

Modeling and Simulation of Biofilters Operated in Periodic Mode

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Abstract

Biofiltration of off gases containing Volatile Organic Compounds (VOCs) is a reliable and cost effective technology for VOCs removal. As most of the enterprises operate in the periodic conditions, a model is developed based on the transient conditions. In the study, a Linear Driving Force (LDF) model is used which takes into account the adsorption of pollutant in the support phase and the rate of biodegradation. The rate equation is given by the modified three-parameter Monod-type expression. The results are compared with the earlier and experimental data as reported in literature. It is also observed that dispersion coefficient plays a significant role in the removal rate of VOCs.

Keywords: Biofiltration, Modeling, Periodic Operation, Monod Kinetics, Transient Behavior

1. Introduction

Since the early twentieth century, biological treatment processes found wide applications in wastewater, air and solid waste pollution control. The need for alternate cost effective treatment technologies led to similar biological treatment processes for waste gas streams. One such treatment technology is biofiltration. Biofiltration technology utilizes the microorganisms to biologically degrade Volatile Organic Compounds (VOCs) and odor contained in waste air streams (Babu and Raghuvanshi., 2004). In biofiltration, a humid, contaminated air is passed through a porous support material on which pollutants degrading cultures are immobilized. It uses microorganisms to break down pollutants present in waste gas streams. The microorganisms grow in a biofilm on the surface of the medium or are suspended in the water phase surrounding the medium particles. The filter bed medium consists of peat/compost/coal/activated carbon, which ensures large surface attachment areas and additional nutrient supply. As the air passes through the bed, the

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contaminants in the air phase sorb into the biofilm and onto the filter medium where they are degraded. Therefore biofiltration is a process that is the combination of all the basic mechanisms such as absorption, adsorption, and degradation and desorption of gas phase pollutants.

There have been various models reported in the literature describing the biofiltration. Ottengraf and Oever (1983) is based on developments made from biodegradation of non-adsorbable substrates in submerged biofilms. They studied three basic kinetic cases in biofiltration such as first order kinetics, zero order kinetics with reaction rate limitation and zero order kinetics with diffusion rate limitation. Zarook and Baltzis (1994) have developed a transient model for the biofiltration of a single VOC taking into consideration the effects of oxygen and interactive kinetics. Devinny and coworkers (Devinny et al., 1991; Hodge and Devinny, 1995; Hodge and Devinny, 1997) developed a model that made simple assumptions about conditions in the water and on the medium in order to emphasize the effects of changing inlet concentrations. Shareefdeen and Baltzis (1994) refined their theory and introduced sorption of the pollutant to the packing and partial coverage of the support medium by biofilm in order to be able to simulate transient changes occurring in the biofilter. Zarook et.al., (1997) observed that a general transient biofiltration model should incorporate dispersion, diffusion, reaction and adsorption phenomena. Since the biofilter contains certain moisture content, the adsorption is used loosely here and it refers to both actual adsorption of VOCs on solid as well as absorption of VOCs in the water retained in the packing materials. At steady state conditions, the adsorption process is in equilibrium and thus it does not come into play. But in practical applications, most of the biofilters operate in transient condition, as VOC emission level in any plant is unlikely to be constant. However under transient conditions, adsorption process needs to be explicitly accounted for in the model development. Recent studies (Zarook et al., 1993; Deshusses and Hamer, 1993; Chang et al., 1993; Oh et al., 1994; Zarook and Baltzis, 1994b) have shown that degradation kinetics are more complex than zero-or first order type kinetics. The above models have not incorporated the adsorption as a separate phase occurring in the biofiltration working in periodic mode.

The model considered in the present study incorporates the adsorption phenomenon occurring in the biofiltration in the periodic mode of operation as under periodic operation of biofilter, it is considered that biofilm is less developed due to nutrient shortage. It also deals with the three parameter Monod type expression for rate kinetics of biodegradation, which is found to be suitable for transient behavior of biofilter.

2. Mathematical Model

In this work, periodic operation of biofilter is considered and it is seen that under periodic operation of biofilter, the biofilm is less developed than under continuous regime due to the temporal nutrient shortages. The Linear Driving Force (LDF) approach is being applied because it has been seen that some of the specific parameters concerning with the biofilm could not be well known. So this approach is being applied which uses linear driving force model to approximate the pollutant interphase transport.

