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Degradation characteristics and comparative study of BTEX elimination in a biofilter

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Biodegradation ofbenzene, toluene, ethylbenzeneand *o*-xylene (BTEX) in a corn-cob based biofilter in five distinct phases for 78 days evaluated in terms of its elimination capacity and removal efficiency. The concentration of the mixture ranges from 0.6056-0.6148, 0.6012-0.6159, 0.6043-0.6164, and 0.6022-0.6155 g/m^3,respectively, which depends upon the initial loading rates. The removal of VOC in biofilter under realistic feeding conditions cannot be achieved more than 47%. The overall maximum removal efficiency of BTEX decreases in subsequent phases from 96.436 g/m^3/hto 46.937 g/m^3/hat inlet loading ranging from 47.72 g/m^3/h to 127.418 g/m^3/h. Additionally, phylogenetic analysis, biological tests, and 16S rDNA gene analysis identified the most profusely grown BTEX degrading strainas *Bacillus Sphaericus*.

Keywords: corn-cob; elimination capacity; BTEX; *B. Sphaericus;* biofiltration.

Introduction

The volatile organic compounds (VOCs) emission is one of the most important contributions to the atmospheric pollution, which leads to a decreasing air quality content[1,2]. VOCs like benzene[3,4], toluene[4], ethylbenzene[5,6], H_2S[7] and *o*-xylene[4] could be effectively removed by biofiltration have been already demonstrated by several researchers. Thus, it makes biofiltration certainly the most commonly used natural gas treatment technology. Biological treatment is eco-friendly, which is performed at ambient temperature, and it does not generate secondary waste streams[8]. The source or what we call substrate of carbon and energy are served by organic compounds, which supply food to allow the multiplication and function of microorganisms[9].

To the best of my knowledge, utmost studies on biofiltration engrossed to diminish the system's complexity and to illuminate the effects of necessary functional parameters such as microbial structure analysis, performance, and modeling of VOCs removal by the treating numerous air pollutants. Though, in cases where the number of compounds is more than one in a biofilter system, the possible microbial and substrate interactions are the reasons for the more complicated response of the system.

This paper investigates biofiltration of BTEX vapours with the use of biofilter material based on a corn-cob by using air stream under varying conditions of loading. BTEX removal efficiencies, elimination capacities, microbial concentrations with changing operating parameters were evaluated in biofilter. Moreover, besides an attempt was made for isolating a pure dominating degrading strain of BTEX.

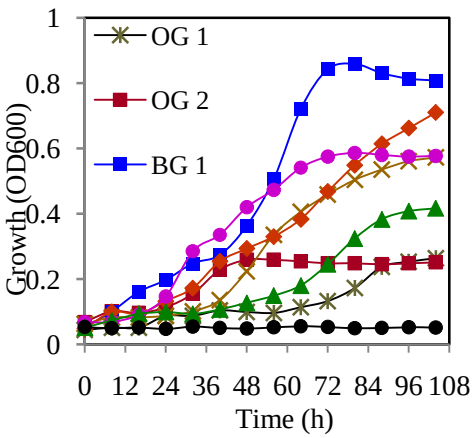
Material

Chemical and growth medium

The preparation of Basal salts medium (BSM) was done by deionized water (Milli-Q Millipore 18.2MΩ/cm resistivity) in which the sole carbon source was BTEX. Later, sterilization of the BSM was carried out in three fragments for avoiding the precipitation of solution at the time of autoclaving.

Screening of isolated strains

Seven pure strains were obtained, and after that, each of them was checked for



their capability to degrade BTEX.

A huge contrast was observed (Fig. 1) in the development of secluded bacterial strains, strain BG 1 is quickest, trailed by BG 2, BG 3, OG 3, OG 4, OG 2 and OG 1 as appeared in Fig. 1(a). Even though OG 1, OG 3, and OG 4 disconnects were developed on a similar substrate, however, the slack stage was around 20 h showing a lower development rate. The capacity of OG 1 and OG 2 to make due in this substrate is altogether restricted. This again shows the event of mutuality connections between the the development of BG 3 between 30 to 55 h was more when contrasted with BG 1, yet by and a large expansion of BG 1 was much as a contrast with BG 3.

