Biochemical Engineering

ChemCon'04 Mumbai

Biofiltration for VOC Removal: A State-of-the-art Review

B.V. Babu* **and Smita Raghuvanshi**
Department of Chemical Engineering
Birla Institute of Technology and Science
Pilani – 333 031 (Rajasthan) India
Fax: 91 1596 244183; Tel: 91 1596 245073 Ext. 205;
E-mail: bvbabu@bits-pilani.ac.in < B V Babu >
smita@bits-pilani.ac.in < Smita Raghuvanshi >

Abstract

Biofiltration is one of the air pollution control technologies that utilizes the microorganisms to biologically degrade Volatile Organic Compounds (VOCs) and odor contained in waste air streams. The microorganism exists on the surface and in a thin water film surrounding the surface of biofilter material and degrades the pollutants present in the fluid. This method is distinguished from other biological waste treatment methods by the fact that there is a separation between the microorganisms and the treated waste. An attempt is made in identifying the limitations of the existing models on biofiltration. Also the biofilm structure is studied using NMRI technique, which opens a new area in the modeling. The mechanism of attached growth and the artificial entrapment of microorganisms to the bedding material are being studied. The various methods of artificial immobilization have a future scope in view of its several advantages, which is being studied in the paper.

Keywords: Biofiltration; Volatile Organic Compounds; Modeling; Simuilation; Biofilm

1. Introduction

Industrial plants and processes use and emit many types of VOCs, which rapidly become atmospheric pollutants. Biotechnology through biodegradation becomes a good alternative for solving emission problems. Biofiltration is distinguished from other biological waste treatments by the fact that there is a separation between the microorganisms and the treated waste. VOCs are emitted by a wide array of products which include: paints, lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, office equipment such as copiers and printers, correction fluids and carbonless copy paper, graphics and craft materials including glues and adhesives, permanent markers and photographic solutions, etc. In this technique, the microbial biomass is static while the treated fluid is mobile which flows through the filter bed. This paper gives a comprehensive state-of-the-art-review highlighting the aspects such as (1) the limitations in modeling of biofilter, (2) recognizing the gaps in modeling, (3) taking note of the limitations which exist because of the pore structure and biofilm structure, (4) discussing the mechanism of attachment of microbes on the filter bed, (5) suggesting the experimental set-up used in biofiltration, and (6) overall putting forward an idea about the great scope of research in the field of biofiltration

2. Literature Review

Several experiments have been conducted and various mathematical models have been established which discuss the importance of various parameters in the biofiltration. Some of the reported models and experimental work are briefed below which unfolds the existing limitations and suggest measures for the improvement in the modeling of biofiltration.

Mohseni and Grant [1] carried out both the experimental and theoretical studies. The experiments were carried out on two identical bench scale biofilters with media consisting of a mixture of compost and wood chips. A steady state model was also developed after making assumption that radial diffusion is not considered and by using Monod Kinetics term for microbial degradation. It predicted the interaction between the compounds during the steady state biofiltration of methanol and α-pinene. They concluded that inert material such as perlite did not improve the performance of the biofilters and provided similar results as those with media containing wood chips and compost.

Delhomenie et al. [2] studied the biofiltration of airborne toluene; the biofilter employed being operated at the laboratory scale for a continuous period of 3 months. The focus of this particular study has been the development of a new compost based filter material, which consists of an association between matured compost and organic binder that will enhance the period of bed's efficient operations.

Spigno et al. [3] used a biofilter to remove hexane from contaminated air streams inoculated by *Aspergillus Niger* fungi. The filamentous fungi include many paraffin degrading species and develop aerial structures which give a large superficial area and allow for a direct pollutant mass transfer from the gas phase to the biological one without the presence of liquid phase which is a limiting factor for hydrophobic compounds [4]. A steady state model was tested to describe certain parameters. It was concluded that system was more efficient for lower pollutant concentrations of (2-7 g/m^3).

Aroca et al. [5] studied the biofiltration system using peat as solid support inoculated with Thiobacillus thioparus (ATCC 23645). The inoculation systems allowed an efficient colonisation of the peat with T. thioparus. The model was developed for treating a gaseous stream containing high concentrations of H_2S for the prediction of the performance of biofilter.

