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Kinetics of Organic and Inorganic Degradation in Biofilter Using Isolated Bacteria from Petrochemical Wastewater Treatment Plant

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Abstract

The objective was to study the kinetics of the degradation of hydrogen sulfide, benzene and xylene in a lab-scale biofilter. Pseudomonas aeruginosa S19 and Bacillus cereus O5-1/1 were fixed on the surface of plastic pall rings and used as media in the lab-scale biofilter. Synthetic polluted air contained hydrogen sulfide, benzene and xylene was generated and introduced into the 106-liter lab-scale biofilter. Various concentrations of hydrogen sulfide, benzene and xylene in the synthetic polluted air were adjusted and introduced into the biofilter. The inlet flowrate of the synthetic polluted air was controlled about 5.0 liters/minute. The concentrations of hydrogen sulfide, benzene and xylene were measured at the inlet and also after passing through the media layers in the biofilter at the heights of 0.25, 0.50, 0.75, 1.00, 1.25 and 1.50 meters. Flowrate, temperature and humidity were recorded.

The retention time of the synthetic polluted air in the biofilter (EBRT) was calculated at each efficiency, inlet and outlet concentration. Results data of each pollutant from the experiment were plotted to determine the correlation according to the various kinds of the kinetic equations. From the results of the study can be concluded that the degradation of hydrogen sulfide, benzene and xylene in the biofilter were zero-order reaction limited by bacterial degradation. The kinetic equations were C_0-C = k_0t. The zero order reaction rate constants (k_0) of these kinetic equations were:

- Hydrogen sulfide, k_0 = 0.0159 ppm. s^{-1}
- Benzene, k_0 = 0.0219 ppm. s^{-1}
- Xylene, k_0 = 0.0458 ppm. s^{-1}.

Keywords : Biofilter; Kinetics; EBRT

Introduction

Polluted air may be treated by biotechnology technique that microorganisms degrade some air pollutants to become non-toxic or odorless gases. Biofilter is an air pollution control system using this technique highly effective in controlling mostly volatile organic compounds and some inorganic compounds. In the case of petrochemical wastewater treatment plant usually emitted volatile organic compounds (VOCs) and hydrogen sulfide gas (H_2S). Biofilter can be used with fluctuate air flow, very low concentration with low operation and installation costs [1, 2]. Biofilter has been used in various industry, such as, wastewater odor control, rubber industry, paint and surface coating industry. Natural materials such as wood chip, compost, soil have been used as media for microorganisms in the nature. The disadvantages of using natural material as media is that it takes rather long time to start up the system (about 1-2 weeks), difficult to scaling up from lab-scale to actual scale, its pressure drop will get higher and the efficiency will decrease when the natural media deteriorate [3]. These disadvantages may lower If synthetic media are applied [4-7].

Materials and Methods

Material Synthesis [8, 9]

Pseudomonas aeruginosa S19 and Bacillus cereus O5-1/1 bacteria were isolated from a petrochemical industry wastewater treatment plant could effectively degrade volatile compound BTEX group [10]. *P.aeruginosa S19* and *B.cereus O5-1/1* were cultured in nutrient broth at 37 degrees Celsius for 48-72 hours. The bacteria were prepared in a solution in a laboratory. Then prepare a container for infusion of material with a capacity of 200 liters. Which contains 120 liters of bacteria mixed and using distilled water to dilute the solution to flood all media materials. The bacteria were immobilized on the media at room temperature for 3 days continuously [10]. These bacteria were fixed on the surface of pall ring plastic media (Figure 1). Vapor of benzene and xylene were generated by passing cleaned air on the surface of liquid benzene and xylene. Hydrogen sulfide was synthesized by a chemical reaction between sodium sulfide and hydrochloric acid. Synthetic polluted air used in this experiment was produced by mixing benzene, xylene vapor and hydrogen sulfide gas with cleaned air in a mixing chamber to control the inlet concentrations and fed into the 106-liter lab-scale biofilter contained the media fixed with bacteria. The inlet flowrate of the synthetic polluted air was controlled about 5.0 liters/minute. The concentrations of hydrogen sulfide, benzene and xylene were measured at the inlet and also after the polluted air passing through the media layer in the biofilter at the height of 0.25, 0.50, 0.75, 1.00, 1.25 and 1.50 meters. Flowrate, temperature and humidity were recorded. The figure of the lab-scale biofilter is shown in Figure 2. The schematic of the lab-scale biofilter experimental system is shown in Figure 3.