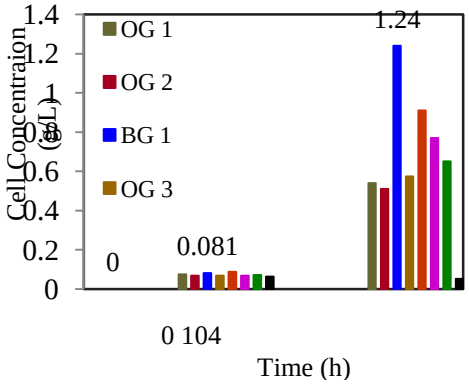


Fig.1. (a) Growth (b) Cell biomass yield of isolated stains from compost based biofilter on the mixture of BTEX

Fig. 1(b), presents the concentrations of underlying and final dry weight cells. It is unmistakably seen that the dry biomass convergence of BG 1 is most elevated among each of the 7 disengages. The last biomass convergence of BG 1 was 1.24 g/L. This focus speaks to a 15 overlay increment to the underlying dry weight. This outcome demonstrates that a lot of carbon acquired from BTEX use is utilized by strain BG 1 for the creation of cell biomass. The centralization of OG confines didnot increment above 0.65 g/L. The more slow development rate and diminished cell yield of OG 1, 2, 3, and 4 disengages demonstrate that these strains have a much lower corruption potential than BG 1. In light of the outcomes, BG 1 was chosen for the next phase of study since it was seen as most bountifully developed strain for BTEX corruption among the other seven confines.

2.4 Strain Identification

The process of identification of isolated bacteria was carried out following

'Bergey's Manual'[10]. The classification of the 07 isolates depends on the morphological, physiological, and biochemical test properties have been shown in previous study[11].

Genomic DNA and sequencing of isolated strains

The genomic DNA was disengaged utilizing standard bacterial methodology. Reasonable ground works [63f(5'-AGGCCTAACACATGCAAGTC3'),1387r(5'-GGCGGAGTGTACAAGGC-3')] were intended to get 16S rRNA quality groupings from BG 1. PCR was completed with standard convention portrayed before. The comparing quality part was intensified from the genomic DNA, the groups relating to the foreseen size of 1.5 kb. The PCR items are created along these lines with the Pfu catalyst (XT5 compound, Genei item).

Moreover, these items were ligated in the pGEMT vector utilizing the TA cloning strategy. After the ligation response, the effective clones were chosen by blue-white screening. The states containing pigment vector of wanted addition were chosen, and positive clones were disconnected. The confined clones were sequenced from The Center for Genomic Application (TCGA), New Delhi, India in forward, and turn around heading. The sequencing was done utilizing ABI PRISM 300 and Model DNA succession. It is besides broke down with existing 16S rRNA successions with GenBank, EMBL, and DDBJ. Along these lines, the taxonomical information was upheld, and BG 1 was re-distinguished as *Bacillus sphaericus*. After affirmation from all sources, detached strain BG 1 was seen as *Bacillus sphaericus*.

Biofilter operation

A biofilter consist of corn-cob packing framework treats the blend of BTEX in upflow design. Analysis of physical and chemical synthesis utilized in corn cob based biofilter were introduced in a past investigation[12].

Results and Discussions

Batch absorption test

In the current investigation of analysis, set III (78 days) considered for evaluating biofilter. As indicated by the method of activity of variable BTEX input focus in five distinct stages (stage I to stage V). The biofilter try (set I) was accounted in previous study [11]. The BTEX stacking pace of the reactor was expanded in several means. Execution of the biofilter was analyzed day by day by pH. Different working conditions, for example, void bed retention time (EBRT), BTEX stacking, dampness substance of pressing media and populace of BTEX corrupting microscopic organisms in the pressing medium impact the overall execution of biofilter as for biodegradation of BTEX. The biofilter framework was evaluated for all these parameters under consistent state conditions. The total extents of the VOC segment in the blend for all stacking condition have appeared in Table 1.

