Korean J. Chem. Eng., **28**(4), 1019-1022 (2011)
DOI: 10.1007/s11814-010-0480-4

Removal characteristics of mixed gas of ethyl acetate and 2-butanol by a biofilter packed with Jeju scoria

Sang-Kyu Kam*, Joong-Kyun Kim**, and Min-Gyu Lee*,†**

*Department of Chemical Engineering, Pukyong National University, Busan 608-739, Korea
**Department of Biotechnology, Pukyong National University, Busan 608-739, Korea
***Department of Environmental Engineering, Jeju National University, Jeju 690-756, Korea
(*Received 21 October 2010 • accepted 15 November 2010*)

Abstract−The removal characteristics of a mixed gas of ethyl acetate and 2-butanol by a biofilter packed with Jeju scoria were investigated. The experiments were conducted by changing the mixing ratio and the inlet loading rate of the mixed gas. There was no significant difference between the removal efficiency of ethyl acetate in the mixed gas and that of ethyl acetate in the single gas, while the removal efficiency of 2-butanol in the mixed gas was higher than that in the single gas. At the same loading rate, there was no significant difference between the removal capacity of ethyl acetate in the single gas and that in the mixed gas consisting of ethyl acetate at higher concentration than 2-butanol. However, the removal capacity of 2-butanol in the mixed gas was higher than that in the single gas when 2-butanol flowed through the biofilter at higher concentration than that of ethyl acetate.

Key words: Biofiltration, Biofilter, Scoria, Mixed Gas, Ethyl Acetate, 2-Butanol

INTRODUCTION

Industrial plants and processes emit many types of volatile organic compounds (VOCs) that rapidly become atmospheric pollutants and greatly threaten the environment and public health [1]. They have been known to be carcinogenic and can cause paralysis to the central nervous system and virulence to the liver and kidneys. Hence, regulation of VOCs has been intensified worldwide, and many techniques for their removal have been developed. The conventional technologies such as thermal and catalytic oxidation, condensation, or adsorption have high operating cost and also produce chemical by-products that must be disposed off before discharge. Especially, they are inadequate for the treatment of high volumes of waste gases containing low concentration of VOCs. For these reasons, one of the most promising technologies for the treatment of VOCs is the use of biofiltration [2,3].

Biofiltration is an air pollution control technology that utilizes microorganisms present in the biofilter media to degrade the pollutants in a waste gas stream. The major advantage of biofiltration is that it is inexpensive and environment-friendly because the pollutants are converted into non-hazardous final products such as carbon dioxide and water [4-6]. Several examples of successful industrial applications in the treatment of VOCs and odors can be found in the literature [7-16]. These studies mainly have focused on the treatment of single gas such as hydrogen sulfide [7,16], benzene [17], toluene [18], xylene [13], ethanol [8], ethyl acetate [1,14], and 2-butanol [14]. However, most VOC gases are produced in the form of mixed gas, and some interactions between the mixed gases can occur when it is removed in a biofilter. Although several researchers have investigated the removal performance of the mixed gases such as aromatic components [4,6,19], H_2S and NH_3 [9], ethyl acetate and toluene [11,12,20], ethyl acetate and amyl acetate [21], and ethyl acetate and ethanol [22], relatively few research works have looked into the interactions caused by the mixtures of ethyl acetate and 2-butanol, which are VOCs emitted from food waste treatment plants, in a biofilter.

The purpose of this study was to investigate the removal characteristics of a mixed gas of ethyl acetate and 2-butanol by a biofilter packed with Jeju scoria, and to obtain a better knowledge of the interaction between the mixed gas of ethyl acetate and 2-butanol. The experiments were conducted by changing the mixing ratio and the inlet loading rate of the mixed gas.

MATERIALS AND METHODS

The experimental apparatus was the same as in the preceding study [14] and shown in Fig. 1. It was composed of a biofilter column, a syringe feeding pump, a mixing chamber, and a nutrient supply pump. The biofilter column (75 cm high with 5 cm diameter) was made of circular acryl tube. One liter of scoria was filled into the biofilter after being screened to the mesh size of 12-17 mm. The physical properties of the biofilter packed with scoria are shown in Table 1.

