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Removal of Benzene and Toluene Using Bacterial Biofilter

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Abstract: ***Gaseous streams and effluents from landfills and industrial processes contain a large number of compounds that are harmful to human health. Much of this is inherently odorous and includes VOCs and inorganic compounds such as ammonia (NH_3), hydrogen sulfide (H_2S), etc. A variety of odorous compounds can be treated by biological processes such as biofilters. Biofilters have a bed on which microorganisms are grown and the bed can be made from waste materials such as wood, PVC pipes, etc. Most biofilters used to remove contaminants from gas contain mixed cultures of bacteria. Biofilters grown on bacteria are more advantageous than biofilters grown on fungi because of their high growth rate and high substrate utilization rate. The present paper describes the removal of benzene and toluene using biofilters using different types of bed materials under different loading conditions.***

Keywords: Biodegradation, Bacterial biofilter, VOC, Elimination Capacity (EC)

1. Introduction

Environmental pollution is one of the worldwide growing threats to humans and natural the environment. Onemajor cause of environmental degradation is air pollutionwhich means contamination of the atmosphere by gaseous, liquid, or solid wastes or their by - products. The air contaminants are classified as organic and inorganic. The major gaseous organic contaminants consist of VOC which are odorous in nature and major inorganic contaminants consist of gases like H_2S, NH_3, NO_2, SO_2, etc. The properties of some of these odorous compounds are shown in Table 1. The concentration of these pollutants is increasing day by day as the number of industries producing the pollutants is increasing. The main sources of the odorous compounds are industries and landfill emissions. The odorous compounds emitted from a typical landfill are styrene, toluene, xylene, acetone, methanol, n - butanone, n - butyl aldehyde, acetic acid, and dimethyl sulfide, dimethyl disulfide, and ammonia (He et al., 2012). The industries are treating these pollutants by various chemical and physical methods. Biofiltration is one of the emerging biological techniques for removing low concentrations of odor - causing compounds in the air. The first proposition to use biological methods to treat odorous compounds was made in 1923 to control emissions of H_2S from a wastewater treatment plant. In 1955 biological treatment techniques were applied to treat low - concentration odorous emissions in Germany. In 1959 biofilter consisting of a soil bed was used at STP in Nuremberg for control odor from incoming sewer. In the biofiltration technique, microorganisms are immobilized on a solid media which oxidizes the odor - causing compounds into the compounds like mineral salts, acids, carbon dioxide, etc. which are not hazardous and have no odor. Biofiltration is advantageous over other methods because it is having low energy input and low operation cost. The bacterial biofilter is advantageous over the fungal biofilter as bacteriahavea high growth rate at a higher temperature than fungi (Pietikainen et al., 2005) and bacterial biofilters produce fewer spore emissions (Arulpoomalai and Patidar, 2014).

Table 1: Properties of Odorous Compounds

Pollutant	Odor	Boiling Point	Density
Styrene	Sweet smell but toxic	145°C	0.909 g/ml
H_2S	Rotten egg type	- 60°C	0.001363g/ml
Ammonia	Strong Pungent odor	- 33.34°C	0.00086g/ml (at 1.013 bar and at boiling point)
Trichloroethylene	Sweet smell but toxic	87.2°C	1.46g/ml
Ethylene	Faint sweet and musky	- 103.7°C	0.001178 g/ml
Benzene	Gasoline - like	80.1°C	0.8765 g/ml
Toluene	Sweet, Pungent benzene like	111°C	0.87 g/ml

The adverse effects of toluene and benzene on human health includeirritationtothe skin and cause dermatitis on prolong exposure as benzene is carcinogenic. A long exposurealso causes damage to the central nervous system, dysfunction, narcosis, tremors, and death. Color vision is mainly affected by toluene as mild eye irritation is caused by it. Toluene inhalation ata high - levelcauses dizziness, and sleepiness, headache, fatigue, irritation of thenose, throat, and respiratory tract. High exposure to toluene is also responsible for liver injury, kidney necroses, swollen liver, and necrosis.

Bacterial Biofilters

Bacteria immobilization is done on the surface of the material of the bed and there is the formation of biofilm as bacteria grow on the surface. When gas effluent - containing pollutants are passed through the biofilter contaminantsare adsorbed on the biofilm. Bacteria use contaminants as a source of nutrients, carbon, and energy for growth. Free air, or, nearly free, of contaminants is then exhausted from the biofilters. Proper media selection affects bio filter performances concerning its compaction and useful life. In addition, the media largely determines environmental conditions for the resident bacteria. The bacteria are the most critical component of the biofilters since they produce the actual transformation or destruction of contaminants. Bacteria can vary significantly in metabolic capabilities and preferences. Naturally occurring microbes are usually suitable and most desirable for treating most gas - phase contaminants. However, some of the more unusual anthropogenic chemicals may require specialized microorganisms. The main control factors for the efficient working of a biofilter include temperature, moisture content, type of media, pH, oxygen content, type of microbes, air flow rate, and inlet concentration (ArulpoomalaiandPatidar, 2013). Several researchers have used laboratory - scale biofilters to treat waste gas effluents. The compounds that are removed efficiently in bacterial biofilters include benzene, toluene (Lee et al., 2009) n - propanol (Dehusses et al., 2012), hydrogen sulfide (Huang et al., 2001), ethanol (Lim, Park, Lee and Hong 2005), ammonia (Melse et al., 2012).

