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Full Length Research Paper

Kinetics of biological treatment of phenolic wastewater in a three phase draft tube fluidized bed bioreactor containing biofilm

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Phenolic wastewater was treated in a three-phase draft tube fluidized bed reactor containing biofilm. Phenol removal rate with biofilm was evaluated both theoretically and experimentally. The results indicate that biodegradation of phenolic wastewater by biofilm process could be treated as a zero order reaction. The volumetric biological removal rate with biofilm is proportional to the specific surface area of the biofilm with characteristic constant (k) 0.74 x 10^{-2} kg PhOH/m^2 biofilm/d. It is proven here that almost 100% phenol removal could be attained at a specific biofilm surface area per volumetric phenol loading rate exceeding 132 m^2/(kg-PhOH/d). The bioparticle diameter and the bioparticle hold-up in the three phase draft tube fluidized bed bioreactor are the decisive factors for the efficiency of the phenol treatment.

Key words*:* Phenol degradation, draft tube fluidized bed reactor, kinetics.

INTRODUCTION

Phenol and its derivatives are the most harmful pollutants present in effluents of several major chemical industries. Discharge of phenolic wastes into the environment may cause serious problems even at low phenol concentrations, as they impart carbolic odour to the water source and can be toxic to aquatics and human beings.

As waste management practices become more specific, for particular type of chemical waste, specific treatment system will have to be developed and applied to abate pollution. In near future, since the regulation concerning discharged wastewater will be imposed more strictly, an economical, compact and highly efficient wastewater treatment will be required. A three-phase fluidized bed biofilm process is advantageous over other biological processes (for example, activated sludge process), for the following reasons:

a) reactor has a large specific biofilm surface area,
b) oxygen is supplied from the gas phase to the liquid phase simultaneously with oxygen consumption by bioxidation,
c) large area of construction is not required,
d) the limit on the operating liquid flow rates, imposed by the microbial maximum specific growth rate as encountered in a continuous stirred tank reactor (CSTR) system is eliminated due to the decoupling of the residence time of the liquid phase and of the microbial cells, and
e) the uses of supporting particles allow the partial replenishment of the fluidized bed without interrupting the operation in order to maintain high microbial activity.

In an aerobic biofilm wastewater treatment, waste-

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Abbreviations: a_s, Specific surface Area of Bioparticle m^{-1}; k, first order rate constant m.d; $k = \rho_d \delta \mu_m / y$, characteristic constant kg/m^2.d; K_s, half saturation constant mgl^{-1}, kg m^{-3}; n, number of tanks (reactors); S, substrate (phenol) concentration, mgl^{-1}, kgm^{-3}; s_i, initial or inlet substrate (phenol) concentration, mgl^{-1}, kgm^{-3}; S_o, outlet substrate (phenol) concentration, mgl^{-3}, kg m^{-3}; L_v, volumetric substrate loading rate kg/m^3/d; PhOH, phenol; R_B, rate of degradation due to biofilm, kg/d; V, volume of reactor, 1, m^3; Y, yield coefficient (kg of biomass/kg of phenol); μ_m, maximum specific growth rate, h^{-1}; δ, effective biofilm thickness for biodegradation, m; and ρ_d, density of biofilm, kg/m^3.

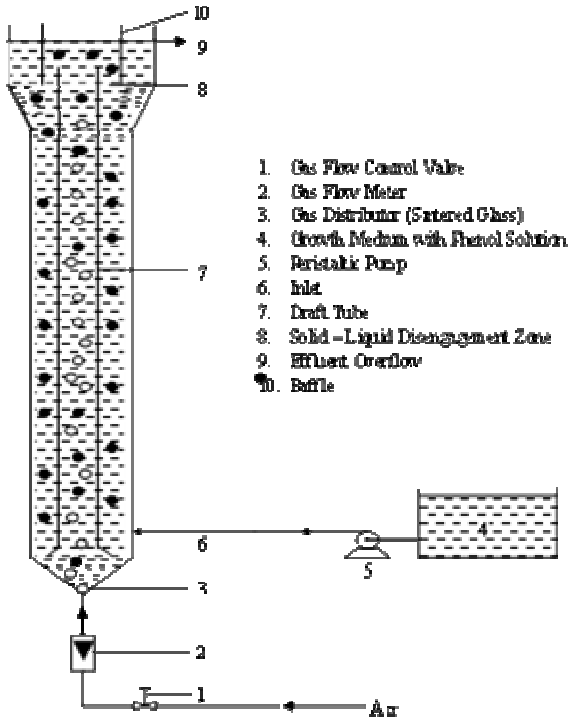

Figure 1. Draft tube fluidized bed bioreactor (DTFBR).

water is treated by both biofilm and suspended sludge. The biological removal rate is greatly affected by the specific surface area of biofilm (Hirata et al., 1998; Cecen and Gonenc, 1994; Hem et al., 1994) for the successful design and operation. It is important to know, the total required biofilm surface area in the reactor for the pollutant biodegradation.

