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Kinetics studies on the removal of Methyl ethyl ketone using cornstack based biofilter

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ABSTRACT

The performance of cornstack based biofilter inoculated with a mixed culture was evaluated for gas phase MEK removal under various operating conditions. Experiments were carried out at different flow rates (0.03–0.12 $m^3\ h^{-1}$) and various initial concentrations (0.2–1.2 g^{-3}). A maximum elimination capacity (EC) of 35 $g^{-3}\ h^{-1}$ was achieved at an inlet loading rate of 60 $g^{-3}\ h^{-1}$ with a removal efficiency of 95%. High elimination capacity reached with this system could have been due to the dominant presence of filamentous fungi among others. The experimental results were compared with the values obtained from the Ottengraf–van den Oever model for zero-order diffusion-controlled region. The critical inlet concentration, critical inlet load and biofilm thickness were estimated using the model predictions.

1. Introduction

Methyl ethyl ketone (MEK) is one such highly toxic ketone compound released into the atmosphere by chemical, petrochemical, food processing, pulp and paper mills, color printing, paint and coating, electronic industries, etc., leading to endanger the air quality and public health (Mitchell, 1992). Therefore, it is necessary to eliminate MEK from the environment, in order to prevent the significant impact on ecosystem and public health. Out of various techniques such as incineration, ozonation, combustion, adsorption, biofiltration has emerged as cost effective technology for eliminating odorous and toxic volatile organic compounds (VOCs) such as MEK from waste gas streams (Devinny et al., 1999). Biofiltration is becoming an established air pollution control technology for the control of volatile organic compound (VOC) and odor emissions from waste gas streams. The application of biofiltration technology throughout the world has increased rapidly in recent years (Devinny et al., 1999). This is largely due to, low costs for operation and maintenance and their environmental soundness over conventional methods.

Biofiltration uses microorganisms fixed to a packing material to breakdown pollutants present in an air stream. Biofilters are not filtration units but a kind of bioreactor which is an example of bioremediation technique. Biofiltration takes place by combination of basic processes such as absorption, adsorption and degradation (Deshusses et al., 1995, 1996). In this process, microorganisms degrade the contaminants by consuming it as carbon source for their growth and thus releasing end products such as carbon dioxide, water and biomass.

During the past decades, Methyl ethyl ketone (MEK) removal has been carried out using synthetic packing material like berl saddles, bioton, activated carbon, polypropylene spheres and wood bars,etc (Farmer, 1994; Deshusses, et al., 1995; Chou and Huang, 1997; Amanullah et al., 2000; Li and Moe, 2003). The result shows lower removal efficiency in most cases.Hence this study is focused on to increase the removal efficiency of MEK using agro waste material viz. corn stack. So far no study has been carried out using this packing material for the removal of MEK. In this study, the obtained experimental results are validated with the Ottengraf–van-den Oever and modified Ottengraf–van-den Oever model for various phases.

2. Mathamatical modeling with Ottengraf–van den Oever

Most of them utilize bacterial strains, either pure or that are isolated from the filtering media, suspended in liquid growth media (Lu and Chang, 2004; Torkian et al., 2003; Lu et al., 2005; Chen and Taylor, 1995; Abumaizar et al.,1998; Strauss et al., 2004; Jorio et al., 2000, 1998). The drawbacks of above methods are that (1) they necessitate prior operations for the conditioning of the

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biomass; (2) they do not necessarily represent the real growth media (the solid bed pellets), which more likely contain consortia of interacting micro-organisms, among them the degrading species; and (3) they do not reflect the mass transfer constraints that exist in a biofilter. A few works only have focused on the experimental protocols for application to growth media (Jorio et al., 1998; Saravanan and Rajamohan, 2009). Since many different phenomena contribute to the effectiveness of a biofiltration process, a model has to be used which can comprehensively foresee bioreactor performance. Ottengraf and Vander Oever (1983) made first attempt to develop a model for the biofiltration of toluene. This model simply deals with conventional biofilter at stationary state. In spite of its simplicity, this model has been widely used also by others (Ottengraf and Vander Oever, 1983; Tang and Hwang, 1997; Govind and Wang, 1997). Ottengraf's model considers the different phenomena ruling biofilter performance: mass transfer and biological reaction. At low inlet concentrations, the driving force ruling the mass transfer is limited. Therefore, the amount of pollutant which passes into the liquid phase is moderate and, as pollutant comes in contact with the biomass, it is completely degraded. In these conditions, diffusion is the rate determining step. With higher gas concentrations, mass transfer is inversely promoted. The amount of pollutant transferred in the aqueous phase is greater and biomass could not be able to completely degrade this amount. In such conditions, the reaction limits the process rate. Ottengraf proposed equations to represent what occurs in the water film in these two opposite situations.