Figure 1 Pall ring plastic media fixed with bacteria on the surface

Figure 2 The lab-scale biofilter

The study of the kinetic of the degradation was done by analyzing the efficiency of the system and the retention time of synthetic polluted air in the biofilter (EBRT). Inlet (C_0) and outlet (C) concentrations of hydrogen sulfide, benzene and xylene at each height of the lab-scale biofilter were calculated for the efficiencies (Eff) of the system. EBRT at each efficiency was calculate according to the volume flowrate of the polluted air and the volume of the media (height of the media bed x cross-sectional area of the lab-scale biofilter). C_0, C, Eff and EBRT were selected to plot to determine the correlation among these parameters according to various kinetic equations.

The Models of the kinetic of the degradation of air pollutants [11-14]

The kinetic of the degradation of air pollutants in a lab-scale biofilter according to microorganisms can be classified into 2 categories:

1. Zero order reaction [23]

   1) Zero Order Reaction Limited.

The zero order with reaction limited is the kinetic of the degradation of air pollutant in a biofilter where the rate of reaction (biological degradation) is slower than the rate of the diffusion of the air pollutants to the biofilm. The process would be reaction limited. The kinetic can be written as the following equation:

$$C_0 - C = k_0 t \qquad \text{(Eq.1)}$$

Where C_0 = Inlet concentration of pollutant (ppm)

C = Outlet concentration of pollutant (ppm)

k_0 = zero order reaction rate constant (reaction limited) ($ppm.s^{-1}$)

t = EBRT (s)