2.1 Assumptions

1. The axially dispersed plug flow for the gas phase is assumed.
2. A linear driving force to approximate the pollutant interphase transport is assumed and it allows for the pollutant adsorption and biodegradation in the support or biotic phase using the first order kinetics with no oxygen limitation.

2.2 Model Development

The mass balance equation for gas phase is given by Eq.1 :

$$\frac{\partial C_i}{\partial t} = D_L \frac{\partial^2 C_i}{\partial x^2} - w \frac{\partial C_i}{\partial x} - \left(\frac{1-\varepsilon}{\varepsilon} \right) [k_{ig} - \text{ads} (q_i^* - q_i)] = 0 \quad (1)$$

with initial and boundary conditions (Eqns. 2-4)

$$C_i(x,0) = 0 \quad (2)$$

$$D_L \left. \frac{\partial C_i}{\partial z} \right|_{x=0} = -w(C_i|_{0-} - C_i|_{0+}) \quad (3)$$

$$\left. \frac{\partial C_i}{\partial x} \right|_{x=H} = 0 \quad (4)$$

The mass balance for the solid phase is given by Eq.5:

$$\frac{\partial q_i}{\partial t} = k_{\text{ig-ads}} (q_i^* - q_i) - r_s \quad (5)$$

The initial condition to solve this equation is given by Eq.6:

$$q_i(x,0) = 0 \quad (6)$$

The adsorption of the organic pollutants on the packing material is given by the linear isotherm by Eq.7:

$$q_i^* = \frac{C_i}{m_2} \quad (7)$$

The LDF model does not accommodate for the varying pollutant conversion. So this effect is incorporated by expressing the rate of biodegradation as given by Eq.8:

$$r_s = \mu \frac{q_i^N}{K_m + q_i} \quad (8)$$

3. Solution Algorithm

The set of partial differential equations (1 & 5) along with their respective initial and boundary conditions (Eqns. 2,3,4,6&7) and rate Eq. (8) are numerically solved by applying finite difference explicit method. Finite difference technique has been successfully applied to solve such type of partial differential equations in other studies by Babu and Chaurasia (2003a; 2003b; 2004a; 2004b; 2004c; 2004d). A mathematical algorithm to solve these equations are developed and implemented into a computer program using MATLAB (v.6.1) software. The same parameters reported by Chmiel et al. (2005) are used for simulation of the present model.

4. Results and Discussion

The model used, as described above, determines the outlet VOCs concentration at different times based on different operating conditions. The breakthrough curves are obtained for the inlet VOC concentrations ranging from 0.02 to 0.1g/m³ of n-butanol and Methyl Ethyl Ketone (MEK). Same parameters given by Chmiel et al (2005) are used and some parameters (see Table-1) are assumed which are not given in literature. The breakthrough profiles are obtained for the MEK and butanol In the present study,

modeling results are compared with the experimental and modeling results as given by Chmiel et al (2005). The standard deviation for MEK was obtained as 0.00242 for the present model and 0.00414 for the Chmiel et al. Present model gives the better result as compared to the reported model. Based on the better results reported by our model, the simulations are carried out for different concentrations of MEK and butanol and results are given in Figs. 3 & 4 respectively. It is observed that for MEK, for inlet concentration $C_{in} = 0.1 \text{ g/m}^3$, breakthrough is achieved earlier and for $C_{in} = 0.04 \text{ g/m}^3$ breakthrough gets delayed. The same profile is obtained for butanol for inlet concentrations of 0.05 g/m^3 and 0.02 g/m^3 resp.

It was observed that dispersion coefficient has significant effect on biofiltration unlike as reported by (Deviny et al., 1995) which states that it has liminal effect for the concentration values ranging from $0-3.33 \times 10^{-4} \text{ g/m}^3$. But in the present study, it was found that, dispersion coefficient D_L plays a significant role in attaining the breakthrough curves as by increasing the values of D_L , breakthrough curve is obtained much earlier showing that as diffusivity increases, removal rate is faster. The stability criterion was not satisfied when D_L value was used as reported in the paper. Another fact, which is established in the paper, is that it uses three-parameter Monod type kinetics for the biodegradation in case of periodic operation of biofilter, which is validating the experimental results. It focuses the importance of having the proper expression for the rate kinetics in biodegradation keeping in view of the transient operating conditions in biofilter

5. Conclusions

The breakthrough profiles are obtained for MEK and butanol for different concentrations. The present model gives the better result as compared with Chmiel et al. (2005) model that is reported in literature. Also it is observed that dispersion coefficient plays an important role in biofiltration.

