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Removal of BTEX by Biofiltration using Novel Rock Wool-Compost Media

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1. Introduction

The attention of air pollution control agencies has been increasingly focused on the control of volatile organic compounds (VOCs) and other air pollutants from stationary sources. A specific group of VOCs that is widely used in industry and that poses serious adverse effects on the quality of air are aromatic hydrocarbons namely benzene, toluene, ethylbenzene and xylene (BTEX) [1]. These are primary components of many petroleum products. BTEX are among the compounds on primary pollutant lists.

The removal of VOC emissions has been traditionally accomplished using physical or chemical methods, such as scrubbing, incineration or adsorption. However these technologies are usually uneconomical for large flow rate and low contaminant concentration waste airstreams. Biofiltration, a relatively new application of biotechnology in environmental engineering, instead of transferring contaminants from one medium to another, or using large amounts of energy to destroy or remove pollutants, utilizes the efficiency of microorganisms to degrade pollutants [2]. Biofiltration is an efficient and potentially cost-effective alternative for the treatment of low concentration polluted air streams. The low operating costs results from the use of microbial oxidation at ambient conditions instead of oxidation by thermal or chemical means. Under the proper conditions, high removal efficiencies can be achieved, Also, the process is environmentally friendly [3]. Biofiltration involves passing the contaminated air stream through a moist bed of compost, peat, soil, or other permeable material that acts as an attachment for a rich microbial population.

A recent study has shown that biofiltration using a media made of a mixture of compost and rock wool is effective in removing ammonia, hydrogen sulfide and toluene [4]. Benzene, ethylbenzene and xylene have a similar structure with toluene but areknown to be more difficult to biodegrade. In this research, the use of rock wool-compost media as a potential biofilter media was tested for the removal of a mixture of BTEX.

2. Materials and Methods

The biofilter media consists mainly of rock wool (UR Company, Korea) and compost. The compost was first screened between 1.19 and 2 mm sieve openings before mixing with fibrous rock wool in 70:30 weight ratios. A small amount of activated carbon (2.5% of combined weight) and a combination of organic and inorganic binding agents were also added. The mixture was then molded to spheres with 0.8 to 1.2 cm diameter and then placed in a drying oven at 60℃ for 6-8 hrs.

The biofilter media was then seeded with *Sphingomonas sp.* D3K1 (KCTC 8935P) strains bacteria, which was previously used for bioremediation of oil-contaminated soil. The D3K1 strains were initially grown in a liquid medium with 10 g/l glucose as carbon source for 3 days at 28℃ and 150 rpm.

After incubation, the medium was then centrifuged, and the concentrated portion was added with fresh media added with 1 g/L sodium benzoate, an easily biodegradable aromatic hydrocarbon. An incubation period of 5 days was given. The media was then centrifuged again and fresh media without any carbon source was added. The liquid was then sprayed to the novel biofilter media.

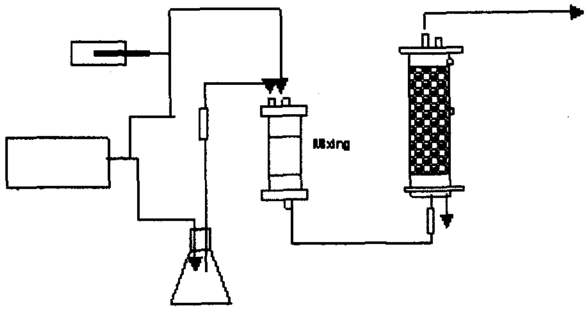

Fig. 1. Process flow diagram for biofiltration of ethylbenzene and *o*-xylene contaminated gas stream.

The target compounds were fed to a biofilter set-up, shown in Figure 1. Equivolume amount of liquid benzene, toluene, ethylbenzene and o-xylene were introduced by a syringe pump (Model 220 KD Scientific) into a tube with 0.5 L/min air stream. The VOC-contaminated stream was then combined with humidified air in a mixing chamber and then directed to the bottom inlet of the biofilter regulated with gas flow meters (Dwyer model RMA Series). The biofilter column has a bed height of 30 cm and an internal diameter of 1cm giving a bed volume of 2.36 L. The experiment was run for 100 days, varying the gas inlet flow rate, 2 and 3 L/min, corresponding to 70.69 and 47.20 sec empty bed residence time (EBRT). Total VOC inlet concentration ranged from 20 to 140 ppm.

The biofilter performance, particularly removal efficiency and elimination capacity, was investigated during, increasing inlet concentration, decreasing EBRT and influence of nutrient addition. Water and nutrients addition was at 150 ml/day. The nutrient composition is similar to that of the D3K1 strain growth medium without carbon source.

VOC concentration for inlet and outlet ports wasdetermined using a gas chromatograph equipped with flame ionization detector (HP6890 Series GC-FID System). The GC carrier gas was nitrogen and the operation conditions were: inlet temperature = 200℃, initial oven temperature = 80℃, final oven temperature = 250℃, detector temperature = 250℃. The retention time of benzene was 5.7 min; toluene, 6.3; ethylbenzene, 6.9 min and *o*-xylene was 7.3 min.

