable operation of a biofilter treating waste air with highly fluctuating hydrogen sulfide inlet load.

Time-evolutions of removal efficiency and elimination capacity versus inlet load were shown as in Figs. 5 and 6, respectively. Up to the 3rd stage of operation the removal efficiency continued to be nearly 100% and the removal efficiencies of hydrogen sulfide at 4th, 5th and 6th stages of operation decreased to 99.5, 99 and 98%, respectively, as shown in Fig. 5. However, it began to decrease when inlet load surpassed, as in Fig. 6, 50 g/m^3/h. At the end of 7th stage of biofilter-run removal efficiency was decreased and maintained at 94% as shown in Fig. 5. The maximum elimination capacity was observed to be ca. 95 g/m^3/h, as shown in Fig. 7, which was higher than that of the work of any other previous investigator [Oyarzun et al., 2003; Cox and Deshusses, 2002; Hirai et al., 2001; Wani et al., 1998; Chung et al., 1996a, b, 2001; Elias et al., 2002] except for that of the work of Hirai et al. [2001] with use of each of two inorganic packing materials(porous ceramics, calcinated and formed

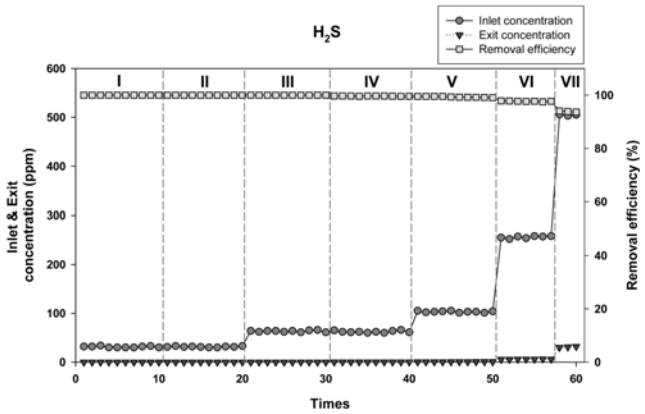

Fig. 5. Removal efficiency, inlet and exit concentrations of hydrogen sulfide versus times.

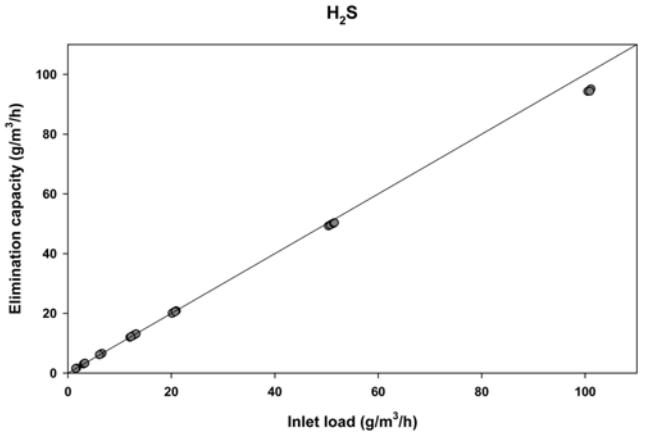

Fig. 7. Elimination capacity versus inlet load of hydrogen sulfide at the exit of biofilter process.

obsidian).

2. Analysis of Packing Media

2-1. Density

The density of equal volume mixture of granular activated carbon and compost was 0.39 before biofilter-experiments.

2-2. pH and Moisture Content

The pHs of packing media from 1st, 2nd and 3rd sampling ports were the same as 7 at the beginning of biofilter experiments. However, they changed to 4.48, 5.27 and 6.33 at the end of biofilter experiments, respectively. Dried weights of the media from 1st, 2nd and 3rd sampling ports were 9.44 g, 8.56 g and 8.68 g (the weight of the media before drying was 20 g), by which moisture contents of the media from 1st, 2nd and 3rd sampling ports turned out to be 52.82%, 57.22% and 56.67%, respectively.

