Performance of a Bioreactor Using Organic Compound and Pall Ring Media for the Treatment of BTEX Vapors

SIQUEIRA, L. C. G a*, De ASSUNÇÃO, J. V. b

a. CETESB – COMPANHIA AMBIENTAL DO ESTADO DE S. PAULO, São Paulo
b. FSP-USP - Faculdade de Saúde Pública da Universidade de São Paulo, São Paulo

*Corresponding author, ligia.siqueira@gmail.com

Abstract

In this study a laboratory-scale biotrickling filter was operated to investigate the performance on treating BTEX (benzene, toluene, ethylbenzene and o-m-p xylenes) vapours in a waste gas stream. In the experiment, a column containing a mixture of compost and Pall rings, and the consortium of microorganisms presents in the compost were tested to biodegrade the vapours of BTEX. Results showed that removal efficiencies were between 86.6 and 93.4% in the phase log (exponential growing) of the consortium microorganisms in the compost after a period of 2-3 weeks for acclimatization for an inlet concentration in the range of 70 to 250 ppm. The maximum elimination capacity (EC) achieved was 29 g/m³-h for a critical loading concentration (CL) of 46 g/m³-h for an empty bed retention time (EBRT) of 2.4 min. The conclusion was that it is valid technology for the treatment of BTEX with the potential of meeting environmental requirements, and its application in Brazil is important as an alternative to more impactful and costly technologies.

Keywords: Biological air treatment, air toxic pollutants control, air emissions control in bioreactors, atmospheric emissions, air pollution.

1. Introduction

During decades the control of VOCs (volatile organic compounds) was focused in high concentration airstreams and in the use of classical processes, like incineration, adsorption and absorption, that can attain good removal efficiencies, but at higher cost and with generation of undesirable wastes and products. The majority of these processes involve physical or chemical principles and they may not be suitable for air streams with low concentrations of COVs. Biological treatment of gaseous streams with low concentration of pollutants can be cheaper and more efficient than classical ones, and it is considered a cleaner process, as it saves energy, does not generate undesirable wastes like exhausted catalysts or saturated activated coal nor liquid effluent that need to be treated or disposed of.
Biodegradation process has been used for at least half of a century and the main application has been the control of odor (VAN LITH, 1997). The main advantages are the simplicity of the equipment, relatively simple operation, usually do not form additional pollutants, the process is safe because occurs at or near ambient temperature and in most of cases, capital and operating costs are lower than classical Technologies. However, it presents limitations, as the effectiveness which is subject to the specific pollutant being treated, sensitivity to temperature fluctuation, and high pollutant concentrations and high moisture content can decrease removal efficiency (HUNTER, OYAMA, 2000).

The first applications of this method were odor abatement such as from livestock, but later it was used to treat emissions from industrial processes such as casting and painting, among others (FRITZ; KERN, 1992). Currently, there are several sources of air pollution where this treatment process can be applied, for instance chemical adhesive production, storage of solvent and other chemicals, composting of organic wastes, food industry, petrochemical plants and furniture industry (DEVINNY et al., 1999).

The biological process were developed to occur in specific devices commonly referred as biofilters, that can have filter media of different materials to support and promote microorganism growth and biodegradation of organic and inorganic compounds including mixtures.

The filter media can be of different materials, natural and synthetic. Natural ones are soil, and pelletized diatomaceous earth that have been used to treat benzene (HASSAN, SORIA, 2009); organic compost for the treatment of BTX and Total Petroleum Hydrocarbons - TPH (NAMKOMONG et al., 2003); wood bark to treat a mixture of ethanol, Methyl ethyl ketone (MEK), Dichloroethylene (DCE) and toluene (ANDRES et al., 2006). All these former examples have used indigenous microorganisms in the biodegradation process. Synthetic materials need microorganism strains previously inoculated and acclimatized for the biodegradation of specific compounds. Filter media like Pall rings previously inoculated with sewage sludge has been used to treat toluene (COX, DESHUSSE, 1999). Polyurethane foam inoculated with sewage sludge has been used to treat a mixture of toluene and xylene (YAMASHITA; KITAGAWA, 1998). It is also possible to use a mixture of materials, natural or synthetic for the filter media. Organic compost and pozzolan have been used to treat a mixture of ketone, trichloroethylene (TCE) and toluene (GRACY et al., 2006); organic compost and wood chips have been used to treat a mixture of toluene and xylene (TORKIAN et al., 2003). These mixtures of materials in the filter media have the function of optimizing the operational conditions, lower pressure drop across the media, minimization the compactness of the bed to prevent clogging or to improve the aeration conditions in the filter bed (DÉLHOMÉNIE, HEITZ, 2005).