This paper reports the results of experimentation in a draft tube fluidized Bed Bioreactor (dtfbr) for the continuous biodegradation of phenol using mixed culture (isolated from mangrove soil) immobilized on activated carbon particle. The phenol removal rates with biofilm are determined both theoretically and experimentally. The biological characteristic constant, useful for establishing the reactor design, is also presented.

MATERIALS AND METHODS

Apparatus

Figure 1 depicts the experimental facilities and details of the Draft Tube Fluidized Bed Bioreactor (DTFBR). The reactor of 3000 ml volume was constructed from polyacrylic sheets and consisted of a 73 mm ID, 450 mm high fitted with a 27 mm ID and 540 mm high draft tube. A 108 mm ID and 144 mm high, solid-liquid separation zone at the top of the reactor had an effluent discharge so that solids entrained by air bubbles around the base of baffle and rising through the separation zone were not washed out of the reactor. The air entered at the base of DTFBR via an air distribution tube. In all the experiments, the liquid flow was typically of the order of 60 to 100 reactor volume per hour. The feed flow rate was typically one reactor volume per hour. Thus the recirculatary flow ensured no short circuiting between the feed and overflow.

Table 1. Constituents of the mineral medium.

Component	Concentration (mgl^{-1})
KH_2PO_4	420
K_2HPO_4	373
$(NH_4)_2SO_4$	244
Nacl	15
$Cacl_2.2H_2O$	15
$MgSO_4.7H_2O$	50
$FeCl_3.6H_2O$	5.4

Start up of the DTFBR

600-900 ml of inoculum (acclimatized to a synthetic phenol wastewater for several months) was added to 2100-2400 ml of medium (given in Table 1) in the DTFBR. The phenol concentration was brought up to 200 mg l^{-1} by the addition of concentrated phenol solution and the system was allowed to run in batch mode until all the phenol had been utilized. Operation was switched to continuous mode with a required dilution rate and a feed concentration of 200 mg l^{-1}. Approximately 24 h were allowed for the microbial population to stabilize. Activated carbon granules were then added to the reactor and the system was left for 6-7 days for the growth of biofilm, before the commencement of further of work. then the biodegradation experiments were conducted at each of the phenol loading rates of 0.77, 1.538, 2.307, 3.076 and 3.846 kg of PhOH / (m^3d) with hydraulic retention time (HRT) of 0.065 day (=1.56 h) to get the data on phenol removal rate, bioparticle diameters (specific biofilm surface area), bioparticle hold up which where used for analysis. The data were taken after the attainment of steady state conditions. The experiments were carried out with different sizes of supporting particles. The analysis of phenol was carried out by spectrophotometric method (APHA, 1992). The specific biofilm surface area was calculated from the diameter of a biofilm attaching particle measured by an image analysis system.

RESULTS AND DISCUSSION

Keeping in view that the reaction in a biodegradation process could be any one of the three, (i) zero order, (ii) first order and (iii) Monod type, the Performance of the DTFBR was viewed in comparison with those of the 1) plugflow (PF) 2) completely mixed type (CMT) and 3) n-tank in series (NTS). Table 2 presents a summary of the results giving the characteristic parameters for each of the three reactor models and for each of the three reactions. The plots of $a_s/(R_B/v)$ vs

$$\text{(i)}\ \frac{\ln S_i/S_o}{S_i - S_o} \quad \text{(ii)}\ \frac{n\left(\sqrt[n]{S_i/S_o} - 1\right)}{S_i - S_o} \quad \text{and (iii)}\ 1/S_o$$

Table 2. Equations for estimation of characteristics of biological treatment.

