Removal of Benzene Emission by A Bio Filter with Immobilized Bacteria

M. Hosseini, M. Mahmoudi and M. Mohammadi

Faculty of Chemical Engineering, University of Technology Babol, Mazandaran, Iran

Abstract: Separation of gas components is an important process in many chemical engineering operations, such as the removal of toxic gaseous pollutants from air. Different methods have been presented for this process by many researchers. Results show that the elimination rate of these methods is not adequately high and most of them are so expensive. Furthermore they usually have harmful environmental effects. This research is based on the introduction of two new and harmless biological techniques to enhance the removal of benzene emissions and the results of a laboratory research on an artificial benzene emission elimination is considered. Two trickling filters are chosen as biological reactors. The first method is to create a liquid flow in the trickling filter under atmospheric pressure and the second one is to use a pressurized trickling filter as a bioreactor. The microbial consortium inoculated in both laboratory reactors. Under atmospheric pressure in a normal bioreactor, the achievable elimination rate of benzene is up to 86%. The results are significantly improved by limiting the liquid flow (increasing the contact time between liquid and microorganism) through the first reactor and by increasing pressure in the second reactor. The removal of benzene was increased by limiting the liquid flow and by the increasing pressure in the second reactor. For the removal process the inlet concentration of benzene was 600 mg m⁻³.

Keywords: Benzene removal · bioreactor · gaseous pollutants

INTRODUCTION

Benzene and other VOC emissions are common constituents of many industrial chemical operation effluents. Automobile exhaust is a major emission source of many important air pollutants, such as hydrocarbons (VOC).

Increasing of such gaseous pollutants in atmosphere, threatens human beings health. Using natural measures such as microorganism is a suitable method for removing the gaseous pollutants. This method is closely associated with the economical and environmental aspects.

In this study two new biological techniques are developed to enhance the removing of benzene and the results of a laboratory research has been considered on an artificial benzene emission elimination. The first method is to create a liquid flow (contact time) through the reactor under atmospheric pressure to create good exchange [1]. The transferring of substances strongly depends on the liquid flow (increasing the contact time between liquid and microorganism). The biological method for air cleaning under atmospheric pressure will be used usually for the elimination of substances which are easily soluble in water.

The results indicate that the benzene elimination improves through the variation of the liquid flow.

The second method is to use a pressurized trickling filter as a bioreactor to increase the elimination rates.

Various techniques concerning such process have been also introduced by other researchers.

The chemical method proposed by McGraw-Hill (2000) for air cleaning has fatal effects on living organisms and is also very expensive [2].

Braun (1995) introduced the physical absorption via the packed bed scrubbers for air cleaning[3]. This method has three disadvantages. It will produce waste water, elimination rate is not adequately high and is too expensive, as well.

The biological method for air cleaning has been also reported in the literature [4-14]. This method is suitable under atmospheric pressure, especially for the elimination of substances which are easily soluble in water in comparison with substances such as benzene.

In comparing with the methods introduced above, the present study has the following advantages:

- It has a good environmental effect on living organisms in comparison with the chemical method.

Corresponding Author: Dr. M. Hosseini, Department of Chemical Engineering, University of Technology Babol, Mazandaran, Iran
• The results are stable and the rate of elimination is also higher in comparison with the others.
• It is less expensive than the chemical method.

MATERIALS AND METHODS

In this study, artificial benzene emission is made in laboratory. Two trickling filters of 400 liters volume have been chosen as biological reactors and we have introduced two new biological techniques to enhance the removal of gaseous pollutants such as benzene emission. The results of a laboratory research on the artificial benzene emission elimination is also considered.

The microbial consortium inoculated in both laboratory reactors by continually exposing it to benzene and a cyclic flow of nutrient medium. The microorganisms adhere to the rough surface of the solid bed material (leca stones). The adjustment of benzene concentration in the gas phase is done by the use of compressed air. Then they catalyze the oxidation of benzene. The flow rate of exhaust and the filter volume (Vf) are 400 l h⁻¹ and 13 liters respectively with an inlet concentration of 600 mg m⁻³.

The first method is to create a liquid flow through the first reactor under atmospheric pressure. We are going to purify the air, which is contaminated with benzene. So we should insert contaminated air into a liquid like water through a bio trickling filter, whose water is supplied with a pump. Then, we pour this compound into a control volume which contains stones. At this stage, separation of gas components takes place.

To comprehend this process, imagine one of the stones. When the first drop splashes on it, a layer of water is created (Fig. 1).

The second drop increases the volume of water layer, so that the water volume in lower part of stone is more than water volume in other parts of the stone due to the gravity. During the time in which water touches stone, alumina contained in stone separates benzene from the compound (contaminated air and water). After pouring the next drop, the layer of water around the stone increases and this layer is torn and a drop of water separates from stone, at the end.