The temperature of the biofilter bed was monitored with a T-type thermometer (Testo Digital thermocouple). The moisture content of the media samples were obtained after performing total solids test (2540 B. APHA Standard Methods) [5]. The medium suspension was measured for pH using a digital pH meter (ThermoOrion model 250A+). Pressure drop was obtained by a digital manometer (Dwyer Series 477). Compaction of the biofilter bed was determined by the change in bed height.

3. Results and Discussion

The biofilter media used combines the inorganic and organic properties of its components. Rock wool, which constitutes 70% of the mixture, is an inorganic media with relatively high porosity, high water holding capacity and good drainage. It is also light and has both hydrophilic and hydrophobic properties depending to how it was manufactured [6]. The added compost is particularly important to provide organics and nutrient to the novel media. As an organic medium, it has more reactive sites for microorganism binding.

Biofiltration of BTEX was carried out over a period of 101 days at varying operating conditions. Two gas flow rates were tested, 2 and 3 L/min corresponding to empty bed gas residence time of 70.69 and 47.20 sec, respectively. Total VOC concentrations varied from 20 to 140 ppm.

The biofiltration performance is described in terms of VOC inlet load (IL, g/m^3/h), removal efficiency (%) and elimination capacity (EC), which are evaluated by the following equations:

$$IL = Q \times C_{gi} / V \qquad RE = X = (C_{gi} - C_{go}) / C_{gi} \times 100 \quad EC = Q \times (C_{gi} - C_{go}) / V$$

The inoculation of the filter material helped in accelerating the establishment of an active microbial population in the filter bed since the biodegradation of BTEX was observed 5 days after the start-up as shown in Figure 2.

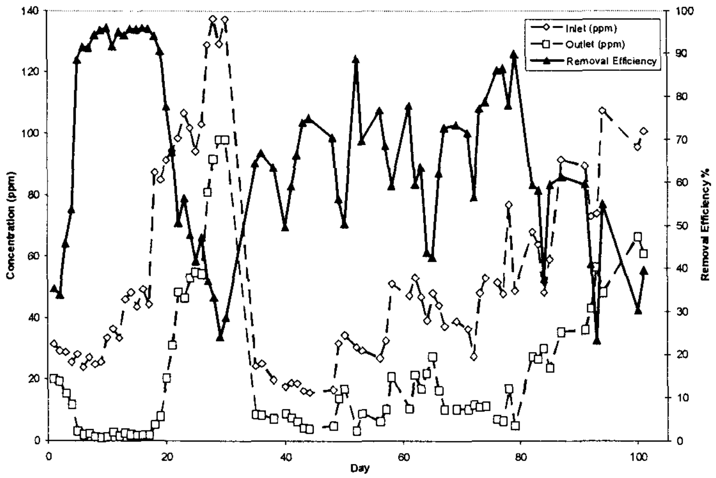

Fig. 2. Time course profile of BTEX biofilter response to increasing contaminant concentration.

Removal efficiencies reached up to more than 90% at low concentrations and high residence time. After 20 days of operation and a VOC concentration increase of about 80 ppm, removal efficiencies experienced a sudden drop. The EBRT was then lowered to 47 sec and the inlet concentration decreased to less than 10 ppm at day 38. Observed removal efficiencies were lower than 50 % for both compounds. Nutrients were then added at days 50, 57 and 65. An increase in removal efficiencies were observed the following days. The frequency of nutrient addition was then increased to every 2 days. The observed removal efficiencies were then observed to fall between 50 to 90%. The computed elimination capacity for total VOC was 17.89 g/m^3/hr. Individual elimination capacities (g/m^3/hr) are as follows: benzene, 7.42; toluene, 5.08; ethylbenzene, 3.25 and *o*-xylene, 4.80.

Other parameters were also observed from the biofilter. Bed temperaturewas determined to range from 24.5 to 32.3℃ and is at least 0.1 degree higher than the ambient temperature (20.4-32.1℃), indicating microbial oxidation activity. Mediamoisture content was calculated to be 40-60%, which was optimum for bacteria growth. Media pH was slightly basic (7.3-8.7) and bed compaction was minimal. No Pressure drop was observed along the media. This could mean that bed height of 30cm was not enough to observe pressure drop.

4. Conclusion

The novel rock wool-compost was found to be a suitable biofilter media for BTEX removal. Start-up took 5 days. Removal efficiencies were generally 0-90%. It reached more than 90% at low concentrations and high residence times. Minimal pressure drop and media compaction was observed. Other parameters such as pH variations, moisture content and bed temperature were correlated to account for the removal of the compounds. Constant nutrient addition was proven vital for a consistent high removal. Maximum elimination capacity for total VOC was 17.89 $g/m^3/hr$.

Acknowledgement

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