References

- Babu, B.V. and Gupta, S., “Modeling and Simulation for Dynamics of Packed Bed Adsorption”, Proceedings of International Symposium & 57th Annual Session of IChE in association with AIChE (CHEMCON-2004), Mumbai, December 27-30, (2004).
- Babu, B.V., Chaurasia, A.S., “Modeling, Simulation, and Estimation of Optimum Parameters in Pyrolysis of Biomass”, *Energy Conversion and Management*, **44** (13) 2135-2158, (2003a).
- Babu, B.V., Chaurasia, A.S., “Modeling for Pyrolysis of Solid Particle: Kinetics and Heat Transfer Effects”, *Energy Conversion and Management*, **44** (14) 2251-2275, (2003b).
- Babu, B.V., Chaurasia, A.S., “Parametric Study of Thermal and Thermodynamic Properties on Pyrolysis of Biomass in Thermally Thick Regime”, *Energy Conversion and Management*, **45** (1) 53-72, (2004a).
- Babu, B.V., Chaurasia, A.S., “Dominant Design Variables in Pyrolysis of Biomass Particles of Different Geometries in Thermally Thick Regime”, *Chemical Engineering Science*, **59** (3), 611-622, (2004b).
- Babu, B.V., Chaurasia, A.S., “Pyrolysis of Biomass: Improved Models for Simultaneous Kinetics & Transport of Heat, Mass, and Momentum”, *Energy Conversion and Management*, **45** (9) 1297-1327, (2004c).
- Babu, B.V., Chaurasia, A.S., “Heat Transfer and Kinetics in the Pyrolysis of Shrinking Biomass Particle”, *Chemical Engineering Science*, **59** (10), 1999-2012, (2004d).
- Chmiel K., Konieczny A., Palica M., Jarzebski A.B., Periodic Operation of biofilters concise model and experimental validation, *Chemical Engineering Science*, **60**, 2845-2850 (2005).
- Deviny, J.S., Deshusses, M.A., Webster, T.S., Biofiltration for air pollution control. Lewis Publishers, Washington DC, 111–13 (1999).
- Hodge, D.S., Deviny, J.S., Modelling removal of air contaminants by biofiltration. *Journal of Environmental Engineering* **121** (1), 21–32 (1995).

Hodge, D.S., Deviny, J.S., Determination of transfer rate constants and partition coefficients for air phase biofilters, *J. Environ Engg* **123** (6), 577 (1997).

Ottengraf, S.P.P., vander Oever, A.H.C., Kinetics of organic compound removal from waste gases with a biological filter, *Biotechnology and Bioengineering* **25**, 3089–3102. (1983).

Shareefdeen, Z., Baltzis B.C., Biofiltration of toluene vapor under steady state and transient conditions, *Chemical Engineering Science.*, **49**, 4347 (1994).

Nomenclature:

| | |
|----------------------|---|
| C_i | odor concentration in gas phase, g/m^3 |
| D_L | dispersion coefficient, m^2/s |
| H | bed height, m |
| $k_{i\text{-g-ads}}$ | overall mass transfer coefficient, 1/s |
| K_m | saturation constant, g/m^3 |
| M_2 | partition coefficient of odor between gas and solid phase, dimensionless |
| N | power exponent |
| q_i | solid phase concentration of contaminant in the biofilter, g/m^3 |
| q_i^* | solid phase concentration of contaminant in the solid phase, g/m^3 |
| r_s | reaction rate, $\text{g/m}^3 \text{ s}$ |
| t | working time, s |
| V | volumetric flow rate, m^3/hr |
| w | gas velocity, m/s |
| x | distance, m |
| ε | porosity of the bed, m^3/m^3 |
| μ | rate constant of biofiltration process, 1/h |
| Subscripts | |
| Ads | adsorbent |
| i | component |
| Superscript | |
| | Equilibrium |