Removal efficiency

During Phase I (14 days), the starting insignificant BTEX concentrations in input air varied between 0.6056-0.6134, 0.6076-0.6150, 0.6043-0.6164, and 0.6052-0.6147 g/m^3, respectively.BTEX input was maintained at a low level (3 L/min) in Phase I. The corresponding EBRT was 3.06 min. When the biofilter was supplied witha four-component VOC mixture (BTEX), less than 72% of overall VOC removal was achieved. On the 14th day, the removal efficiency (RE) of BTEX increased rapidly and stabilized to maximum, i.e., upto 71.39, 75.17, 72.13, and 69.53%, respectively.

In Phase II, BTEX input was greater than before from 3 L/min to 4 L/min. In this case, the EBRT has raised from 3.06 to 2.3 min as

Table 1 Range of operating conditionsof each phasefor BTEX

Phase	Operating period (days)	Flow rate (L/min)	Pollution concentration (g/m^3) range				Average loading (g BTEX/m^3/h)	EBRT (min)
			B	T	E	X		
I	156-169	3	0.6056-0.6134	0.6076-0.6150	0.6043-0.6164	0.6052-0.6147	47.7503	3.06
II	170-184	4	0.6076-0.6137	0.6070-0.6147	0.6060-0.6141	0.6063-0.6146	63.7613	2.3
III	185-201	5	0.6073-0.6148	0.6077-0.6147	0.6078-0.6142	0.6023-0.6149	79.7032	1.84
IV	202-223	6	0.6077-0.6135	0.6034-0.6159	0.6075-0.6134	0.6042-0.6155	95.5237	1.53
V	224-233	8	0.6075-0.6134	0.6012-0.6152	0.6076-0.6130	0.6022-0.6115	126.9497	1.15

compared to phase I. During this Phase, very slight variation is observed during the removal efficiency of benzene and ethylbenzene. Still, in the case of toluene and *o*-xylene, nearly 5% removal efficiency was decreased, i.e., from 75.17 to 70.48% and 69.53 to 64.34%, respectively.

Phase III (day 185 to 201) which flow rate of the gas mixture was maintained at 5 L/min (EBRT 1.84 min). The average concentration of BTEX was at 0.6103, 0.6122, 0.6118, and 0.6098 g/m^3, respectively, and the average organic loading rate to the biofilter was increased from 63.76 to 79.70 g/m^3/h. In this Phase, the response was found to be similar to phase II without any change. There was a sudden decrease in removal efficiency of BTEX from 69.69 to 40.80, 70.48 to 38.47, 70.52 to 39.59, and 64.34 to 37.59%, respectively.

In the phase IV (day 202 to 223), average concentration was maintained at 0.6109, 0.6098, 0.6103 and 0.6100 g/m^3, respectively. The input gas flow rate was greater than before from 5 to 6 L/min, in this manner EBRT decreased to 1.53 min. Later on, there was an improvement in the removal efficiency of BTEX by 50.25, 55.85, 48.58, and 51.93 %, respectively.

In Phase IV, input rates were rapidly altered from phase IV to V for the study of adaptability of the microbial cultures and the time required achieving it. The results obtained were quite predictable. Phase V lasted from day 223 to 233 for 10 days, and BTEX average concentrations were maintained at 0.6103, 0.6065, 0.6088, and 0.6074 gm^{-3}, respectively. The input gas flow rate increased from 6 to 8 L/min, so it decreases EBRT from 1.53 to 1.15 min. This was increased approximately by a factor of 1.6 (126.94 g/m^3/h) from Phase III (79.70 g/m^3/h). Initially, a steep sudden decrease in removal efficiency was observed. At this Phase, the removal efficiency was gradually increased but was less than 46.57, 53.08, 46.17, and 41.84% for BTEX, respectively.

Elimination capacity

The biofilter execution was additionally assessed as far as the elimination capacity (EC) of BTEX for different stacking rates, which reflects the threshold of the biofilter to expel the poisons, has been plotted in Fig. 2. Plotted symbols presents to the exploratory information of BTEX, while diagonal line shows to the 100% evacuation.

