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# Modeling the behaviors of adsorption and biodegradation in biological activated carbon filters

*Chung-Huei Liang*[a], *Pen-Chi Chiang*[a,*], *E-E Chang*[b]

[a]Graduate Institute of Environmental Engineering, National Taiwan University, No. 71, Chou-shan Road, Taipei 106, Taiwan
[b]Department of Medicine, Taipei Medical University, 250 Wu Hsing Street, Taipei 110, Taiwan

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ABSTRACT

This investigation developed a non-steady-state numerical model to differentiate the adsorption and biodegradation quantities of a biological activated carbon (BAC) column. The mechanisms considered in this model are adsorption, biodegradation, convection and diffusion. Simulations were performed to evaluate the effects of the major parameters, the packing media size and the superficial velocity, on the adsorption and biodegradation performances for the removal of dissolved organic carbon based on dimensionless analysis.

The model predictions are in agreement with the experimental data by adjusting the liquid-film mass transfer coefficient ($k_{bf}$), which has high correlation with the Stanton number. The Freundlich isotherm constant ($N_F$), together with the maximum specific substrate utilization rate ($k_f$) and the diffusion coefficient ($D_f$), is the most sensitive variable affecting the performance of the BAC. Decreasing the particle size results in more substrate diffusing across the biofilm, and increases the ratio of adsorption rather than biodegradation.



## 1. Introduction

The biological activated carbon (BAC) process, which contains adsorption and biodegradation mechanisms, has been widely used in water and wastewater treatments for lowering the regeneration cost and prolonging the life of granular activated carbon (GAC) beds. Researchers and operators have been attempting to elucidate each mechanism for the purpose of simulation and optimization. For biodegradation, Hozalski et al. (1995) reported that the removal efficiency did not vary significantly under a certain empty-bed contact time (EBCT) ranging between 4 and 20 min. Melin and Ødeggard (2000) indicated that the optimum EBCT was approximately 20 min, since longer EBCT could not significantly increase the removal efficiency. Rittmann et al. (2002) reported that EBCT greater than 3.5 min had insignificant effects on dissolved organic carbon (DOC) removal in pilot filters treating ozonated groundwater. Li et al. (2006) reported that the optimum EBCT was 15 min for an ozone-BAC process to treat raw waters.

A well-validated mathematical model can provide valuable information to assess and predict the performance of BAC, and some representative models are listed in Table 1 (Chang and Rittmann, 1987; Sakoda et al., 1996; Walker and Weatherley, 1997; Abumaizar et al., 1997; Hozalski and Bouwer, 2001; Badriyha et al., 2003). Chang and Rittmann (1987) developed a mathematical model that could quantify the extent of adsorption and biodegradation. One of its remarkable contributions is to illustrate and quantify the mass transfer of substrates diffusing through the biofilm, metabolized by microbes, and finally reaching the surface of GAC. The limitation is that it cannot be used under unsteady or plug-flow conditions. Sakoda et al. (1996) suggested a theoretical

*Corresponding author. Tel.: +886 2 2362 2510; fax: +886 2 2366 1642.
E-mail address: pcchiang@ntu.edu.tw (P.-C. Chiang).
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**Nomenclature**

| | |
|---|---|
| $A_f$ | surface area of a BAC granule ($L^2$) |
| $b_{tot}$ | total decay coefficient (1/T) |
| $d_p$ | packing media diameter (L) |
| $D_f$ | diffusivity in biofilm ($L^2$/T) |
| $D_z$ | dispersion coefficient in the liquid phase ($L^2$/T) |
| $K_b$ | half-velocity concentration in water (M/$L^3$) |
| $k_b$ | max. specific substrate utilization rate in water (M/CFU-T) |
| $k_{bf}$ | liquid-film mass transfer coefficient (dimensionless) |
| $K_f$ | half-velocity concentration in biofilm (M/$L^3$) |
| $k_f$ | max. specific substrate utilization rate in biofilm (M/CFU-T) |
| $k_F$ | Freundlich isotherm coefficients (dimensionless) |
| $K_L$ | Langnuir isotherm coefficients (dimensionless) |
| $L_c$ | column length (L) |
| $L_f$ | length of the biofilm (L) |
| $m_g$ | mass of a GAC granule (M) |
| $N_{Da}$ | Damköhler number (dimensionless) |
| $N_F$ | Freundlich isotherm coefficients (dimensionless) |
| $N_{Re}$ | Reynolds number (dimensionless) |
| $N_{Sh}$ | Sherwood number (dimensionless) |
| $N_{St}$ | Stanton number (dimensionless) |
| $q_0$ | Langnuir isotherm coefficients (M/M) |
| $q_a$ | adsorption capacity (M/M) |
| $r_f$ | biofilm radius (L) |
| $r_g$ | GAC granule radius (L) |
| $S_b$ | substrate concentration in the liquid phase (M/$L^3$) |
| $S_{b0}$ | influent concentration (M/$L^3$) |
| $S_f$ | substrate concentration in the biofilm (M/$L^3$) |
| $V_g$ | volume of a GAC granule ($L^3$) |
| $x$ | distance along the BAC column (L) |
| $X_b$ | cell density in the liquid phase (CFU/$L^3$) |
| $X_f$ | biofilm density (CFU/$L^3$) |
| $Y$ | specific yield (CFU/M) |
| $v_s$ | superficial velocity (L/T) |

*Greek symbols*

| | |
|---|---|
| $\varepsilon$ | porosity (dimensionless) |
| $\nu$ | kinetic viscosity of the bulk solution ($L^2$/T) |
| $\rho_g$ | GAC granule apparent density (M/$L^3$) |

model for a BAC column, in which the mechanisms included dispersion, convection, biodegradation and adsorption. The primary assumption for simplifying is that the substrate concentration on the interface between the biofilm and the GAC is identical to that in the bulk solution. However, this assumption implies that there is no concentration reduction within the biofilm; thus, that model is not fit for the condition with thick biofilm. In 1997, Walker and Weatherley proposed a

**Table 1 – Some of the representative BAC models**

| Reactor type | Mechanisms considered[a] | Kinetic condition | | | | Mass transport description[b] | Solution method | References |
|---|---|---|---|---|---|---|---|---|
| | | Substrate in bulk phase | Substrate in biofilm | Biofilm amount | Substrate in GAC | | | |
| Complex mixing | A, B | Non-steady monod | Monod | Non-steady | Non-equilibrium | 1, 2, 3, 4, 5 | Analytical | Chang and Rittmann (1987) |
| Column | A, B, C, D | Non-steady no biodegradation | n.a.[c] | Steady | Equilibrium | 1 | Analytical | Sakoda et al. (1996) |
| Column | A, B | Uniform Monod | Monod | Non-steady | n.a.[c] | 1 | Analytical | Walker and Weatherley (1997) |
| Column | A, B, C | Non-steady no biodegradation | Monod | Steady | Non-equilibrium | 1, 5 | Analytical | Abumaizar et al. (1997) |
| Column | B, C, D | Non-steady Monod | Monod | Non-steady | n.a.[c] | 1, 2, 3 | Numerical | Hozalski and Bouwer (2001) |
| Column | A, B, C, D | Non-steady no biodegradation | Monod | Non-steady | Non-equilibrium | 1, 2, 3, 4, 5 | Numerical | Badriyha et al. (2003) |

[a] A = adsorption, B = biodegradation, C = convection, D = dispersion.
[b] 1 = bulk phase, 2 = interface between bulk phase and biofilm, 3 = biofilm, 4 = interface between biofilm and GAC, 5 = GAC.
[c] Not analyzed in the article.