The objective of this study was to investigate the capacity of biotreatment of a set of compounds known as BTX, a mixture of benzene, toluene, ethylbenzene and o,m,p-xylenes, which are considered to be toxic for humans and that are frequently emitted to the atmosphere by several sources. (SIQUEIRA, 2011)

2. METHOD

2.1. Experimental design

Air flow rate of approximately 1 L/min, passed through a 4 liter conical flask with a 50 ml-Becker inside containing 10 ml of the BTX. The air containing BTX vapors were then conducted to the biofilter, entering through the bottom, becoming then in contact with the filter bed consisting of mixture of fresh organic compost and Pall rings.

The exit of gas was at the top of the column, made of glass. Measurements of the concentration of the entry and exit gases were taken every half hour by a portable photoionization gas analyzer (MiniRAE 2000, da RAE Systems), previously calibrated. After leaving the biofilter effluent gas passed through a wash-bottle containing silica gel, to determine moisture by gravimetric method. The gas volume was measured by a dry gas meter and the dry gas flow rate was indicated by a rotameter all them previously calibrated. A mercury thermometer was used to measure temperature of gases. After each test, pressure drop across filter media was measured by a micro manometer. Ambient temperature remained constant at 23°C. In Figure 1 it is showed a schematic representation of the experimental apparatus used. Table 1 presents parameters and conditions adopted.
Table 1 Main experimental parameters and conditions adopted

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column height (m)</td>
<td>1.20</td>
</tr>
<tr>
<td>Column inner diameter (m)</td>
<td>0.08</td>
</tr>
<tr>
<td>Bed height (m)</td>
<td>0.48</td>
</tr>
<tr>
<td>Bed volume (m$^3$)</td>
<td>0.0024</td>
</tr>
<tr>
<td>Air flow rate (m$^3$/h)</td>
<td>1 Lpm</td>
</tr>
<tr>
<td>Pressure drop across media (mmH$_2$O))</td>
<td>1.1-1.4</td>
</tr>
<tr>
<td>Inlet BTEX concentration (ppm)</td>
<td>70-250</td>
</tr>
</tbody>
</table>

2.2. Packing material

The filter media was a mixture of organic compost and Pall rings. The organic compost, according its manufacturer was a mixture of bark wood or sawdust, limestone, sugar cane waste (like bagasse and ash), red earth, ground wood and coal. And there was no manure, nor mineral addition (maybe NPK from sugar cane) and no earthworm. The Pall ring had cylindrical shape (diameter 1”; height 1”) and was made from polypropylene. Fresh organic compost was used in each assay.

2.3. Biodegradation and biofilter performance parameters

The biodegradation parameters used to indicate biofilter performance or operating conditions were inlet BTEX concentration load (CL), elimination capacity (EC), a removal efficiency (ER) at a given empty bed removal time (EBRT) and surface load (SL). These parameters are defined as:

Concentration loading (CL) (g/m$^3$.h):

\[
CL = (C_{in}/Q_g)/V_g
\]  

Elimination capacity (EC) (g/m$^3$.h):

\[
EC = [(C_{in}-C_{out})/Q_g]/V_g
\]  

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Efficiency of removal (ER) (%): 
\[ ER = \frac{(C_{in} - C_{out})}{C_{in}} \times 100 \]  (3)

Empty bed residence time (EBRT) (min.):
\[ EBRT = \frac{V}{Q_g} \]  (4)

Surface load (SL) (m$^3$/m$^2$.h):
\[ SL = \frac{Q_g}{A_l} \]  (5)

being:
- $C_{in}$ and $C_{out}$ = inlet and outlet concentration of BTEX respectively (ppm)
- $Q_g$ = air flow rate (m$^3$/h)
- $A_l$ = cross sectional area of filter bed (m$^2$)
- $V_l$ = volume of filter bed (m$^3$)
- $V_g$ = volume of gases (m$^3$)

2.4. Humidification process

Filter media was humidifier by using a phosphate solution instead of water, which in addition to wetting provides nutrients for microorganism growth. It was prepared by passing air through an impinger that contained phosphate solution, during 10 minutes. The flow rate was 1 Lpm. The solution is also commonly inserted through the top of the column throwback to a sprinkler. Additional spraying of solution was located on the top of the column and every two days the solution was sprayed. All leachate returned to column by its top. These procedures were taken to maintain enough moisture content in the packed bed.

2.5. Monitoring

Ambient condition: periodic measurements of room temperature, barometric pressure and relative humidity of air throughout the experimental period.

Pressure drop: pressure drop of the packed column was measured by a micro manometer with a minimum reading division length of 1mm of water column.

Gas flow rate: gas flow rate was controlled by a rotameter with a minimum division length reading of 1 liter/min.

Gas volume: periodic measurements of gas volume were done by using a dry gas meter with a minimum division length reading of 1 liter.

Temperature: temperature of the gases was measured using a Mercury bulb thermometer from -10°C to 50°C and a scale division of 1°C.

