CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

In summary, the results presented and discussed in this research show that biofiltration of xylene with selected microorganisms was very effective for xylene treatment at low inlet concentration. This experiment isolated and identified xylene degrading microorganisms, studied performance of biofilters of three dominant species and monitored microorganisms at the end of operation.

5.1 Conclusions

5.1.1 Isolation and Identification of Xylene Degrading Microorganisms

Three types of Aspergillus (M1, M2, and M4) and one of type of Penicillium (M3) were isolated from the filter media materials after acclimatization with xylene for 1 and 2 months. Four dominants species were identified by text, picture, index description and DNA sequencing technique. They were defined as *Aspergillus flavus* and *Aspergillus terreus*, *Penicillium glabrum, and Aspergillus niger* for M1, M2, M3, and M4, respectively with total plate count 10^6 to 10^8 CFU/g. In this experiment only fungi were selected as degrading microorganisms because of fungi can stay in more general condition than bacteria. The feeding rate of xylene for acclimatization of 1 L/m with high inlet loading rate about 5-6 $gm^{-3}h^{-1}$ might be toxic to bacteria or other microorganisms in biofilter. After 3 months operation, the selected fungi still remained in biofilter in the same environment without more nutrients for all operation period. In biofilter with mixed consortium at first start, fungi were dominant species over bacteria. It is similar as previous research of Estévez *et al* (2005) mixed culture of bacterial–fungal consortium was inoculated in biofilter and the bacteria were gradually overgrown by the fungi. The fungi can survive longer than bacteria in biofilter and be able to degrade pollutants better than other microorganisms. This finding was supported by many research works which reveals that fungal biofilter had better efficiency to degrade many pollutants than bacteria

(Garcia-Pena *et al.*, 2001). *Paecilomyces variotii* CBS115145 was used to treat toluene-contaminated air and it was found that the elimination capacity was around 250 gm $^{-3}h^{-1}$, which was higher than the values usually reported for bacteria (García-Peña *et al.*, 2005).

Through the fungal body is simple in structure, it is highly adaptable genetically and physiologically. One alternative way to improve biofilter efficiency is the use of filamentous fungi as the biological agents in biofiltration. These organisms are more resistant to acid and low- humidity conditions and the transfer of the hydrophobic pollutant has been shown to be improved by the increased transfer surface, due to the formation of the aerial mycelium, and the more favorable phase equilibrium with the hydrophobic nature of the fungi (Vergara-Fernández *et al.*, 2005).

5.1.2 Biofiltration Performance

Three dominant species were inoculated in biofilters to test biofiltation performance. The sterilized biofilter media were consisted of coconut husk and manure at 70:30. Biofiltration of xylene vapor was carried out over a periods of 95 days at various xylene concentrations and empty bed retention time. The control parameters were 50 % moisture content, pressure drop 0.25-1 cm of water, pH ranging from 5.5 to 8.5, and temperature range of 28-33°C. The following conclusions can be addressed from the experiment:

1. Influence of Gas Flow Rate

The result was shown when increasing flow rate with less EBRT led to decreasing the removal efficiency. At an EBRT of 705 s with flow rate 0.2 L/m, the highest removal efficiency was 96.6 % for *Aspergillus flavus* (M1), 96.4 % for *Aspergillus terreus* (M2) and 99.2 % % for *Penicillium glabrum* (M3).

At lower EBRT 280 s with flow rate 0.5 L/m, the removal efficiency was 68.8-74.0%, 65.2-74.5%, and 77.1-81.0 % for M 1, M 2 and M 3, respectively. And at the lowest EBRT of 140 s, the removal efficiencies for all microorganisms were 51.9-61.8 %, 52.7-61.2 %, and 57.4-77.3 % for M 1, M 2 and M 3, respectively. An average removal efficiency of M1, M2, and M3 were 75.5, 75.8 and 83.1 %, respectively. The removal efficiency for control column was 7.4-28.8 %, in average at 18.9 %. From this result about almost 20 % of xylene vapor was removed by adsorption to the filter materials and about 60 % of xylene was degraded by biodegrading process of microorganisms, and the type of packing is also important to increase efficiency of overall biofiltration performance.

The maximum removal efficiency found in this research is very high for all experiments compare to the previous studies. In compost- based biofilter removal efficiency of xylene was 80 %. (Delhomenie, *et al.* 2003). In biofiltration of xylene emissions with variations in the pollutant inlet concentration and gas flow rate, while biofilter was operated for a period of 2 months. Namkoong, *et al.* (2003) studied biofiltration of gasoline vapor by compost media. The average removal efficiency of xylene was 85%, during 4 months of stable operation.

2. Influence of Inlet Concentration

With lower inlet concentration, the removal efficiency increased and at higher inlet concentration, the removal efficiency decreased. At low inlet concentration of 0.01-1.3 g m^{-3} , the removal efficiency was 62.2-99.2 %. At inlet

concentration of 1.9-3.3 g m^{-3}, the removal efficiencies were 65.2-81.0 % and at high inlet concentration of 5.2-6.3 g m^{-3} the removal efficiency was 52.7-77.3 %.

In this study with higher empty bed retention time and lower flow rate condition, single culture of microorganisms could degrade highly xylene concentration (0.01-6.3 g $m^{-3)}$ than the case of mixed culture of microorganisms in biofilter as a reported result at 0.2–4 g m^{-3} (Jorio *et al.*, 2000) and 1.39 g m^{-3} (Elmrini *et al.*, 2004)). From the research result as shown in Figure 4-9 the removal efficiency of control column was an average of 18.9 %. Therefore the adsorption process can reduce amount of xylene when it take more time in bed filter. Although microorganisms were capable to degrade xylene at high concentration (5.2-6.3 g m^{-3}), the removal efficiency was lower and tended to reduce at the end of operation. The limitation of xylene concentration should be further studied. The column diameter is also the one important parameter. This research was done in column size 5-cm.of diameter with 200 cm. long. Industrial application required bigger column, the higher inlet concentration with suitable ratio of microorganisms and suitable flow rate should be attempted.