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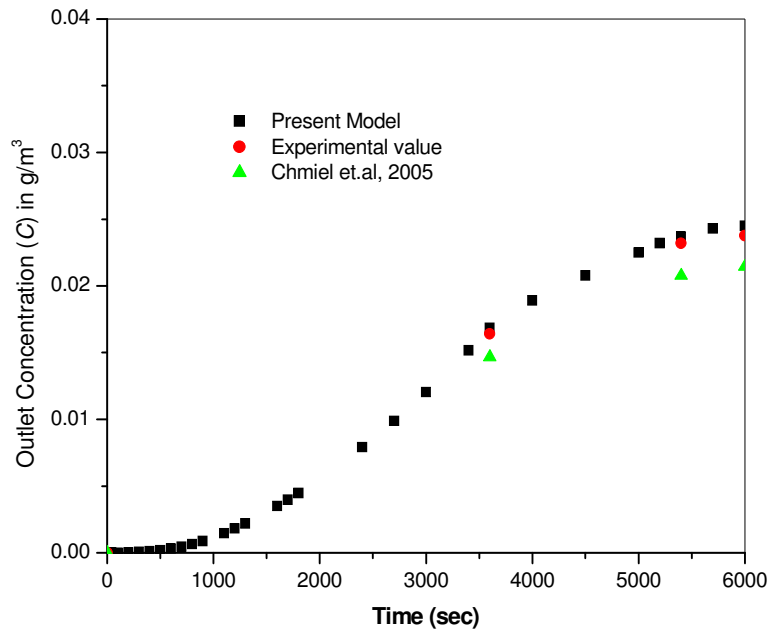


Figure 1: Comparison between the present model, experimental value and model reported by Chmiel et.al, 2005 for Butanol

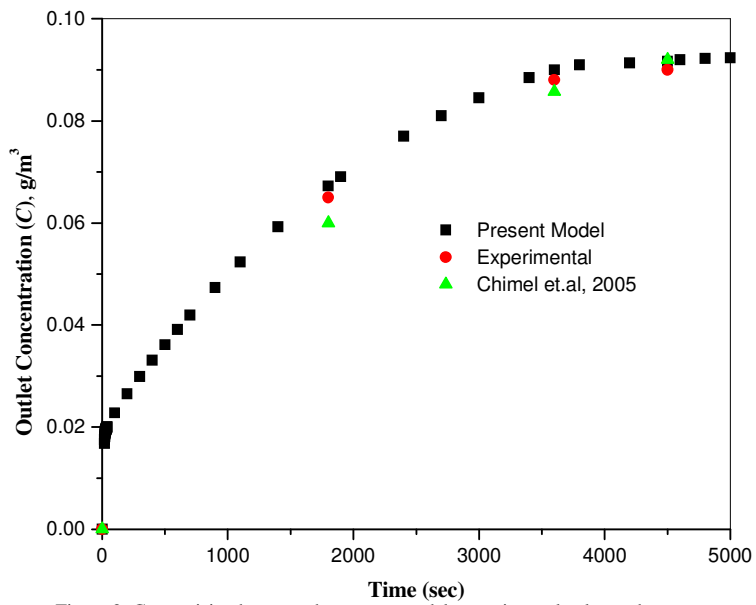
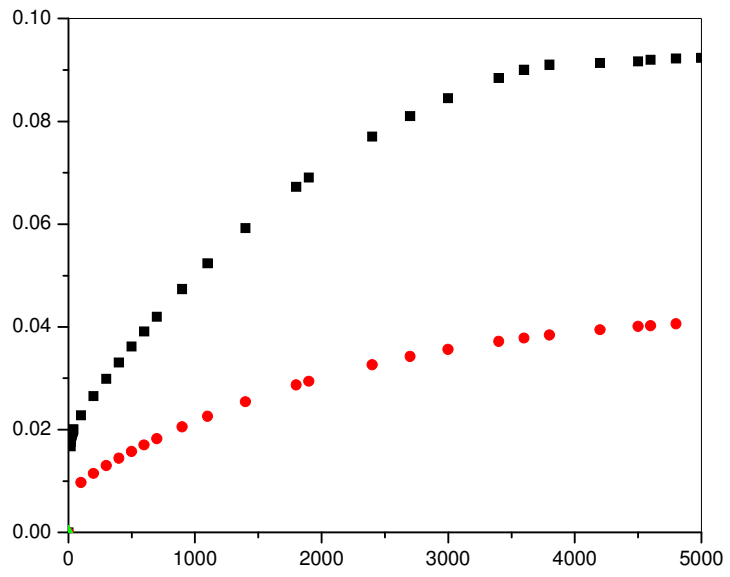


Figure 2: Comparison between the present model, experimental value and model reported by Chmiel et.al, 2005 for MEK



ERROR: rangecheck
OFFENDING COMMAND: .buildcmap

STACK:

-dictionary-
/WinCharSetFFFF-V2TT621301FBt
/CMap
-dictionary-
/WinCharSetFFFF-V2TT621301FBt