The return sludge, of which the cell concentration was 5,730 mg/L as MLVSS, obtained from waste water treatment plant using *Bacillus* sp., was circulated in a biofilter tower for three days to attach the micro-organisms onto the packing material. Nutrients for micro-organisms were continuously supplied through a pump at a flow rate of 5 mL/min and its composition was the same as in the preceding study [14]: KH_2PO_4, 2.5 g; K_2HPO_4, 2.5 g; NH_4Cl, 2.5 g; $MgSO_4\cdot 7H_2O$, 6.8 g; $CaCl_2\cdot 2H_2O$, 0.5 g; $FeSO_4\cdot 7H_2O$, 0.3 g; and KNO_3, 1.5 g (per 1 L).

A constant amount of mixed solution of ethyl acetate and 2-butanol

†To whom correspondence should be addressed.
E-mail: mglee@pknu.ac.kr

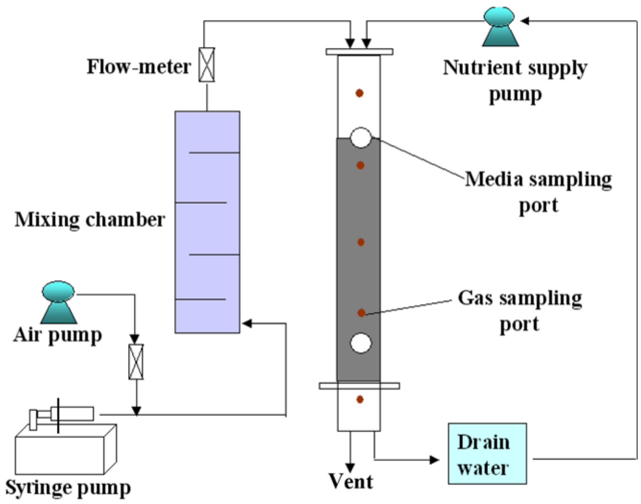

Fig. 1. Schematic diagram of the experimental apparatus [13].

Table 1. Physical properties of the biofilter packed with scoria

Items	Values
Apparent density, g/cm^3	2
Packing density, g/cm^3	0.8
Void volume ratio	0.5
Water holding capacity, % (w/w)	31.7
Mesh size, mm	12-17

was supplied by a syringe pump (Ken-a Mechatronics, KMSP-15MP), and the liquid was vaporized by an air supplied from air pump. Then, it was mixed in a mixing chamber to make the concentration constant. The mixed gas of ethyl acetate and 2-butanol with constant concentration flowed into the upper part of the biofilter, and then discharged at the bottom part of the biofilter. The concentrations of ethyl acetate and 2-butanol gases were analyzed by gas chromatography (HP 5890 series II, U.S.A) with flame ionization detector. The detection limit by the gas chromatography for ethyl acetate and 2-butanol was below 1 ppmv.

RESULTS AND DISCUSSION

1. Change of Mixing Ratio of the Mixed Gas

To investigate the interaction between ethyl acetate and 2-butanol in the mixed gas, the mixing ratio of ethyl acetate and 2-butanol in the mixed gas was changed and the biofilter was operated at empty bed contact time (EBCT) of 30 sec (gas flow rate of 2 L/min). First, with fixed concentration of 2-butanol at 250 ppmv, the inlet concentration of ethyl acetate was increased stepwise from 300 to 750 ppmv. Fig. 2 shows the inlet and the outlet concentrations of ethyl acetate and 2-butanol, and Fig. 3 shows the removal efficiency according to the change of inlet concentration of ethyl acetate. As seen in Fig. 2, when 300 ppmv of ethyl acetate flowed into the biofilter, neither the ethyl acetate nor 2-butanol gases were detected at the outlet of the biofilter. When inlet concentrations of ethyl acetate were further increased up to 500, 600, and 750 ppmv, 2-butanol was not detected at the outlet regardless of inlet concentration of ethyl

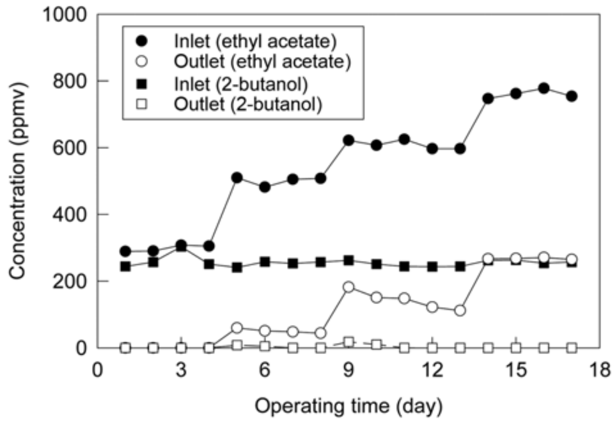

Fig. 2. Inlet and outlet concentration profiles of each gas during the biofilter operation for the mixed gas of ethyl acetate and 2-butanol (the concentration of 2-butanol was fixed at 250 ppmv).