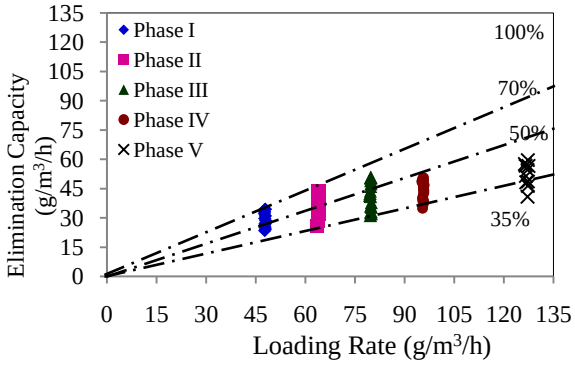


Fig. 2. Elimination capacity as a function of in let load of total BTEX.

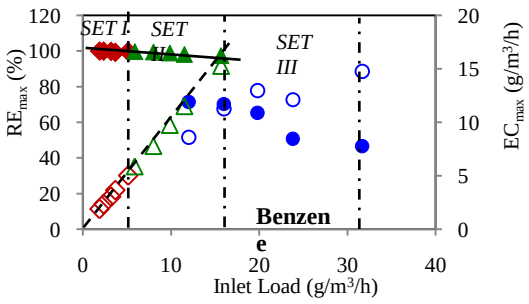
A remarkable variety of the EC in different stages was seen because of the change in influent concentrations and removal rates. From day 156 to 169 (stage I), the inlet average concentration of BTEX was 47.750 g/m^3/h. The relating normal elimination capacity found to be 29.203 g/m^3/h. The elimination capacities of BTEX were expanded with the expansion in influent BTEX loading. At day 156 (phase I), the loading rate was increased to 47.72 g/m^3/h, this increase had an immediate negative impact on the elimination capacity, diminishing around 23.45 g/m^3/h. Logically, the diminishing rate came back to higher worth and balanced out at around 34.42 g/m^3/h. At day 170, the stacking rate was expanded up to 63.56 g/m^3/h. The increased EC was not in relative extent. However, following barely any days, the EC began to diminish. Up to the furthest limit of this test, the normal stacking rate was expanded roughly 2.6 occasions from stage I to arrive at a threshold of EC 59.72 g/m^3/h. From Fig. 2, in phase V, the channel BTEX heap of 127.24 g/m^3/h, the most elimination capacity of the biofilter was 59.72 g/m^3/h. During stage III, the biofilter was worked at an average BTEX heap of 79.70 g/m^3/h, the most extreme EC accomplished was 50.774 g/m^3/h. However, in stage IV, elimination capacity was achieved at 49.15 g/m^3/h, when the biofilter was worked about at a similar normal BTEX heap of 95.52 g/m^3/hat fluctuating conditions. The ECt displayed a direct relationship with the volumetric stacking pace of up to 127.24 g/m^3/h, showing that the biofilter never arrived at its most extreme disposal limit under this condition. This could be because of the poor evacuation in stage IV and V because the EC is greatest at most extreme expulsion proficiency. The writing uncovers that the large portion

of the biofilters utilized for the treatment of paint VOCs is worked at EBRTs lies in the range 40 s to 2 min with stacking rates extending from 6 to 40 g/m³/h[15]. By examination with other revealed values on the biofiltration of paint mixture[16], the elimination capacity and removal efficiency are low in this investigation. In another past report[17], the average elimination capacity of 220 g/m³/hwas found with removal efficiency of 89.59% for BTX with inlet concentration of 1 g/m³/hat 15 s gas living arrangement time in the bioactive froth emulsion biofilter.

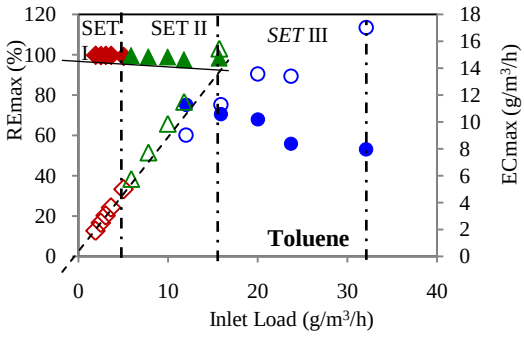
Comparison of the performance of biofilter for set I, II and III

Biofilter had been worked for 233 days to assess the biodegradation pattern of an individual part by a pure strain which was plentifully developed in the environment of BTEX. To check the repeatability of the outcomes, biofilter were worked in three-set I, II, and III. Further, each set was worked in five particular stages (stage I-V) at different working conditions. In each set, the groupings of every part of BTEX were practically the same, yet flow rate was shifted from 3, 4, 5, 6, and 8 L/min in Phase I, II, III, IV, and V, individually.