2-3. Microbial Counts

Thiobacillus sp. IW immobilized on the packing media of a biofilter was observed by field emission scanning electron microscope (Hitachi, S-4300) as shown in Fig. 8. Microbial count fixed on packing media was determined by observation with fluorescence microscope (16×100) (Axiolab, Xeiss, Germany) as shown in Fig. 9. The total bacterial numbers (TBN) for the 1st, 2nd and 3rd sampling ports turned out to 1.52×10^9/g, 7.30×10^8/g and 4.62×10^8/g, respectively. Thus, the microbial distribution in the biofilter was in the way that total bacterial number (TBN) was decreased as the effective height of the position of sampling port was increased.

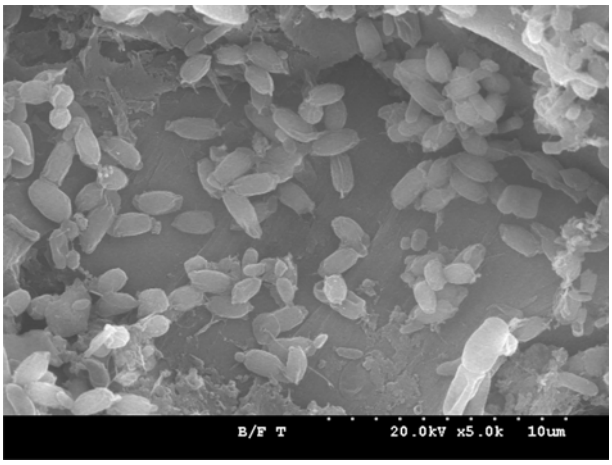

Fig. 8. *Thiobacillus* sp. IW observed on the surface of the packing-media of biofilter by field emission scanning electron microscope (Hitachi, S-4300).

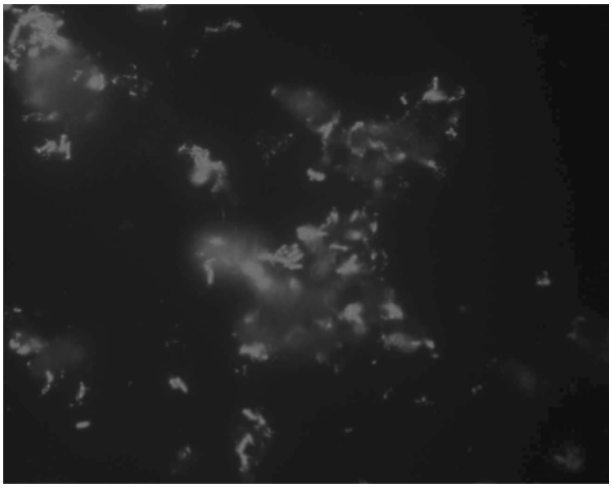

Fig. 9. *Thiobacillus* sp. IW observed by fluorescence microscope (16×100) (Axiolab, Xeiss, Germany).

CONCLUSION

During 10 days (20 times) after start-up of the biofilter the transient behavior of all breakthrough curves for all sampling ports showed that hydrogen sulfide was continuously adsorbed on the media and that the adsorption of hydrogen sulfide was under way since theoretical inlet loads of 1st and 2nd stage operations were very low. At 3rd stage of biofilter-operation (21 times-30 times) the feeding rate of concentrated hydrogen sulfide was increased by factor of two so that the breakthrough curve at the 1st sampling port responded rapidly to approach a new state of saturation, which suggested that the adsorption capacity of biofilter-media may be relatively small or its affinity to hydrogen sulfide may be relatively high, compared to such volatile organic compound as toluene. It was obvious that the breakthrough curves at the 1st, 2nd, 3rd and 4th (exit) sampling ports responded rapidly to the change of operating conditions of a biofilter in the beginning of 7th (last) stage of operation. Thus, the buffer capacity of the biofilter-media (i.e., mixture of granular activated carbon and compost) to hydrogen sulfide was expected to be too small to maintain stable operation of a biofilter treating waste air with highly fluctuated hydrogen sulfide inlet load. Up to the 3rd stage of operation the removal efficiency continued to be nearly 100%. However, it began to decrease when the inlet load surpassed 50 g/m^3/h. At the end of the 7th stage of biofilter-run removal efficiency was decreased and maintained at 94%. The maximum elimination capacity was observed to be ca. 95 g/m^3/h, which was higher than that of the work of any other previous investigator except for that of the biofiltration-work with use of each of two inorganic packing materials (porous ceramics, calcinated and formed obsidian).