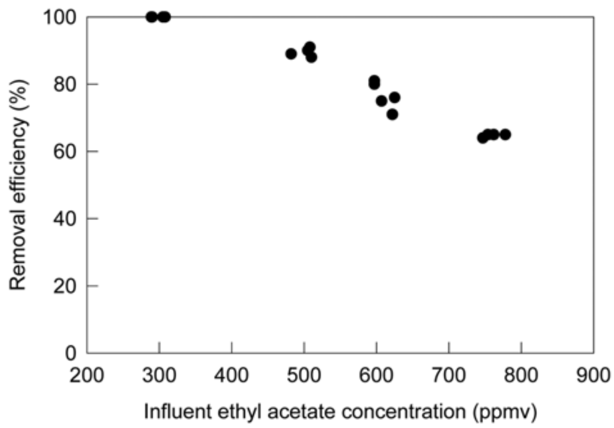

Fig. 3. Effect of inlet concentration of ethyl acetate on removal efficiency for the mixed gas operation of ethyl acetate and 2-butanol (the concentration of 2-butanol was fixed at 250 ppmv).

acetate. However, outlet concentrations of ethyl acetate were found to be 48, 127, and 268 ppmv, respectively. In this case, their removal efficiencies of ethyl acetate by the biofilter were gradually reduced to 90, 79, and 64% as seen in Fig. 3. Meanwhile, our preceding study for the treatment of the single ethyl acetate gas showed that the outlet concentration of ethyl acetate was measured to be 280 ppmv, and its removal efficiency was 72% when the inlet concentration of single ethyl acetate gas flowed into the biofilter at 1,000 ppmv [14]. However, when total concentration of inlet mixed gas was 1,000 ppmv (250 ppmv of 2-butanol+750 ppmv of ethyl acetate), the outlet concentration of ethyl acetate was measured to be 268 ppmv and its removal efficiency was 64% (Fig. 3). Comparing the removal efficiency of ethyl acetate at the same inlet concentration, the removal efficiency of ethyl acetate in treatment of the mixed gas of ethyl acetate and 2-butanol was 8% lower than that from single ethyl acetate gas experiment. This result showed that the removal efficiency of ethyl acetate was slightly affected by the presence of 2-butanol. This might be due to the common-metabolic effects of microorganisms, and microorganisms could be inhibited by factors such as

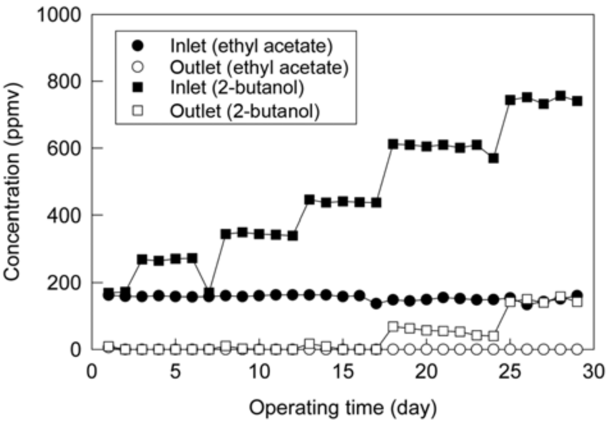

Fig. 4. Inlet and outlet concentration profiles of each gas during the biofilter operation for the mixed gas of ethyl acetate and 2-butanol (the concentration of ethyl acetate was fixed at 150 ppmv).