Otten et al. [6] conducted experiments to evaluate the removal efficiencies of butyric acid, and the modeling of biofilter was carried by neglecting the axial diffusion and assuming that there are no concentration variations in the radial direction. Four parameters were identified that strongly influenced model performance: surface area of the biofilm per unit volume of packing material (A_S), empty-bed residence time (EBRT), maximum specific growth rate of microorganism (μ_m), and microbial yield coefficient (Y).

Lu et al. [7] presented a mathematical model that incorporates mass transfer process and biofilm reactions using trickle bed air biofilter for Butyl Acetate (BA) removal. The effluent gas phase BA concentrations predicted by the model were in good agreement with the measured data. The parameters like surface area of the biofilm per unit volume of packing material, empty bed residence time and microbial yield coefficient on BA influence the performance of the biofilter.

3. Possible Improvements in Models

All the models, which are been found till now in the field of biofiltration have some limitations such as (1) no radial concentration gradient across the biofilter is considered, (2) no gas-phase resistance at the air-biofilm interfaces are considered and (3) reaction occurring in the pores is not considered.

These limitations can be checked and new and improved models can be developed by incorporating those parameters that were neglected, by relaxing some of the assumptions made in the earlier studies and by considering the reactions taking place inside the pores of the filter material. The reaction-taking place in the pores of filter material, if considered will efficiently upgrade the models and the validity with the experimental results will be more accurately established.

4. Limitations based on bio-film & pore structures

Besides this, there are other significant areas in biofiltration like biofilm structure and pore structure of filter bed material that has a wide scope of research. Taking in view the pore structure, biofiltration differs from other methods in a way that during the operation biomass is being created which changes the bed's pore structure. The NMRI technique is described below, which shows the importance of consideration of reaction occurring inside the pores of Biofilter.

4.1 Sophisticated Instrumental Techniques

The traditional perception of the flow pattern around biofilms describes two separated zones: the biofilm zone and the fluid zone. The biofilm zone contacts the fluid zone with its outer plane and the fluid does not penetrate into the biofilm, but flows upon it. This perception may not be accurate. Lewandowski et al. [8] showed nuclear magnetic resonance imaging (NMRI) experiments, which showed that biofilms could have a complex heterogeneous structure consisting of cell clusters, separated by interstitial voids. Water can flow through the entire biofilm creating two flow fields; one above the biofilm and another within the biofilm. These flow fields interact with each other in a complex manner. It is assumed that these flow patterns enhance the substrate flux from the bulk liquid to the biofilm. So there will be interaction within the biofilm with each other and this interaction, which so far has been neglected in all the studies, give modeling results that do not significantly match with the experimental results. So using NMRI technique, the heterogeneous structure of biofilm was confirmed which itself opens a challenge in the biofiltration field making it confirm to consider the reaction which takes place inside the pores of the filter bed.

5. Mechanism of attachment of microbes in Biofiltration

Biofiltration is distinguished from other biological waste treatments by the fact that there is a separation between the microorganisms and the treated waste. The immobilization of microorganisms to the bedding material can be divided into two main immobilization processes: (1) the self-attachment of microorganisms to the filter bedding material, which is defined as `attached growth', and (2) the artificial immobilization of microorganisms to the bedding material.

5.1 Attached Growth

The self-attachment of microorganisms to the filter bedding material takes place by different forces, which govern the microbial attachment like electrostatic attractions, covalent bond formation and hydrophobic interactions in the bedding material. Usually, none of the forces could be considered as dominant The strength of the attachment and the composition of the forces, which govern the attachment of microbes on the bed depend on different environmental conditions, different microbial species, and different surface properties and with different fluid properties [9].

5.2 Artificial immobilization of the microorganisms to the filter bedding material

This is the most challenging field in biofiltration as different immobilization techniques have been identified for the attachment of microbes to the bed. The artificial immobilization of the microorganisms to the filter bedding material takes place by various techniques such as (1) micro encapsulation, (2) membrane separation, (3) Covalent bonding and covalent cross-linking, (4) entrapment of microorganisms within polymer beads. The brief description of the processes is given below.