Reaction	Reactor type		
	Plug flow	Complete mixing in each n steps	Complete mixing in overall system
Monod	$\frac{a_s}{R_B/V}=\frac{1}{K}+\frac{K_s}{K}\cdot\frac{\ln(S_i/S_0)}{S_i-S_0}$	$\frac{a_s}{R_B/V}=f(K,K_s,S_i,S_0)$	$\frac{a_s}{R_B/V}=\frac{1}{K}+\frac{K_s}{K}\cdot\frac{1}{S_0}$
Zero order	$\frac{a_s}{R_B/V}=\frac{1}{K}$	$\frac{a_s}{R_B/V}=\frac{1}{K}$	$\frac{a_s}{R_B/V}=\frac{1}{K}$
First order	$\frac{a_s}{R_B/V}=\frac{1}{K}\cdot\frac{\ln(S_i/S_0)}{S_i-S_0}$	$\frac{a_s}{R_B/V}=\frac{1}{K}\cdot\frac{n[\sqrt[n]{(S_i/S_0)}-1]}{S_i-S_0}$	$\frac{a_s}{R_B/V}=\frac{1}{K}\cdot\frac{1}{S_0};k=K/K_s$

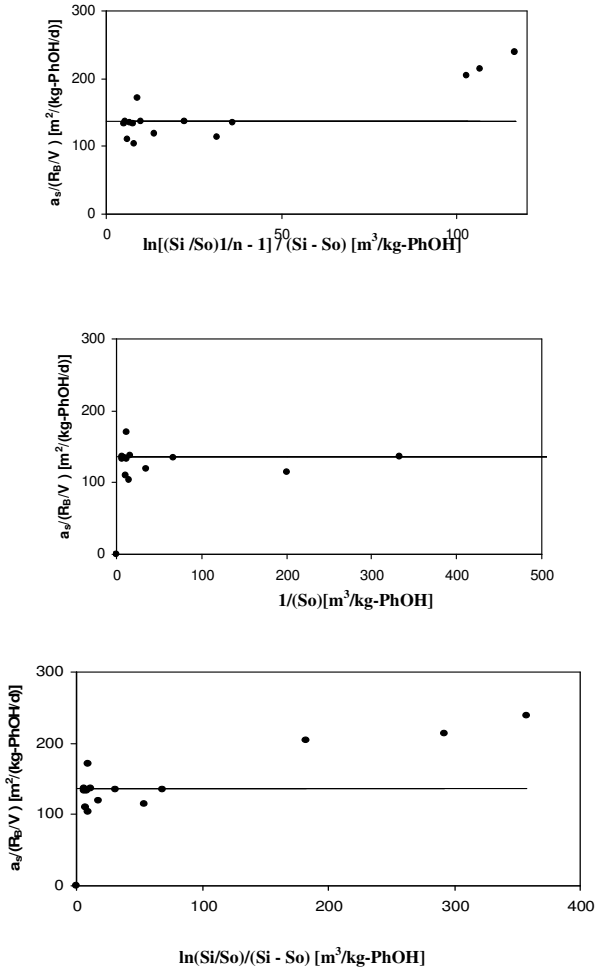

Figure 2. Characteristics of phenol degradation.

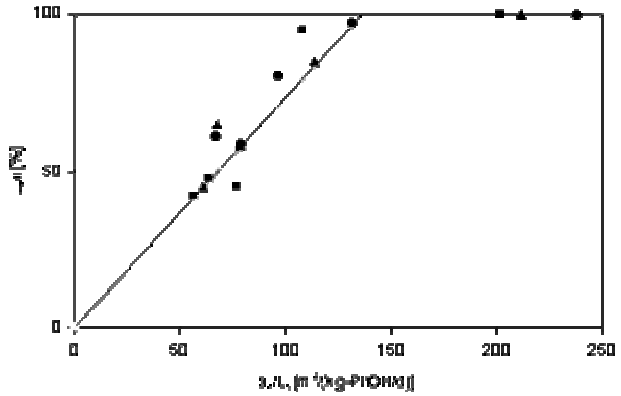

Figure 3. Dependence of overall removal efficiency on biofilm.

exhibited (in all the cases) straight lines, parallel to the abscissa, as shown in Figure 2, which indicates that the biological phenol degradation by biofilm is of a zero order reaction. The characteristic coefficient (K) value obtained from Figure 2 is 0.74 x 10^{-2} kg PhOH/m^2biofilm/d. Then the volumetric biological removal rate $R_B/V = ka_s$ and the biological removal efficiency $\eta_B = ka_s/L_v$.