2.1. Mass balance

Pollutant concentration in the gas phase can be expressed by the following expression:

$$-U_g \frac{dU_g}{dh} = NA_s \tag{1}$$

where U_g is the superficial gas velocity ($m\,h^{-1}$), h is the reactor height (m), N is the flux of substrate from the gas to the solid ($gm^{-2}\,h^{-1}$) and A_s is the specific surface area ($m^2\,m^{-3}$).

Mass balance in the gas/biofilm can be written as follows:

$$D\frac{d^2C}{dx^2} - k_o = 0 \tag{2}$$

where D is the diffusion coefficient ($m^2\,h^{-1}$), x is the direction perpendicular to the gas-solid interface and k_0 the zero-order constant ($gm^{-3}\,h^{-1}$). Such equations can be solved considering the different boundary conditions in reaction limitation and diffusion limitation assumptions.

2.2. Zero- order kinetic with reaction limitation

In this condition, introducing m as the dimensionless gas-solid partition coefficient, the following boundary conditions can be used:

$$x = 0,\ C = C_g/m \tag{3}$$

$$x = \delta,\ dC/dx = 0 \tag{4}$$

and Eq. (2) has the following solution:

$$\frac{C}{C_g/m} = 1 + \frac{1}{2}\frac{\Phi^2}{C_i/C_o}\left(\sigma^2 - 2\sigma\right) \tag{5}$$

where Thiele number; $\sigma = x/\delta$ is the dimensionless length coordinate in the biolayer; and $m = (C_g/C_l)_{\text{equilibrium}}$ is the distribution coefficient.

$$\varphi = \sqrt{\frac{k_m}{D'C_{go}}} \tag{6}$$

Then, N can be written as

$$N = \frac{-D'}{\delta}\left(\frac{dC_l}{d\sigma}\right)_{\sigma=0} = k\delta \tag{7}$$

Substituting Eq. (7) into Eq. (1) using the boundary condition $C_g = C_g$, in for $h=0$, the solution becomes:

$$\frac{C_o}{C_i} = 1 - \frac{A_s k_o \delta H}{C_i U_g} \tag{8}$$

where H is the height of the tower. Assuming $A_s k_o \delta = K$ to be constant, it follows that

$$\eta = 1 - \frac{C_o}{C_i} = \frac{A_s k_{o\delta} H}{C_{g,in} U_g} \tag{9}$$

Elaborating Eq. (8), and solving as function of the elimination capacity, the following expression can be obtained (Ottengraf and Vander Oever, 1983)

$$EC = EC_{\max} = A_s k_o \delta \tag{10}$$

A critical point can be determined, supposing that $C=0$ at the water-solid interface, or when $x=\delta$ Substituting this value into Eq. (5), a critical Thiele number can be determined:

$$\varphi = \delta\sqrt{\frac{k_o m}{D'C_i}} = \sqrt{2} \tag{11}$$

where $\Phi < \Phi$ cr, reaction is the rate determining step of the process.

2.3. Zero- order kinetic with diffusion limitation

Mass balance into the (Air/biofilm) phase should be solved using different boundary conditions. Defining ë as the distance from the interface gas/liquid at which $C=0$, boundary condition (4) can be substituted by the following:

$$x = \lambda\ \ dC/dx = 0 \tag{12}$$

Obtaining a new equation for the water phase

$$\frac{C}{C_o/m} = 1 + \frac{1}{2}\frac{\Phi^2}{C_i/C_o}\left(\sigma^2 - 2\sigma\frac{\lambda}{\delta}\right) \tag{13}$$

λ can be easily determined with Eq. (13), fixing $C=0$ for ó$=\lambda/\delta$:

$$\lambda = \sqrt{2\frac{D'C_o}{km}} \tag{14}$$

With this new condition, N is equal to $k_0\lambda$ and pollutant concentration in the gas phase can be calculated:

$$\frac{C_o}{C_i} = \left(1 - \frac{A_s H}{U_g}\sqrt{\frac{k_o D}{2C_i m}}\right) \tag{15}$$

EC is now a function of the mass loading rate and the correlation is represented by the following expression:

$$EC = L\left(1 - \left(1 - A_s\sqrt{\frac{k_o D}{2m}}\sqrt{\frac{V}{QL}}\right)^2\right) \tag{16}$$