5.2.1. **Micro encapsulation Method:** This method consists of wrapping droplets containing microorganisms with a thin membrane. The microorganisms can freely move within their own capsule, consuming substrates that penetrate through the membrane cover. The microcapsule membranes are generally made of nylon and cellulose nitrate. Usually, the diameter of these microcapsules varies from 10 to 100 μm [10]. The main advantage of this technology is low diffusion restriction of the thin membrane.

5.2.2. Membrane Separation: The main principle of this method is to separate the microorganisms from the bulk fluid by the use of sheets of membrane. The membranes will allow the substrates to penetrate to the microorganism's zone, while preventing the microorganisms from mixing with the fluid to be treated [11]. The membranes used in this method are usually porous ultra filtration membranes (separates in the range of 0.002±0.1 lm)

5.2.3 Covalent bonding and covalent cross-linking: The outer surfaces of microbial cells contain large quantities of a variety of reactive groups. The covalent bonding method includes the creation of covalent bonds between those reactive groups and different ligands on the bedding material. The covalent cross-linking method is support free and involves the joining of the microorganisms to each other to form a large, three-dimensional complex structure. The most commonly used coupling agent is probably glutaraldyde although carbodiimine, isocyanate and amino silane have also been frequently used [9].

5.2.4 Entrapment within polymers beads

This method consists of trapping microorganisms within a three-dimensional polymer matrix. The pores in the matrix are smaller than the microbial cells, keeping them trapped within the material but the pores still allow the penetration of substrates through the polymer matrix towards the trapped microorganisms [12]. The main disadvantage associated with this method is the higher diffusion restriction which some polymer materials possess compared to the other immobilization methods. The advantages include the achievement of a high viable biomass concentration, higher resistance to toxic compounds within the treated fluid, the possibility of immobilizing together different species of microorganisms separated physically from each other, greater plasmid stability within genetic engineered microorganisms, which are immobilized in this method.

Various experiments also are to be carried for the validating the models proposed in biofiltration. The most widely used biofiltration setups are (1) the conventional biofilter system [2] and (2) the trickling biofilter system [13].

6. Conclusions

Biofiltration is one of the better processes of removal of VOCs. The improvements in the models can be carried by the incorporation of some changes in the model and by significantly consideration of the reaction-taking place inside the pores of the models. The methods like self-attachment of the filter bed material by microbes and the artificial immobilization methods are the challenging fields in which there is an immense scope of research.

References

[1]. M. Mohseni, D. Grant-Allen, Chemical Engineering Science, 55(2000), 1545.
[2]. M.C. Delhomenie, L. Bibeau, N. Bredin , S. Roy, S. Broussau, R. Brzezinski, J.L. Kugelmass, M. Heitz, Advances in Environmental Research, 6(2002), 239.
[3]. G. Spigno, C. Pagella, M. Fumi, R. Molteni, D. Macro-De-Faveri, Chemical Engineering Science, 58(2003), 739.
[4]. S.M. Zarook, A.A. Shaikh, S.M. Azam, Biochemical Engineering Journal, 1(1998), 77.
[5]. E. Aroca , O. Patricio, A. Fernando, C. Chrisitan, Process Biocehemistry, 39(2003), 165.
[6]. L. Otten, T.M. Agzal, M.D. Mainville, Advances in Environmental Research, 20(2002), 1.
[7]. C. Lu, C. Kwotsair, S. Hsu, J. Lin, Chemical Engineering Science, 59(2004), 99.
[8]. Z. Lewandowski, P.Stoodley, S. Altobelli, Water Science Technology, 31(1995), 153.
[9]. J. Tampion, M.D. Tampion, and Immobilized Cells: Principles and Application. Cambridge University Press, Cambridge, 1987.
[10]. G.F. Bickerstaff, Immobilization of enzymes and cells. Humana Press, Clifton, UK, (1997).
[11]. S.N. Gaeta, Membrane Technology: Applications to Industrial Wastewater Treatment. Kluwer Academic Publishers, Dordrecht, (1995).
[12]. J. Woodward, Journal of Microbial Methods, 8(1988), 91.
[13]. Cohen Y, Bioresource Technology, 77(2001), 257.