The relation between the specific biofilm surface area per volumetric phenol loading rate (a_s/L_v) and rate of biological removal efficiency (η_B) is shown in Figure. 3. The straight line in Figure 3 is obtained from $\eta_B = ka_s/L_v$. This line indicates that efficiency of biological phenol removal with biofilm increases with increases of a_s/L_v and 100% of removal could be achieved at a_s/L_v larger than 132 m^2/kg PhOH/d.

Figure 4 shows the relation between the specific surface area of biofilm (a_s) and overall volumetric biological removal rate (R_B/V); the straight line which passes through the origin is represented by the equation $R_B/V = Ka_s$. R_B/V, increases linearly with increasing a_s. When the specific biofilm surface area is large enough for loaded phenol to be biodegraded, almost 100% of phenol could be removed for a specified volumetric phenol loading rate.

Figure 5 shows the biological removal rate by bioparti-

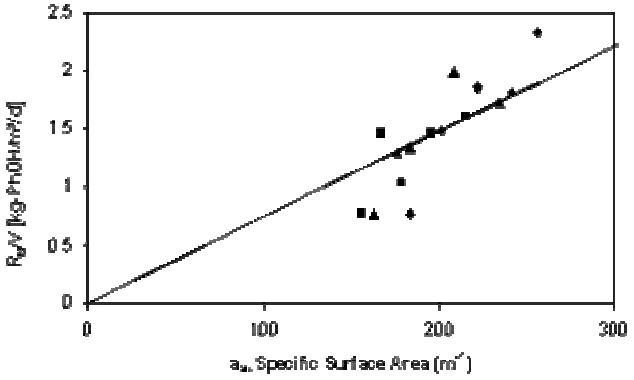

Figure 4. Effect of specific surface area of biofilm on phenol removal rate.

cle with different diameters and holdups. The lines represent the equation, $R_B/v = 6\ k\varepsilon_s/d_B$ using bioparticle holdup (ε_s) as a parameter. The experimental levels agree well with the theoretical line, indicating that the biological removal rate by biofilm is proportional to the biofilm surface area.

Conclusion

Phenolic wastewater was treated in a DTFBR using mixed culture (isolated from mangrove soil) biofilm attached on activated carbon particle. By considering the effect of specific surface area of biofilm, phenol removal rates with biofilm were evaluated theoretically and experimentally. The results are:

1. Biological phenolic wastewater treatment in the three phases DTFBR could be characterized as a zero order reaction.
2. The volumetric biological removal rate with biofilm (R_B/v) was proportional to the specific surface area of biofilm i.e., $R_B/v = Ka_s$ and K value was evaluated as 0.74 x 10^{-2} kg PhOH/m^2 biofilm /d.
3. Nearly 100% of phenol removal could be achieved at a larger specific biofilm surface area per unit volumetric phenol loading rate (a_s/L_v) than 132 m^2/(kg PhOH/d).
4. Bioparticle diameter and bioparticle hold-up are the decisive factors for the volumetric biological removal of phenol with biofilm in three phase DTFBR.

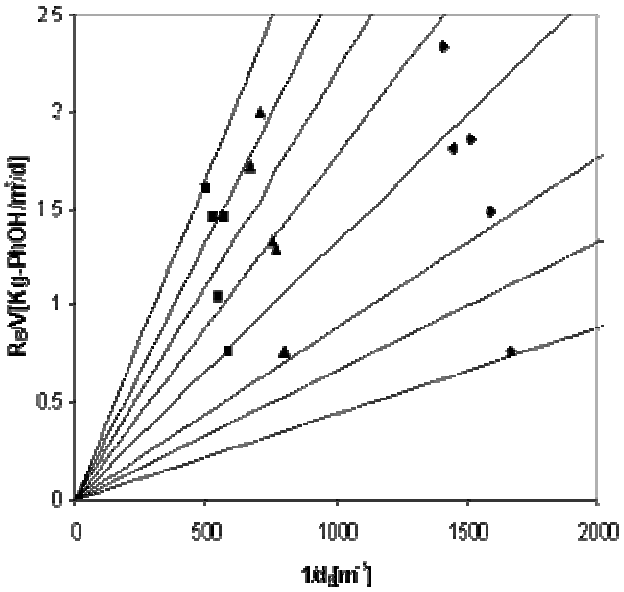

Figure 5. Effect of bioparticle diameter and bioparticle hold-up on phenol removal rate with biofilm.

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