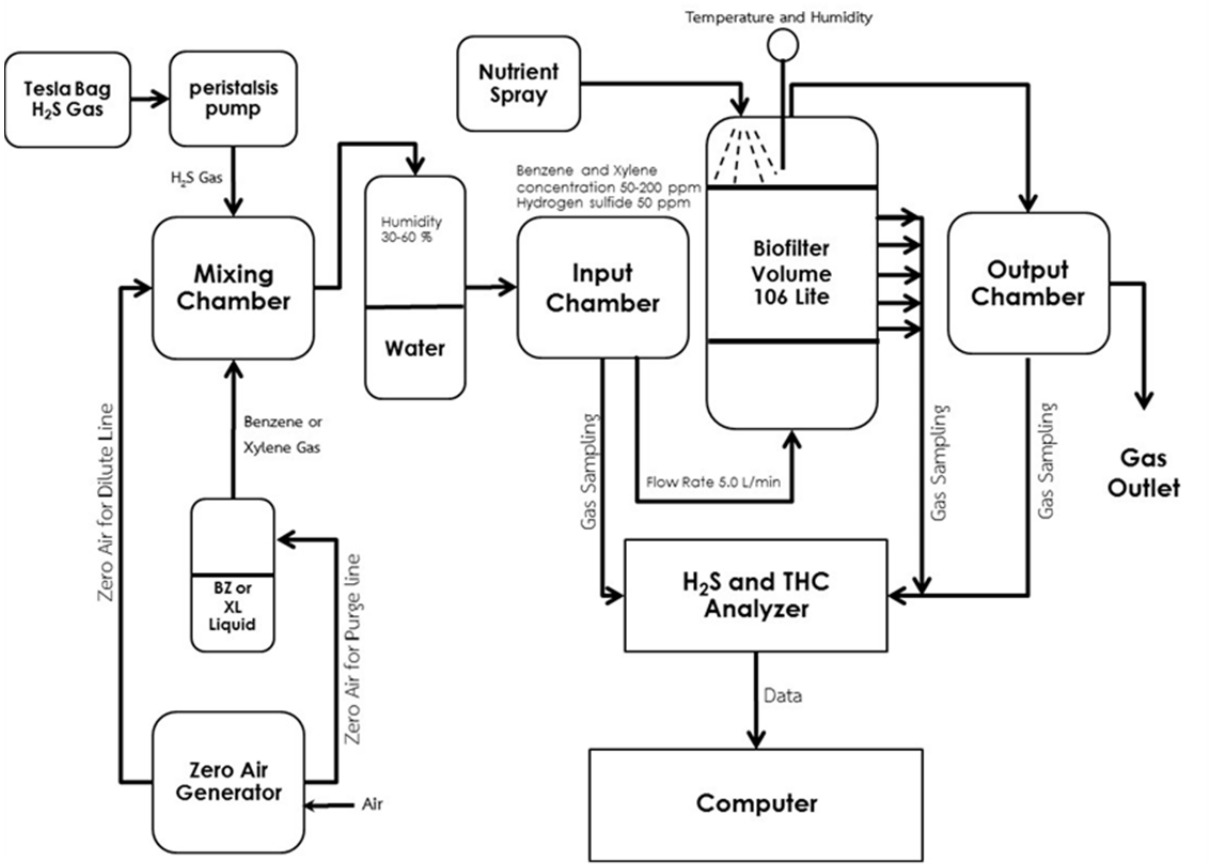

Figure 3 Schematic of the lab-scale biofilter system

2) Zero order Diffusion limited.

The diffusion limited model occurs when the pollutant reaches its maximum degradation ability in the biofilm at a depth that is less than the actual biofilm thickness. In this case, the diffusion limits the overall removal in the biofilm. The equation for this type of the kinetic is given by:

$$C = C_0\left(1 - \beta_1 \frac{t}{\sqrt{C_0}}\right)^2 \qquad \text{(Eq.2)}$$

$$\beta_1 = A_s\sqrt{\frac{k_0\, f(X_V).D}{2m}}$$

Where t = EBRT (s) ($ppm^{0.5}.s^{-1}$)

As = biofilm surface area per unit volume of biofilter (m^{-1})

k_0 = zero order reaction rate constant (Zero Order Diffusion Limitation) ($ppm.s^{-1}$)

D = Diffusivity of the pollutant in water ($m^2.s^{-1}$)

M = Henry's Constant of the pollutant

$f(X_v)$ = ratio of diffusivity of a compound in the biofilm to that in water (dimensionless)

2. First Oder Reaction [23]

First Order Reaction is the reaction where the degradation of the pollutant in the biofilter depends on the inlet concentration of the pollutant. The first order reaction model equation is given by:

$$\ln \frac{C}{C_0} = -k_1 t \qquad \text{(Eq.3)}$$

Where k_1 = first order reaction rate constant (s^{-1})

Results and Discussions

Kinetics of the degradation of hydrogen sulfide, benzene and xylene in the lab-scale biofilter were studied according to the kinetic equation in the form of 1) zero order reaction with reaction limited (Plotting C_0-C vs EBRT) 2) zero order with diffusion limited (Plotting $(1-(C/C_0)^{0.5})$ x $(C_0^{0.5})$ vs EBRT), and, 3) first order reaction (Plotting ln (C/C_0) vs EBRT). The results are summarized as follows.

For hydrogen sulfide, the tests for kinetic equations are as shown in Figure 4, Figure 5 and Figure 6. Considering the determination coefficient (R^2), the kinetic equation model of hydrogen sulfide degradation in the Lab-scale biofilter was found in zero-order with reaction limited. The determination coefficient (R^2) was 0.4512 with the first order reaction rate constant (k_1) of 0.0006 s^{-1}.

The tests for the kinetic equations for benzene are as shown in Figure 7, Figure 8 and Figure 9. Considering the determination coefficient (R^2), the kinetic equation model for the degradation of benzene was found in zero-order with reaction limited. The determination coefficient (R^2) was 0.4512 with the first order reaction rate constant (k_1) of 0.0006 s^{-1}.

For xylene, the tests for the kinetic equations are as shown in Figure 10, Figure 11 and Figure 12. The kinetic equation model of the degradation of xylene was found in zero-order with reaction limited with the determination coefficient (R^2) of 0.2575 and the zero order reaction rate constant (k_1) of 0.0006 s^{-1}.