Studies on Biofilters

Biofilters have been used for treating various types of air contaminants using a variety of beds and microbes. A summary of studies using biofilters forthe removal of benzene and toluene is given in Table 2.

Table 2: Summary of studies for removal of Toluene and BenzeneUsing Biofilter

Biofilter Details	IL (g m $^{-3}$h $^{-1}$) and EBRT (sec)	RE (%) and Max EC (g m $^{-3}$h $^{-1}$)	Reference
Glass column, 45 cm in length, 5 cm in diameter, 510 ml working volume, fibrous bed; *Pseudomonas putida and pseudomonasfluorescense*; Benzene, Toluene, Ethylbenzene, o - xylene		Max EC Benzene10 Toluene13 Ethylbenzene16 o - xylene12	Yang, 1999
Perpex sheet five square cross - tion modules each of size0.16m×0.16m×0.20m, filled with polyurethane foam; Mixed bacterial culture; Toluene	IL 126.27; EBRT 112	RE More than 90%; Max EC 90.48	Singh, 2010
Bed packed with ceramic and activated carbon; *Alcaligenes (Achromobacter), Xylosoxidas*; Benzene, toluene and xylene.	Total loading 472.65; EBRT 15	RE 89.59%; Total EC423.45	Golbabaei, 2010
Compost based bed; Mixed culture; Toluene	IL 135	RE 95%; Max EC 128	Rene, 2005
Acrylic cylinder, 5 × 70 cm, packed with mixture of sieved yard waste compost and ceramic beads; Mixed microbial consortia obtained form a municipal sewage treatment plant; Benzene	IL 128 EBRT 25 - 147	RE>78% Max EC 64	Rene, 2010
Cylindrical acrylic resin columns, height 50cm, diameter 10cm, PU foam cubes; *Rhodococcus sp.*; Benzene and toluene	IL Benzene54, Toluene66	RE Benzene96%, Toluene98%; Max ECBenzene40, Toluene40	Ryu and Cho, 2009
Perspex pipe, 14 cm diameter, 60 cm height, corn cob packing; *Bacillus sphaericus*; BTEX	Total IL loading 63.14; EBRT 183.6 (for 3L capacity)	RE 96.43% Max EC BTEX60.89	Rahul, 2013
Glass column, 5cm inner diameter, 80 cm long, wood charcoal and glass beads layer, packing; *Pseudomonas Putida*; Toluene	IL 1104.5	RE 99.5%; Max EC 872.5	Singh, 2010
Pyrex glass column, 4 cm internal diameter, 110 cm height, inorganic/polymeric composite chip packing; *Nitrosomonas and nitrobactor, Thiobacillus thioparus, Pseudomonas aeruginosa, Pseudomonas putida*; Ammonia, H_2S and toluene.	IL Ammonia3.9 H_2S7.63 Toluene11; EBRT 30	RE Ammonia2 to 98%, H_2S2 to 100%, Toluene2 to 80%; Max EC Ammonia2.7, H_2S6.4, Toluene4.0	Chung, 2008
PVC column, 20cm internal diameter, 50cm height, Rashig ring, pall ring, Lava rock, SMP (Structured mixed packing) packings; Activated sludge; Toluene	IL Rashig ring167.84, Pall ring173.21, Lava rock167.90, For SMP330.63; EBRT 60	RE More than 95% Max EC Rashig ring159.45 Pall ring164.55, Lava rock159.51, SMP314.1	Sun, 2011
Two glass vessels, 5cm internal diameter, 23cm long, packed with micro porous polypropylene hollow fiber, Activated sludge; Toluene and Hexane.	EBRT 2.3 to 9.4	Max EC Toluene (alone) 750, Hexane (similtaneous removal) 440	XiunadDeshusses, 2011
Glass column, 6cm diameter, 50 cm length, packed with porous peat moss; *Pseudomonas pseudoalcaligenes, Acinetobacter johnsonii, and Pseudomonas alcaligenes*; Benzene, toluene, o - Xylene, m, p - Xylene.	IL Benzene14.5, Toluene12, m, p - Xylene11.8; EBRT 264	RE Benzene 95%, Toluene100%, m, p - Xylene86%; Max EC Benzene13.8, Toluene12, o - Xylene1.58, m, p - Xylene10.2	Oh, 2002