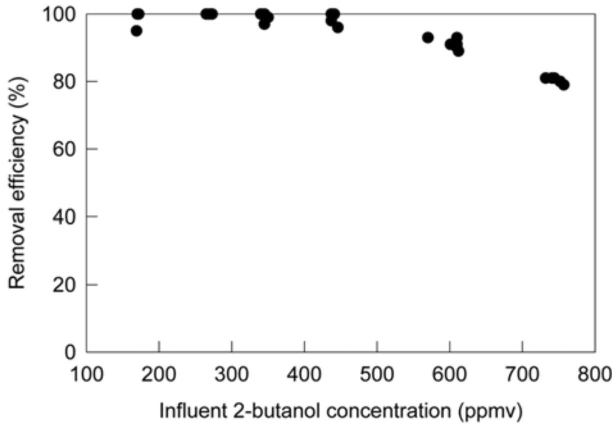

Fig. 5. Effect of inlet concentration of 2-butanol on removal efficiency for the mixed gas operation of ethyl acetate and 2-butanol (the concentration of ethyl acetate was fixed at 150 ppmv).

the presence of acidic intermediates [21]. However, the exact interactive mechanism remains unknown. Some researchers also reported similar results. According to Hornos et al. [11], the removal efficiency of ethyl acetate was not significantly affected by the presence of toluene, but toluene degradation was inhibited in the presence of ethyl acetate. Liu [20] reported that the removal efficiency of toluene was low when the waste gas contained a high concentration of ethyl acetate.

The mixing ratio of the mixed gas was also changed by fixing the inlet concentration of ethyl acetate at 150 ppmv, and increasing the concentration of 2-butanol gas stepwise from 250 to 750 ppmv. Fig. 4 shows inlet and outlet concentrations of ethyl acetate and 2-butanol when various concentrations of 2-butanol flowed into the biofilter with the fixed concentration of ethyl acetate at 150 ppmv. As seen in Fig. 4, when the inlet concentration of 2-butanol was increased stepwise up to 250, 340, and 440 ppmv, 2-butanol was removed entirely. However, when inlet concentration of 2-butanol was increased to 600 and 750 ppmv, the outlet concentration of 2-butanol was measured to be 48 and 147 ppmv. And their removal efficiencies were gradually reduced to 92 and 80%, respectively (Fig. 4). Under this situation, ethyl acetate gas was not detected regardless of inlet concentration of 2-butanol. According to our preceding study [14], when the inlet concentration of single 2-butanol gas flowed into the biofilter at 900 ppmv, the outlet concentration of 2-butanol was measured to be 237 ppmv and its removal efficiency was 74%. When total concentration of inlet mixed gas was 900 ppmv (150 ppmv of ethyl acetate+750 ppmv of 2-butanol), the outlet concentration of 2-butanol was measured to be 157 ppmv and its removal efficiency was 79% (Fig. 5). The removal efficiency of 2-butanol in treatment of the mixed gas of ethyl acetate and 2-butanol was 5% higher than that from single 2-butanol gas experiment.

2. Change of Inlet Loading Rate of the Mixed Gas

The removal capacity of a biofilter depends on the operating conditions of the system and the type of packed material. Thus, it is an important variable in the design of a biofilter. To change the inlet loading rate, the inlet concentration of ethyl acetate in the mixed gas was increased stepwise with a constant inlet concentration of 2-butanol at 250 ppmv. In Fig. 6, the removal capacity of the biofilter for the mixed gas according to the change of total inlet loading rates is compared to that of ethyl acetate as a single gas. Four different inlet loading rates of the mixed gas were applied: 224, 303, 345, and 417 g/m^3/hr. For each loading rate, the removal capacities were 224, 282, 290, and 303 g/m^3/hr, respectively. The removal capacity increased as the inlet loading rate increased. In our preceding study [14], the removal capacities of the biofilter for single ethyl acetate gas were found to be 224, 278, 288, and 310 g/m^3/hr, respectively, at the same inlet loading rates. Comparing the removal capacity at the same loading rates, there was no significant difference between the removal capacity for the treatment of single ethyl acetate gas and the total removal capacity for the treatment of the mixed gas of ethyl acetate and 2-butanol; the difference in total removal capacity of the biofilter was only 0-7 g/m^3/hr.