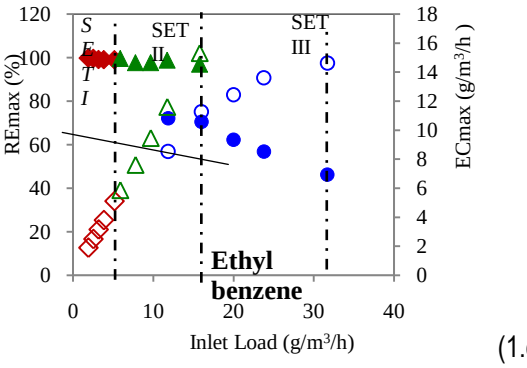
Based on lab experience, the outcomes were accounted for in writing. Each of the three sets has expected to perform well as for the expulsion of BTEX. The observation between removal efficiency and elimination capacity versus inlet loading shows in Fig. 3 for experimental set I, II, and III. The total BTEX elimination capacity and inlet loading are introduced in Figs. 3(a-d) at the maximum removal efficiency in each phases (phase I-V) of each set. Figs. 3(a)shows that removal effectiveness is practically consistent in the set I and II and is over 99% up to the benzene heap of 15.68 g/m³/h. It is noticeable that further increment in the bay stacking in set III, removal efficiency step by step



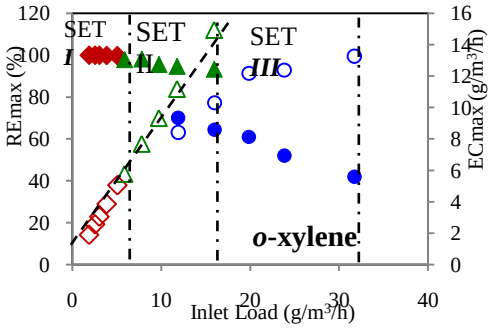
(1.a)



(1.b)



(1.c)



(1.d)

Fig. 3. Variations in maximum removal efficiency and maximum elimination capacity with respect to maximum inlet loading rate of (a) benzene, (b) toluene (c) ethyl benzene and (d) *o*-xylene in set I, set II and set III

diminishes. Most reduced RE (46.57 %) was acquired at the inlet heap of 31.70 g/m³/h.

The reduced removal efficiency at a higher input rate can be credited to low residence time of benzene just as to substrate inhibition[18]. Elimination capacity increased linearly up to inlet loading rate of 15.68 g/m³/h (up to set II) after which it tended towards a reduction in set III. Fig 3(a) shows that the regression coefficient for the elimination capacity is more than 0.999; it upheld linearity among EC and inlet load at practically constant RE (over 99%). The constant RE lines relating to RE = 100% have additionally appeared in these figures. It is seen that at further increment in

loading rate past the 15.68 g/m^3/h, the removal efficiency diminishes up to 46.57%, and relating EC likewise diminishes in sets III. Maximum EC of 14.76 g/m^3/hwas acieved corresponding to the inlet loading rate of 31.70 g/m^3/h(RE = 46.57%). These values of EC are higher in comparison to the values reported by others[19]. Figs. 3(b-d) also show the same types of patterns for toluene, ethylbenzene, and *o*-xylene, respectively, in set II. The maximum elimination capacity of ethylbenzene (Fig. 3(c)) and *o*-xylene (Fig. 3(d)) is approximately the same as benzene (14.76 g/m^3/h), but at low removal efficiency of 46% and 41%, respectively is observed. Toluene attained the highest EC at 17.04 g/m^3/hcorresponding to the inlet loading rate of 32.09 g/m^3/h(RE = 53%). It is clear from Figs. 3(a-d), the EC and RE were maximum for toluene as compare to other compounds of BTEX. Similar pattern was also reported for toluene as compare to benzene[15].