Acrylic pipe of 94 cm total height and 19.4 cm internal diameter, packed with Compost and woodchips; *Microbacteriumschleiferi, Bacillus coagulansand Stenotrophomonas maltophilia*; Toluene and n - Propanol.	IL Toluene175; EBRT 94 - 157	RE Toluene70% to 100%, n - Propanol100%; Max EC Toluene67, n - Propanol85	Mudliar and Deshusses, 2012
Stainless steel column, 45cm height, 20cm diameter, packed with peat moss and composted chiken manure; *Pseudomonas spp.;* Toluene	IL 70; EBRT 64.8	RE 87%; Max EC Toluene61	Juteau, 1999
Stainless steel column, 3 segments, 5cm diameter and 20cm height each, palm shells (0.5 - 1cm) and activated sludge packing; Activated sludge; Toluene and Methanol.	IL Toluene680 Methanol640; EBRT 71 (9 for max EC)	RE Toluene100% (53% for max. EC), Methanol100% (62% for max. EC); Max EC Toluene346, Methanol380	Chetpattana nondh, 2005
Glass column, inner diameter 5cm, height 65 cm, sterilized peat and glass beads, packing; *Acinetobacter sp.;* Toluene	IL 514.28 (for max. EC); EBRT 28	RE 90% (47% for max. EC); Max EC242	Zilli, 2000
Glass column, inner diameter 5cm, height 65cm, Raw sugarcane bagasse, Sieved sugarcane bagasse and peat + glass beads packings; *Pseudomonas sp.;* Benzene	IL Benzene Raw sugarcane bagasse6.1, Sieved sugarcane bagasse12, Peat + glass beads31; EBRT 60, 30, 15	RE Raw sugarcane bagasse 52% Sieved sugarcane bagasse 53% Peat + glass beads 84% Max EC Raw sugarcane bagasse 3.2 Sieved sugarcane bagasse6.4 Peat + glass beads 26	Zilli, 2004
Acrylic plastic pipe (30×30×200cm), slags (20 - 40 mm) packing; *Pseudomonas fluorescens, some unclassified species Nocardia &Mycobacterium*; Toluene	IL 85 EBRT 225 (for max EC)	RE 97% (62% for max EC); Max EC53	Chou, 1999
Acryl column 6cm diameter, 15cm long, crab shells packing; *Pseudomonas fluorescence*; Toluene		RE 97%; Max EC 72.8	Yeom, 2009
5.2cm internal diameter, 100cm height, composted chicken manure and peat moss packing; Mixed culture; Benzene, Toluene and Xylene	Total loading75; EBRT 18	Overall RE 97% TotalEC108 (for max. EC)	Tahraoui, 1998
Hybrid system, reactor made with pyrex tubes, GAC and compost packing; *Burkholderiacepacia; Pseudomonas putida*; Toluene and Ethanol	IL Toluene295, Ethanol242; EBRT 82	RE Toluene44%, Ethanol95%; Max EC Toluene130, Ethanol230	Lim, Park, Lee and Hong, 2005
Glass column 6cm diameter, 60cm length, packed with Vermiculite; bark chips, hydroball; *Pseudomonas pseudoalcaligenes*; Toluene, m - Xylene and p - Xylene	IL Toluene15.7, m - Xylene5.77, p - Xylene9.866	RE Toluene90.4%, m - xylene95.3%, p - Xylene82.1%; Max EC Toluene14.2, m - Xylene5.5, p - Xylene8.1	Oh and Choi, 2000
Transparent plexiglass 10cm internal diameter, height 65cm, Structured and cubic synthetic polyurethane sponges (10 pores per cm) packing; Fresh activated sludge; Toluene	IL 161; EBRT 5 - 30 (30 for max. EC)	RE 81to100% (max.99.1%); Max EC 133.9	Yang, 2011
Glass column, 5cm internal diameter, 65cm total Height, powdered compost of municipal solid waste and glass beads packing*; Genus Rhodococcus dominated, genera Bordetella and Neisseria*; Benzene	IL 24.8; EBRT 40, 20, 10	RE 81 - 100%; Max EC 20.1	Daffonchio, 2006
Poly acrylic tubes (5×70 cm), sieved compost (3–6 mm), and ceramic beads (4–6 mm) packing; Mixed microbial consortium obtained from STP; Benzene and toluene	IL Benzene69.79, Toluene108.74; EBRT147, 294, 441	RE Benzene72.7% (41.5%for max EC), Toluene81.1% (62.3 for max. EC); Max EC Benzene31.66, Toluene76.47	Rene, 2015

∗ IL - Influent loading, EBRT - Empty bed residence time, RE - Removal efficiency,
EC - Elimination Capacity, - onds

2. Conclusion

Many laboratories, as well as large - scale studies, have been carried out on the treatment of air - containing benzene and toluene. These studies have clearly shown that biofilter is one of the most economical and efficient methods for treating contaminants. The presence of microorganisms is very important as they degrade the contaminants by using them as a food source. Moreover, biofilterscontribute to sustainable development through reusing waste products such as plastics, polyurethane foam, small stones, coconut coir, etc. A wide variety of microbes can also be used which makes biofilter a robust method for the treatment of contaminants in the air.

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