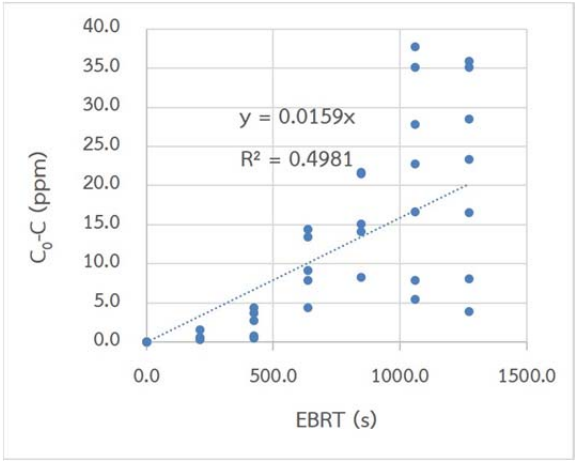

Figure 4 Plotting C_0-C vs EBRT for testing the kinetic on zero order with reaction limited of hydrogen sulfide

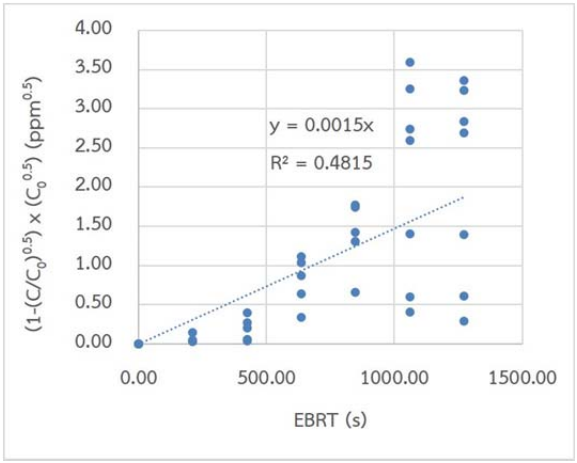

Figure 5 Plotting $(1-(C/C_0)^{0.5})$ x $(C_0^{0.5})$) vs EBRT for testing the kinetic on zero order with diffusion limited of hydrogen sulfide

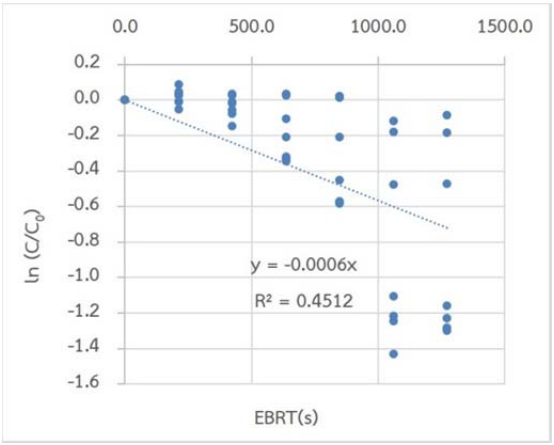

Figure 6 Plotting ln(C/C_0) vs EBRT for testing the kinetic on first order of hydrogen sulfide

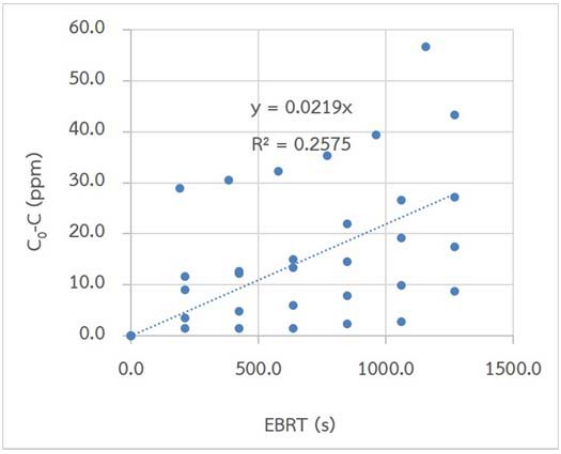

Figure 7 Plotting between C_0-C vs EBRT for testing the kinetic on zero order with reaction limited of benzene