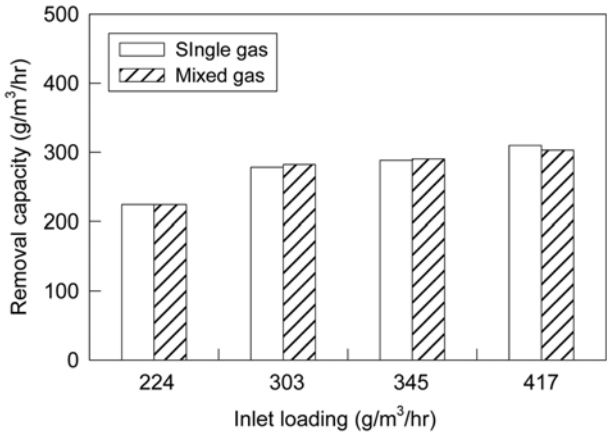

Fig. 6. Relationship between inlet loading rate and removal capacity for ethyl acetate single gas and mixed gas of ethyl acetate and 2-butanol (the concentration of 2-butanol was fixed at 250 ppmv, and the concentration of ethyl acetate was changed from 300 to 750 ppmv).

The removal capacity of the biofilter for the mixed gas according to the change of total inlet loading rates was also tested by changing the 2-butanol concentration with a fixed concentration of ethyl acetate. The inlet concentration of 2-butanol was increased step-

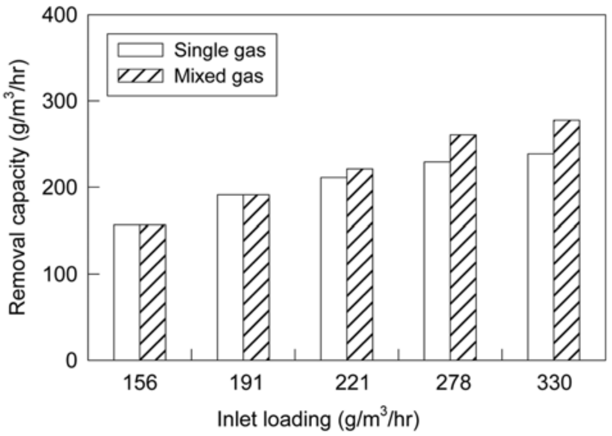

Fig. 7. Relationship between inlet loading rate and removal capacity for 2-butanol single gas and mixed gas of ethyl acetate and 2-butanol (the concentration of 2-butanol was fixed at 250 ppmv, and the concentration of ethyl acetate was changed from 300 to 750 ppmv).

wise from 250 to 740 ppmv at 150 ppmv of ethyl acetate. Four different total inlet loading rates were applied: 156, 191, 221, 278, and 330 g/m^3/hr. Fig. 7 shows that the removal capacities of the biofilter for the mixed gas were 156, 191, 221, 261, and 278 g/m^3/hr, respectively, for each loading rate. At the same inlet loading rates, the removal capacities of the biofilter for single 2-butanol gas were 156, 191, 211, 229, and 239 g/m^3/hr, respectively [14]. At the same loading rate, the difference in the removal capacity of the biofilter between single 2-butanol gas and mixed gas of 2-butanol and ethyl acetate was 0-39 g/m^3/hr. The removal capacity of the biofilter increased when 2-butanol was flowed through the biofilter at higher concentration than that of ethyl acetate. Wen et al. [22] reported that the removal capacities of ethyl acetate or ethanol in the mixture were greater than those of pure ethyl acetate or ethanol as single pollutant. On the other hand, microorganisms attached on the surface of media require time to adapt to a particular initial substrate concentration. Thus, the adaptation period of the microorganisms influences the performance of a biofilter in removing VOCs [10,15]. The period of adaptation can also vary with substrate concentrations even under the same conditions. It has been known that the adaptation period is longer when mixed pollutant gas is treated [23]. In this study, microorganisms required at least 2-4 days to adapt to the change of substrate concentration in the biofilter for the treatment of mixed gas of ethyl acetate and 2-butanol (Fig. 2 and 4). It was also observed that ethyl acetate was degraded well as compared with 2-butanol by the microorganisms used in this experiment. Thus, the introduction of ethyl acetate with relatively high degradation in 2-butanol removal biofilter might result in an increase of the number of microorganisms and their activities, and finally 2-butanol could be treated effectively at high concentration.