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REFERENCES

Buisman, C. J., Geraats, B. G, Ljspeert, P. and Lettinga, G., "Optimization of sulphur production into a biotechnological sulphide-removing reactor," *Biotechnol. Bioeng.*, **35**, 50 (1990).

Cho, K.-S., Ryu, H. W. and Lee, N. Y., "Biological deodorization of hydrogen sulfide using porous lava as a carrier of *Thiobacillus thioxidants*," *Journal of Bioscience and Bioengineering*, **90**, 25 (2000).

Chung, Y.-C., Huang, C. and Tseng, C.-P., "Biodegradation of hydrogen sulfide by a laboratory-scale immobilized *Pseudomonas putida* CH11 biofilter," *Biotechnology Progress*, **12**, 773 (1996a).

Chung, Y.-C., Huang, C. and Tseng, C.-P., "Operation optimization of *Thiobacillus thioparus* CH11 in a biofilter for hydrogen sulfide removal," *Journal of Biotechnology*, **52**, 31 (1996b).

Chung, Y.-C., Huang, C. and Tseng, C.-P., "Biological elimination of

H_2S and NH_3 from wastegases by biofilter packed with immobilized heterotrophic bacteria," *Chemosphere*, **43**, 1043 (2001).

Cox, H. H. and Deshusses, M. A., "Co-treatment of H_2S and toluene in a biotrickling filter," *Chemical Engineering Journal*, **87**, 101 (2002).

Eckhart, A., *Proceedings of biological treatment of industrial waste gases*, Dechema, Heidelberg, Germany, Mar. 24-26, 2pp (1987).

Elias, A., Barona, A., Arreguy, A., Rios, J., Aranguiz, I. and Penas, J., "Evaluation of a packing material for the biodegradation of H_2S and product analysis," *Process Biochemistry*, **37**, 813 (2002).

Hirai, M., Kamamoto, M., Yani, M. and Shoda, M., "Comparison of the biological H_2S removal characteristics among four inorganic packing materials," *Journal of Bioscience and Bioengineering*, **91**, 396 (2001).

Hirai, M., Ohtake, M. and Shoda, M., "Removal kinetics of hydrogen sulfide, methanethiol and dimethyl sulfide by peat biofilters," *J. Ferment. Bioeng.*, **70**, 334 (1990).

Islander, R. I., Devinny, J. S., Mansfield, F., Postyn, A. and Shin, H., "Microbial ecology of crown corrosions in sewers," *J. Environ. Eng.*, **117**, 751 (1990).

Lee, T. J., Kwon, O. Y. and An, S. J., "Removal of odor causing compounds using adsorption of crushed refused-tire and phenol oxidizing bacteria, *Cryptococcus Terreus A*," *J. KSEE*, **22**, 1601 (2000).

Lim, K. H. and Lee, E. J., "Biofilter modeling for waste air treatment: Comparisons of inherent characteristics of biofilter models," *Korean J. Chem. Eng.*, **20**, 315 (2003).

Lim, K. H. and Park, S. W., "The treatment of waste-air containing mixed solvent using a biofilter; 1. Transient behavior of biofilter to treat waste-air containing ethanol," *Korean J. Chem. Eng.*, **21**, 1161 (2004).

Lim, K. H., "The treatment of waste-air containing mixed solvent using a biofilter; 2. Treatment of waste-air containing ethanol and toluene in a biofilter," *Korean J. Chem. Eng.*, **22**, 228 (2005).

Ottengraf, S. P. P., *Exhaust gas purification, Biotechnology* (H. J. Rehm, G. Reed, eds), VCH, Weinheim, Germany, Vol. 8, pp.426-452 (1986).

Oyarzun, P., Arancibia, F., Canales, C. and Aroca, G. E., "Biofiltration of high concentration of hydrogen sulfide using *Thiobacillus thioparus*," *Process Biochemistry*, **00**, 1 (2003).

Sorial, G. A., Smith, F. L., Suidan, M. T. and Biswas, P., "Evaluation of trickle bed biofilter media for toluene removal," *Journal of the Air & Waste Management Association*, **45**, 801 (1995).

Wani, A. H., Branion, M. R. and Lau, A. K., "Effects of periods of starvation and fluctuating hydrogen sulfide concentration on biofilter dynamics and performance," *Journal of Hazardous Materials*, **60**, 287 (1998).