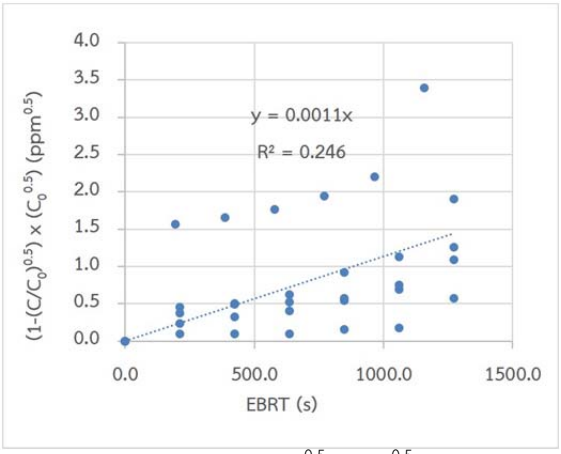

Figure 8 Plotting $(1-(C/C_0)^{0.5}) \times (C_0^{0.5})$ vs EBRT for testing the kinetic on zero order with diffusion limited of benzene

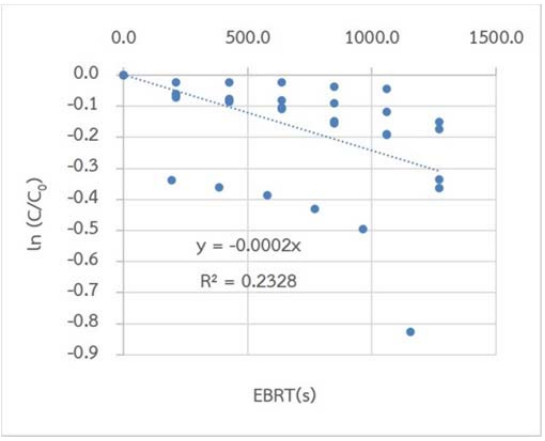

Figure 9 Plotting between ln(C/C_0) vs EBRT for testing the kinetic on first order of benzene

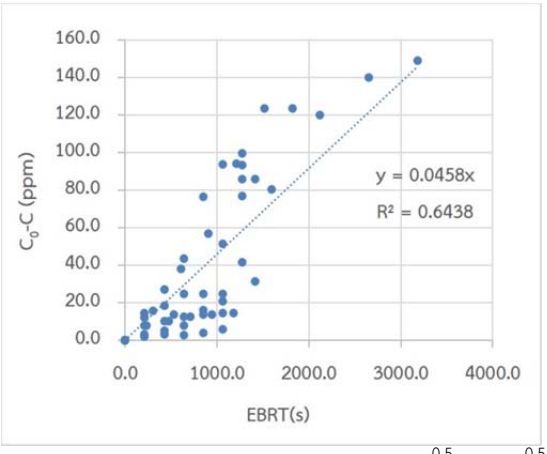

Figure 10 Plotting between $(1-(C/C_0)^{0.5}) \times (C_0^{0.5})$ and EBRT for testing the kinetic on zero order with diffusion limit of hydrogen sulfide

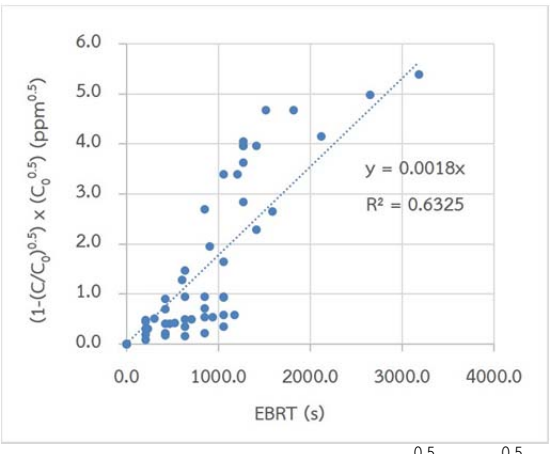

Figure 11 Plotting between $(1-(C/C_0)^{0.5}) \times (C_0^{0.5})$ and EBRT for testing the kinetic on zero order with diffusion limited of hydrogen sulfide