Conclusions

The degradation of BTEX was constrained for generally expulsion in the biofilter. For the concentrations variations from 0.6056 g/m^3 to 0.6148 g/m^3 for benzene, 0.6012 g/m^3 to 0.6159 g/m^3 for toluene, 0.6043 g/m^3 to 0.6164 g/m^3 for ethylbenzene and 0.6022 g/m^3 to 0.6155 g/m^{3}for o-xylene. The biofilter cannot accomplish reasonable removals of more noteworthy than 47% under possible taking care of conditions. The overall maximum removal efficiency of BTEX diminishes in ensuing stages from 96.436 g/m^3/hto 46.937 g/m^3/hat inlet loading ranging from 47.72 g/m^3/hto 127.418 g/m^3/h.

References

1. A. A. Hassan and G. A. Sorial, *J. Hazard Mater.*, 2010, **184**, 345-349.
2. R. Lebrero, E. Rodriguez, M. Martin, P. A. Garcia-Encina and R. Munoz, *Water Res.,* 2010, **44**, 3905-3914.
3. J. M. Chen, R. Y. Zhu, W. B. Yang and L. L. Zhang, *Biores. Technol.,* 2010, **101**, 8067-8073.
4. J. R. Robledo-Ortiz, D. E. Ramirez-Arreola, A. A. Perez-Fonseca, C. Gomez, O. Gonzalez-Reynoso, J. Ramos-Quirarte, and R. Gonzalez-Nunez, *Int. Biodet. & Biodeg.* 2011, **65**, 539-546.
5. M. E. Ramos, P. R. Bonelli, A. L. Cukierman, M. M. L. Ribeiro Carrott and P. J. M. Carrott, *J. Hazard. Mater.,*2010, **177**, 175-182.
6. L. Li, S. Liu and J. Liu, *J. Hazard. Mater.,* 2011, **192**, 683- 690.
7. K. Vikrant, S. K. Kailasa, D. C. W. Tsang, S. S. Lee, P. Kumar, B. S. Giri, R. S. Singh and K. H. Kim, *J. Cleaner Prod.*, 2018, **187**, 131-147.
8. M. A. Deshusses, *Curr. Opin. in Biotechnol.,* 1997, **8(3)**, 335-339.
9. A. Jantschak, M. Daniels and P. Paschold, *IEEE Transactions on Semiconductor Manufacturing,* 2004, **17(3)**, 255-260.
10. R. E. Buchanan and N. E. Gibbons, (Eds.), Bergey's Manual of Determinative Bacteriology. Williams and Wilkins, Baltimore, 1974.
11. Rahul, A. K. Mathur and C. Majumder, *Biores. Technol.,* 2013, **133**,166-174.
12. Rahul, A. K. Mathur and C. Balomajumder, *Res. J. Chem. Sci.*, 2011,**1(5)**, 52-60.
13. J. P. Lodge, Methods of air sampling and analysis, Lewis Publishing Inc. New York, 1989.
14. A. K. Mathur, J. Sundaramurthy and C. Balomajumder, *J. Hazard. Mater.,* 2006, **137**,1560-1568.
15. T. Webster, A. P. Togna, Y. Yang and Guarini, *Air & Waste Manage. Assoc.*, San Diego, California, 1998.
16. B. M. Qi, W. M. Moe, K. A. Kinney, *J. Environ. Eng.,* 2005, **131(2)**, 180-189.
17. F. G. Shahna, F., Golbabaei, J. Hamedi, H. Mahjub, H. R. Darabi, and S. J. Shahtaheri, *Chinese J. Chem. Eng.,* 2010, **18(1)**, 113-121.
18. B. A. Kocamemi and F. C. Cecen, *Water Sci. Technol.*, 2007, **55**, 67-73.
19. A. K. Shukla, R. S. Singh, S. N. Upadhyay and S. K. Dubey, *Biores. Technol.*, 2010, **101**, 8119-8126