CONCLUSIONS

The removal characteristics of the mixed gas of ethyl acetate and 2-butanol by the biofilter packed with Jeju scoria were investigated. When inlet concentrations of ethyl acetate were treated at 500, 600, and 765 ppmv with the fixed concentration of 2-butanol at 250 ppmv, 2-butanol was not detected at the outlet and the removal efficiencies of ethyl acetate were gradually reduced to 90, 79, and 65%. When inlet concentrations of 2-butanol of 250, 340, and 440 ppmv with the fixed concentration of ethyl acetate at 150 ppmv were treated, both ethyl acetate and 2-butanol were not detected. When inlet concentrations of 2-butanol were further increased up to 600 and 740 ppmv, ethyl acetate gas was not detected regardless of inlet concentration of 2-butanol, but the removal efficiency of 2-butanol was reduced to 92 and 80%, respectively. At the same loading rate, there was no significant difference between the removal capacity of ethyl acetate in the single gas and that in the mixed gas consisting of ethyl acetate at higher concentration than 2-butanol. However, the removal capacity of 2-butanol in the mixed gas was higher than that in the single gas when 2-butanol flowed through the biofilter at higher concentration than that of ethyl acetate.

REFERENCES

1. C. Lu, M. R. Lin, J. Lin and K. Chang, *J. Biotechnol.*, **87**, 123 (2001).
2. B. Auria, G. Frere, M. Morales, M. E. Acufia and S. Revah, *Biotechnol. Bioeng.*, **68**, 448 (2000).
3. J. W. Van Groenestijn and P. G. Hesselink, *Biodegradation*, **4**, 283 (1993).
4. R. Abumaizar, W. Kocher and E. H. Smith, *J. Hazard. Mater.*, **60**, 111 (1998).
5. K. Chang, C. Lu and M. R. Lin, *J. Biosci. Bioeng.*, **92**, 126 (2001).
6. G. Leson and A. Winer, *J. Air Waste Manag. Assoc.*, **41**, 1045 (1991).
7. K. S. Cho, H. W. Ryu and N. Y. Lee, *J. Biosci. Bioeng.*, **90**, 25 (2000).
8. P. Christen, F. Domenech, G. Michelena, R. Auria and S. Revah, *J. Hazard. Mater.*, **B89**, 253 (2002).
9. Y. C. Chung, C. Huang, C. P. Tseng and J. R. Pan, *Chemosphere*, **41**, 329 (2000).
10. M. A. Deshusess, *J. Environ. Eng.*, **123**, 563 (1997).
11. A. F. J. Hornos, C. Gabaldon, M. V. Soria, P. Marzal, P. J. M. Roja and M. Izquierdo, *Biotechnol. Bioeng.*, **96**, 651 (2007).
12. S.-C. J. Hwang, C.-M. Lee, H.-C. Lee and H. F. Pua, *J. Biotechnol.*, **105**, 83 (2003).
13. H. Jorio, L. Bibeau, G. Vie and M. Heitz, *Chem. Eng. J.*, **76**, 209 (2000).
14. S. K. Kam, K. H. Kang and M. G. Lee, *J. Microbiol. Biotechnol.*, **15**, 977 (2005).
15. E. A. Maria, P. Fermin, A. Richard and R. Sergio, *Biotechnol. Bioeng.*, **63**, 175 (1999).
16. P. Oyarzun, F. C. Christian and G. E. Aroca, *Process Biochemistry*, **39**, 165 (2003).
17. C. W. Kim, J. S. Park, S. K. Cho, K. J. Oh, Y. S. Kim and D. G. Kim, *J. Microbiol. Biotechnol.*, **13**, 301 (2003).
18. G. T. Martin and R. C. Loehr, *J. Air and Waste Manage. Assoc.*, **46**, 539 (1996).
19. G. A. Sorial, F. L. Smith, M. T. Suidan, A. Pandit, P. Biswas and R. C. Brenner, *J. Environ. Eng.*, **123**, 530 (1997).
20. Y. Liu, X. Quan, Y. Sun, J. Chen, D. Xue and J. S. Chung, *J. Hazard. Mater.*, **B95**, 199 (2002).
21. W.-C. Chan and M.-Q. Su, *Biores. Technol.*, **99**, 8016 (2008).
22. J. Wen, Y. Chen, X. Jia and D. Chen, *Chem. Eng. J.*, **106**, 171 (2005).
23. S. P. P. Ottengraf and V. D. Oever, *Biotechnol. Bioeng.*, **25**, 3089 (1983).