CHAPTER 5
CONCLUSIONS

5.1 Conclusions

D. sanderiana has the highest benzene removal efficiency of 8 ornamental plants that were screened for benzene removal at an initial benzene concentration of 20 ppm for 72 h under room temperature in a static system. The plant was exposed to 20 ppm of initial benzene concentration for 4 cycles: each cycle refers to 72 h fumigation under room temperature. The result suggests that benzene removal by *D. sanderiana* can be a sustainable technology because this plant can still uptake high benzene even though it was exposed for a long period of time. In addition, benzene uptake in the 2nd, 3rd, 4th cycles were found to be faster than in the first cycle because the plant needed time to adapt when it was under stress conditions. Dark and light conditions can affect benzene uptake by *D. sanderiana*. Under light conditions, *D. sanderiana* showed higher benzene removal than under dark conditions. Stomata, which are normally reported as a main benzene uptake pathway, were observed under light and dark conditions. The result showed that stomata were closed under dark conditions. The result suggests that the closing of stomata under dark conditions can decrease benzene removal efficiency of *D. sanderiana*. However, the cuticle of the plant cans still uptake benzene. Benzene uptake under light and dark conditions with benzene uptake pathways of stomata and cuticle was calculated to be 54% and 46%, respectively. The cuticle of *D. sanderiana* also took up high levels of benzene. The application of plant wax to adsorb benzene was also studied. Plant leaves from 21 species such as *Homalomena rubescens, Citrus hystrix, Musa paradisiaca, Mangifera indica, Catura metet, Lagerstroemia inermis, Cananga odorata, Cassia siamea, Bougain villea, Litchi chinensis, Coccinia grandis, Dieffenbachia picta, Attacus atlas, Polyalthia longifolia, Acrostichum aureum, Ficus religiosa, Alstonia scholaris, Anthurium andraeanum, Plerocarpus Indicus, Lagerstroemia macrocarpa,* and *Dracaena sanderiana* were used to adsorb 20 ppm of benzene in a static system at room temperature for 72 h. Materials from 6 species of plant leaf such as *Dieffenbachia picta, Acrostichum aureum, Ficus religiosa, Lagerstroemia macrocarpa, Alstonia scholaris,* and *Dracaena sanderiana* were used to adsorb benzene. Wax from selected plant leaf materials were extracted and analyzed both for their quantity of wax and wax composition. The relationship of benzene adsorption efficiency and quantity of wax was found to be a logarithmic curve with R^2=0.65. The result suggests that increasing wax quantity can enhance benzene adsorption efficiency. Wax composition analysis showed that plants with high benzene adsorption efficiency contain high quantities of alpha-linoleic acid and dodecyl cyclohexane. A linear regression of the relationship between benzene adsorption efficiency and quantity of alpha-linoleic showed R^2=0.44. Alpha-linoleic acid can be a key factor for benzene adsorption. For industry application, plant leaf materials from 6 plant species were immobilized on glass beads by cassava glue and were applied in a continuous adsorption system. The plant leaf materials with the highest benzene adsorption capacity were obtained from *A. aureum* and *A. scholaris*. The study of benzene adsorption mechanism by plant leaf materials involved physical adsorption because benzene was easily desorbed by hexane. The adsorption mechanism was confirmed by FT-IR. Similar function groups on the surface of the materials before and after benzene adsorption were not different. Plant leaf materials from *A. aureum* and *A. scholaris* were applied to be a packing bead for biofilter with *P. putida*. *A. aureum* and *A. scholaris* leaf cassava-beads immobilized with *P. putida* showed higher benzene removal than other conditions (*A. aureum* and *A. scholaris* leaf cassava-beads without *P. putida* and cassava-bead immobilized with *P. putida*). Suitable retention time was calculated. The result showed that 1.2-1.5 min (around 10 g m^{-3} h^{-1}) was a suitable retention time in this biofilter. The result showed that an enriched medium was a suitable nutrient in the biofilter. Phytoremediation showed high potential to removal gaseous benzene in indoor conditions. The application of using living plant to remove indoor gaseous benzene in the real world should be implemented. Living roofs and walls might be designed and used to treat air pollution at home or offices in the future. In addition, some microorganisms can also remove benzene, so plant-microbe interaction should be further studied. Plant and microorganism-associated plant leaf might uptake benzene higher than only plant alone. The suitable of microorganisms to enhance benzene removal efficiency should be screened. The relationship between plants, microorganisms and microbe-other microbes interaction will be investigated. For biofilter development, supported medium is normally needed to feed in a biofilter system. Nutrient feeding process required time, high skill regulator and also complication to manage. Therefore, packing beads with carbon and energy sources will be designed and used in the system in order to operate easily.

5.2 Suggestions

From the calculation, the use of plant to remove benzene can be considered as an effective technology. Only 1 living plant (130 cm^2 leaf area) can completely remove 1.7 µg/m^3 of benzene within 24 h. However, the application of benzene phytoremediation and bioremediation still need to be designed for home and office. Living wall, the growing plant on the wall of the building, should be studied and investigated the efficiency for benzene and other pollutants. To design active living wall for improving of efficiency of gaseous removal, the wall should be designed together with pump, and retention time will be increased following design and air flow rate. Real world application with living wall should be investigated.

The application of plant hormone to increase benzene removal efficiency by plant should be investigated. Some hormone for example jasmonate, ethylene, cytokinin, etc can help plant to survive under stress conditions. Addition of these hormones may be possible way to enhance benzene removal efficiency. Effect of hormone on benzene removal and plant physiology should be further studied.

To design biofilter that have high benzene removal efficiency and easy to control. Plant materials immobilized with glucose syrup as a carbon source for microorganisms should be studied because glucose is normally used as carbon and energy sources for microorganisms. So the application of this material may improve benzene removal efficiency and make the system to be easier to control than the system that needed to be feed by enriched medium.