At steady state, the benzene absorption and consumption rates must be balance:

\[ Q_{\text{benzene}} = \text{absorption} = \text{consumption} \]

\[ k_p \left( c^*_i - c_i \right) = \frac{x \mu}{Y_{\text{benzene}}} \]

Where \( d = A/V \) is the gas-liquid interfacial area per unit liquid volume, \( k_p \) is the mass transfer coefficient, \( c^*_i \) is the liquid-phase concentration which is in equilibrium with the bulk gas phase, \( x \) is cell density, \( Y_{\text{benzene}} \) is the ratio of moles of cell formed per mole of benzene consumed and \( \mu \) is the specific growth rate. If the benzene dependence on the specific growth rate \( \mu \) follows the Monod form, then:

\[ \mu = \frac{\mu_{\text{max}} c_i}{k_{\text{benzene}} + c_i} \]

\[ Y_{\text{benzene}} k_p (c^*_i - c_i) = x \mu_{\text{max}} \frac{c_i}{k_{\text{benzene}} + c_i} \]

Assuming \( c_i << c^*_i \)

\[ c_i = c_i \left[ \frac{Y_{\text{benzene}} k_p x \mu_{\text{max}}}{1 - Y_{\text{benzene}} k_p x \mu_{\text{max}}} \right] \]

The second method was to use a pressurized trickling filter as a second bioreactor.

The elimination rate can be calculated by the following equation:

\[ R = \frac{(C_{\text{in}} - C_{\text{out}})}{C_{\text{in}}} \times 100 \text{ [%]} \]

Total amount of gaseous pollutants load is:

\[ F = G \cdot C_{\text{in}} \]

For the total specific load we have:

\[ f = \frac{F}{V_f} \]

Fig. 1: A layer of water is created when the first drop splashes
RESULTS AND DISCUSSION

The results have been significantly improved by limiting the liquid flow through the first reactor (Fig. 5) and by increasing the pressure of the second reactor (Fig. 6 and 7). Under atmospheric pressure in a normal bioreactor (Fig. 4), the achievable elimination rate of benzene was up to 86% and the results were unstable. The removing of benzene emission was increased to 95% by limiting the liquid flow with a residence time of liquid 5 min. By increasing the pressure in the reactor up to 4 bars the removal was 99%. For the removal process was the inlet concentration of benzene 600 mg m⁻³.

The pressurized reactor has two advantages: first, the results are constant and stable; second, the elimination rate is higher than the normal bioreactor under atmospheric pressure.

In order to find out that the elimination is done only by microorganisms and not by surface adsorption of the leca stones, the experiment has been carried out in two stages. In the first stage the trickling bed is used with active materials (with existing microorganisms).

![Figure 2: Schematic diagram of the bio trickling filter under atmospheric pressure](image)

![Figure 3: Schematic diagram of the pressurized bioreactor](image)

The specific efficiency "r" is given by:

$$r = f \cdot R$$  \hspace{1cm} (6)

The exposure to the benzene emission has been continuously carried out with a cyclic flow of nutrient medium in reactor, which causes the activity of microbial culture. The adjustment of the concentration of exhaust emission is done with compressed air. In order to increase the pressure of system (second method), a compressor is used. The water sprays in trickle bioreactor and benzene enters from the bottom of the bioreactor (Fig. 2 and 3).

**Medium:** (liquid I + liquid II)

<table>
<thead>
<tr>
<th>Liquid I</th>
<th>Concentration (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MgSO₄ 7H₂O</td>
<td>200 mg</td>
</tr>
<tr>
<td>CaSO₄ 2H₂O</td>
<td>40 mg</td>
</tr>
<tr>
<td>FeSO₄</td>
<td>80 mg</td>
</tr>
<tr>
<td>Liquid of trace element</td>
<td>1 ml</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Liquid II</th>
<th>Concentration (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na₂HPO₄ 2H₂O</td>
<td>774 mg</td>
</tr>
<tr>
<td>KH₂PO₄</td>
<td>865 mg</td>
</tr>
</tbody>
</table>

![Figure 4: The Elimination rate for benzene under atmospheric pressure by a normal bioreactor after the day from inoculation until 15 days](image)

![Figure 5: The Elimination rate for benzene under atmospheric pressure v.s. liquids residence time](image)
CONCLUSION

First method: The results of the experiments demonstrated that the elimination rates are reduced by increasing the liquid flow (liquid film) through the reactor and increased through a minimum amount of liquid film (Fig. 5). The final elimination rates in the system vary between 37 and 99%.

Second method: Concerning the influence of biological reaction caused by benzene through the increase of partial pressure, the most significant results on the elimination rates are shown in Fig. 6 and 7. The final elimination rates in the system vary between 80 and 99% under 3 bars and 63 and 99% under 4 bars.

Nomenclature and units

- \( R_t \): Elimination rate efficiency [in %]
- \( C_{in} \): Inlet concentration [g m\(^{-3}\)]
- \( C_{out} \): Outlet concentration [g m\(^{-3}\)]
- \( Q \): Flowrate [m\(^3\) h\(^{-1}\)]
- \( F \): Total load of pollutants [g h\(^{-1}\)]
- \( f \): Total specific load [g m\(^{-3}\) h\(^{-1}\)]
- \( r \): Specific efficiency [g m\(^{-3}\) h\(^{-1}\)]
- \( V_f \): Filter volume [m\(^3\)]
- \( \sigma' \): Specific surface of leca-stones [m\(^2\) m\(^{-3}\)]
- \( k_t \): Mass transfer coefficient [m s\(^{-1}\)]
- \( \varepsilon \): Liquid-phase concentration in equilibrium with bulk gas [g m\(^{-3}\)]
- \( x \): Cell density [g m\(^{-3}\)]
- \( \gamma_{benzene} \): Ratio of formed cell moles to benzene consumed moles [g g\(^{-1}\)]
- \( \mu \): Specific growth rate [h\(^{-1}\)]
- \( K_{benzene} \): Monod constant [g m\(^{-3}\)]

REFERENCES