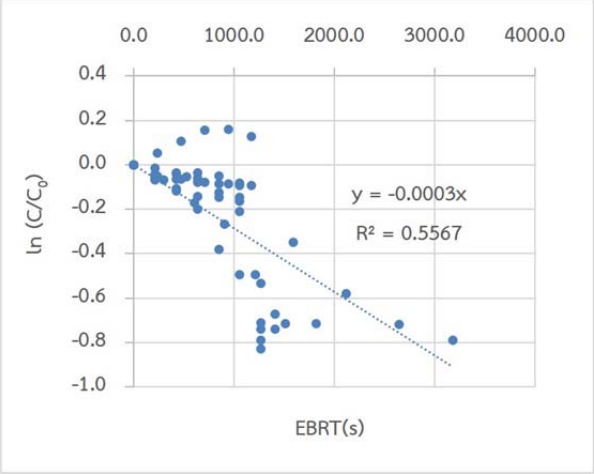

Figure 12 Plotting between ln(C/C0) and EBRT for testing the kinetic on first order of hydrogen sulfide

Table 1 Summary of the study of the degradation kinetic of hydrogen sulfide, benzene and xylene

Degradation Kinetic	Equation	k	Determination coefficient, (R^2)
Hydrogen sulfide			
Zero order reaction limited	$C_0-C = k_0t$	k_0 = 0.0159 ppm. s^{-1}	0.4981
Zero order diffusion limited	$(1-(C/C_0)^{0.5}) \times (C_0^{0.5}) = \beta_1 t$	β = 0.0015 $ppm^{0.5}.s^{-1}$	0.4815
First order reaction	$\ln (C/C_0) = -k_1.t$	k_1 = -0.0006 s^{-1}	0.4512
Benzene			
Zero order reaction limited	$C_0-C = k_0t$	k_0 = 0.0219 ppm. s^{-1}	0.2575
Zero order diffusion limited	$(1-(C/C_0)^{0.5}) \times (C_0^{0.5}) = \beta_1 t$	β_1 = 0.0011 $ppm^{0.5}.s^{-1}$	0.2460
First order reaction	$\ln (C/C_0) = -k_1.t$	k_1 = -0.0002 s^{-1}	0.2328
Xylene			
Zero order reaction limited	$C_0-C = k_0t$	k_0 = 0.0458 ppp. s^{-1}	0.6438
Zero order diffusion limited	$(1-(C/C_0)^{0.5}) \times (C_0^{0.5}) = \beta_1 t$	β_1 = 0.0018 $ppm^{0.5}.s^{-1}$	0.6325
First order reaction	$\ln (C/C_0) = -k_1.t$	k_1 = -0.0003 s^{-1}	0.5567

From the results of the kinetic study of hydrogen sulfide gas degradation and benzene, xylene in the lab-scale bio-filter using bacteria isolated from the wastewater treatment plant of a petrochemical industry in the group P. aeruginosa S19 and B. cereus O5-1 / 1 found that the kinetics of hydrogen sulfide, benzene and xylene was a zero order reaction which was limited by the degradation reaction of bacteria which can be summarized as in Table 1.

The study of kinetic decomposition of hydrogen sulfide, benzene and xylene in a lab-scale bio-filter using bacteria (P. aeruginosa S19 and B. cereus O5-1 / 1) isolated from the

wastewater treatment plant of a petrochemical industry were studied. Synthetic polluted air were generated by mixing cleaned air with hydrogen sulfide, benzene and xylene. According to the result of the study, the kinetic of the degradation of hydrogen sulfide, benzene and xylene in the biofilter were zero-order reaction which was limited by bacterial degradation reaction. The kinetic equations were C_0-C = k_0t. The zero order reaction rate constants (k_0) for these kinetic equations were:

- Hydrogen sulfide, k_0 = 0.0159 ppm. s^{-1}
- Benzene, k_0 = 0.0219 ppm. s^{-1}
- Xylene, k_0 = 0.0458 ppm. s^{-1}.

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