3. Elimination Capacity

The average elimination capacity of M1, M2, and M3 were 18.5, 16.1 and 22.2 g.m^{-3} h^{-1}, respectively. The elimination capacity of control on average was 5.1 gm^{-3} h^{-1}. The maximum elimination capacity of M1 and M2 are nearly the same at the value of 88 and 91 gm^{-3} h^{-1}. However, M3 have higher maximum value of elimination capacity at 115 gm^{-3} h^{-1}. It could be implied that M3 have a better activity than M1 and M2.

4. Carbon dioxide Production

Under the aerobic condition, one part of organic compound was break down to be CO_2 and water and used as the essential carbon source for microbrial

growth. Carbon dioxide production of microorganisms was increased from the degrading activities of microorganisms in biofilter.

Mass balance of the system, 1 mole of xylene (106) will degrade to be 1 mole of carbon dioxide (352) and 5 moles of water (90). The mass ratio of completed reaction should be 3.3 (352/106).

$$\underset{106\ +336}{C_8H_{10}+10.5O_2} \longrightarrow \underset{352+\ 90}{CO_2+5H_2O}$$

The mass balance evaluation is express in term of ratio between of carbon dioxide production (PCO_2) and elimination capacity (EC)of xylene . In this experiment the average mass ratio of PCO_2 versus EC was equal to 1.8 for *Aspergillus flavus* and in range of 0.76 – 3.0. The mass ratio of PCO_2 and EC for *Aspergillus terreus* was slightly lower at 0.62 – 2.9 and at the average ratio of 2.0. In case of *Penicillium glabrum* ,the ratio was 0.67-3.1 and in average of 2.0. The average ratio of PCO_2 versus EC of all cases in this study was lower than the other studies that reported at 2.5 (Jorio *et al.,* 2000) and 2.7 (Elmrini *et al.,* 2004). Experimental results were lower than 3.3, the stoichiometric ratio in case of complete chemical oxidation of xylene. It could be implied that during biodegradation process, some of the carbon from xylene is converted into biomass for microbial growth and the CO_2 produced may be accumulated in aqueous phase in some forms, such as HCO_3^-, H_2CO_3, CO_3^{-2}.

Three types of dominant species namely *Aspergillus* (M1 and M2) and one of type of *Penicillium glabrum* (M3) was found to be able to degrade xylene vapor in biofilter with high removal efficiency of 96.6 %, 96.4 % and 99.2 % at low inlet concentrations. The activities of M1 and M2 (Aspergillus species) were similar, whereas M3 (*Penicillium glabrum*) shows a better performance in xylene degradation.

5.1.3 Intermediate Species of Xylene

Intermediate species of xylene were evaluated, spectra of them from column2 (inoculate with M1), column3 (inoculate with M2), and column 4 (inoculated with M3) was shown in Appendix C. The result shows that inlet and outlet spectra and chromatogram were similar for all column only ethybenzene and p-, o-, m- xylene was found. The intermediate species was not observed in these experiments. The possible reason is the empty bed retention time did not allow long time enough to generate intermediate species.

5.1.4 Monitoring on Microorganisms

All microorganisms were still survived after 3 months operation period. The microorganisms from each column were monitored at the end of the experiment to compare with the start up microorganisms. The microorganisms were found to be the same types of inoculated microorganisms at the end of process. The microorganisms were defined as *Aspergillus flavus* from column 2, *Aspergillus terreus* from column 3 and *Penicillium glabrum* from column 4 with amount of microorganisms were 2.5×10^{9}, 1.3×10^{10}, and 4.1×10^{9} CFU/g for M1, M2 and M3 respectively. There was no significant difference in removal efficiency and elimination capacity of M1 and M2 for genus Aspergillus. However, the higher removal efficiency was observed for M3 of genus Penicillium. In this experiment amount of microorganisms was very high at 10^{9} - 10^{10} CFU/g with slightly higher amount for M 2, the result shows similar range of previous study at 10^{8} - 10^{10} CFU/g. (Jorio *et al.*, 2000). In conclusion, the type of microorganisms in biofilters is more important than amount of microorganisms if we inoculate in same and enough quantity of microbial at start up of operation. *Penicillium glabrum* is more recommended to treat xylene vapor in biofilter.

In conclusion, no difference of the removal rate was detected during the operation period between M1 and M2, whereas M3 (*Penicillium glabrum*) showed a better performance in xylene degradation. All fungi in this experiment were highly

effective and stable in long-term operation in normal environmental condition in biofilter. The significant of this research in term of environmental management is that microorganisms could be applied to treat xylene and other solvent in industry and also could be applied for indoor air quality management.

5.2 Recommendations for Future Work

1. The effect of initial moisture content in media on biofilter performance should be investigated.

2. The various types of filter media materials should be investigated with the same control condition in biofilter.

3. The gas samples should be collected at different locations along the column in order to monitor the intermediate and performance along the column.

4. The effect of nutrient adding should be performed to compare the limitation of nutrient on microorganisms in biofilter.

5. The effect of pH in media on types of microorganisms should be studied.

6. Biofilter performance of mixed and pure cultures should be compared