3. RESULTS AND DISCUSSION

Main results of performance parameters are showed in Table 2. The retention time in the bed void (EBRT) resulted in 2.2 and 2.4 minutes, above those reported in literature (0.25 to 1 min) (converted and ZILLI, 1999; SWANSON and Loher, 1997), but within track 0.25 min seconds to several minutes DELHOMENIE et al. (2005). A higher EBRT helps to increase removal efficiency by promoting the dissemination and retention of BTEX in the bed and contact between pollutants and microorganisms, which may have contributed to the high efficiency found around 93% in the stationary phase.

The surface load (SL) was found in the range between 11.9 and 13.1 m$^3$/m$^2$.h, values below those found in literature (50-120 m$^3$/m$^2$. Hr) (CONVERTI and ZILLI, 1999). Being lower the surface load, the retention time should be higher in order to increase the removal efficiency (Swanson and Loher, 1997). It is in agreement with the results due to the operating conditions used, as the lower surface load was found associated with a high retention time (2.2 to 2.4 minutes), thus favoring the removal efficiency of up to 93.6%.
Regarding the elimination capacity (EC), the range of values found in this study, 4-29 g/m³h is near the lower limit of the study done by CONVERTI and ZILLI (1999), that is 10-160 g/m³h. As the elimination capacity is a function of the biodegradability conditions of the medium, lower removal capacities are associated with low mass loads and low concentration of the pollutant in the gas and increased retention time (CONVERTI and ZILLI, 1999). Thus, the result is in agreement with the conditions under which the tests were performed: low surface load, low concentrations of BTEX (70 - 250 ppm) and high retention time.

When comparing the maximum EC obtained (29 g/m³h), for a critical mass load in bed of 46g/m³h for the bed with compost mixed with Pall rings, with the range of 20 to 30 g/m³h found for biodegradation of BTEX in the bed with compost only (HUNTER and OYAMA, 2000), it is observed that the value obtained is very close to the expected maximum. The value obtained is also very close to the value of 30g/m³h found by Gracy et al. (2006) in a biofilter filled with compost only tested for the biotreatment of toluene, using different mass loads.

The maximum efficiency of removal (ER) achieved was around 93%, which are close to those found by ZILLI (1999), which came from 95 to 99% for aromatics, such as benzene and toluene, present in the emissions of tanks gasoline. For BTEX emissions from petroleum refining, the removal efficiency is in the range 75 to 90% and may eventually reach values higher than 95%.

Table 2 –Results of the performance parameters in the biofiltration experiment

<table>
<thead>
<tr>
<th>PERFORMANCE PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBRT</td>
<td>22.2-2.4</td>
</tr>
<tr>
<td>SL</td>
<td>11.9 - 13.1</td>
</tr>
<tr>
<td>CL</td>
<td>8 -67 (46 critical)</td>
</tr>
<tr>
<td>EC</td>
<td>4 - 29</td>
</tr>
<tr>
<td>ER</td>
<td>86.6 - 93.4</td>
</tr>
</tbody>
</table>

The mass load in bed (CL) was found between 8 and 67 g/m³h so close to values below the range 10-160 g/m³h found by CONVERTI and ZILLI (1999). High mass loads favor the clogging of the filter medium (Swanson and Loher, 1997). There was no clogging of the bed during the tests, which was indicated by the little variation in pressure (Figure 2), and it can also be attributed to the low mass load in the bed.

Fig.2: Variation of the pressure drop during the experiment
Variation pattern in removal efficiency (RE) is shown in Figure 3 according to time of biofilters operation, which showed a biodegradation curve similar to the curve developed by Monod. It is also observed that the removal efficiency (RE) of BTEX increases after a period of adaptation of the microorganisms to system conditions. The growth in the number of microorganisms resulted in an increased biological degradation of BTEX and in the stationary phase the process seems to be more intense.

The growth of microorganisms is in accordance with study done by KLAPKOVA et al. (2006), with a percolator biofilter for removal of a mixture of toluene and xylene in a bed of compost and using a consortium of endogenous microorganisms, indicating that the growth of microorganisms in this environment is relevant for the biodegradation process to attain and to maintain higher removal efficiency.

4. Conclusions

The experiment showed that it is feasible to treat low concentrations of BTEX by biodegradation process and to achieve high removal efficiencies. This technology has some limitations, since for each type of pollutant should be developed a set of design criteria and monitoring parameters. Moreover, conditions provided to the system should be adequate, as the choice of microorganisms more compatible with the pollutant, homogeneous temperature throughout the bed, moisture content and distribution compatible with the micro biota, pH without drastic changes, among others, in order to have good level of biodegradation and to maintain removal efficiency more constant throughout its useful lifetime.

It is important to develop environmental technologies that are simpler and cheaper, and that use local inputs and appropriate to the conditions of the country. Bioreactors fall into this category and can become a viable alternative to meet the requirements of environmental legislation.

5. References


