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KINETICS STUDIES ON DEGRADATION OF STARCH WASTEWATER IN AN INVERSE FLUIDIZED BED REACTOR

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ABSTRACT

A three-phase inverse fluidized bed reactor was used to treat the starch industry wastewater. Experiments were carried out at different initial substrate concentrations (2250, 4475, 6730 and 8910 mg COD/L) and for various hydraulic retention time (40, 32, 24, 16 and 8h). Reactor performance shows above 90% COD removal for lower organic loading rates. The data obtained were fitted to various kinetic models, namely, First order model, Diffusional model and Singh model. From the results it was found that the First Order model fits the data well while other two fails to represent the present study.

INTRODUCTION

During the last few years, the application of fluidization in the field of biotechnology has increased considerably (Fan *et al*. 1989). The main application of fluidization principle is in the field of environmental biotechnology (Schugerl, 1989). Fluidized bed bioreactor has several advantages over other conventional reactors for the treatment of wastewater (Sokol, 2001). The inverse fluidization is a multiphase gas-liquid-solid system. The difference between ordinary fluidization and inverse fluidization lies in the density of solid particles used in the reactor. If the density of the particles used is greater than the fluid, it is

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ordinary fluidization; if it is less than fluid it is called as inverse fluidization. Inverse fluidization has all the advantages of ordinary fluidization. In addition, the use of low-density particles has some advantages and overcomes the problem, which occurs during conventional fluidization. Low-density particles require low fluid velocity for their expansion and hence low power requirement. In IFBBR, the control of biofilm thickness is achieved within a narrow range (Karamanev, 1987). The particle-particle and particle wall collision maintains a constant biofilm thickness (Sokol, 2001).

Biological treatment processes have been successfully described by the theory of continuous cultivation of microorganisms and process kinetics have been used for the mathematical description of aerobic biological degradation (Karthikeyan, 2001). In this work, data obtained from the continuous degradation of starch wastewater in an inverse fluidized bed reactor were fitted to various biokinetic models. The model, which represents the continuous study, was identified.

The First Order Model

The first order model is given by (Pfeffer, 1974)

$$-\frac{dC_S}{dt} = -k_f C_S \qquad \text{.......} 1$$

On integration between known limits, the model can be written as

$$\ln\left(\frac{C_S}{C_{SO}}\right) = -k_f t \qquad \text{......} 2$$

The Diffusional Model

Suidan *et al.* (1987) demonstrated that substrate utilization kinetics within biofilm can accurately be described by a model including reaction with diffusion and four different situations may occur

i) The biofilm is deep and the surface substrate concentration is very low; in this case the fermentation takes place following pseudo-first order kinetics not depending on the biofilm thickness.

ii) The biofilm is deep and the surface substrate concentration is very high and approaching that in the bulk; the fermentation rate variation with the square root of substrate concentration is typical of a diffusion-limited zero order reaction :

$$-\frac{dC_S}{dt} = k_D C_S^{0.5} \qquad \text{......} 3$$

iii) The biofilm is fully penetrated and the surface substrate concentration is very low; once again, pseudo first order kinetics would be consistent with the process but the fermentation rate would depend on biofilm thickness.

iv) The biofilm is fully penetrated and the surface substrate concentration is very high and approaching that of the bulk; in this case the fermentation rate should follow zero order kinetics.

$$-\frac{dC_S}{dt} = k_D' \qquad ....4$$

The Diffusional model is given by

$$-\frac{dC_S}{dt} = k_D C_S^{0.5} \qquad ......5$$

When integrated between the known limits, the above equation becomes

$$\sqrt{C_S} - \sqrt{C_{So}} = -\frac{k_D}{2}t \qquad ......6$$

The Singh Model

A modified version of the first order kinetic model was proposed by Singh *et al.* (1983). During degradation, the rate could vary according to the nature of the substrate under consideration, which changes both qualitatively and quantitatively as the digestion process proceeds with time. This necessitates the incorporation of time function to control the kinetic constant.

The Singh Model is given by

$$-\frac{dC_S}{dt} = \frac{k_{Si} C_S}{1+t} \qquad ......7$$

Integrating the above equation between the proper limits, it becomes

$$\ln\left(\frac{C_S}{C_{SO}}\right) = -k_{Si}\ln(1+t) \qquad ......8$$

Experimental Methods

The starch industry wastewater obtained from the industry was characterized. Experiments were carried out in an inverse fluidized bed bioreactor with low density supporting particles. The supporting particles used in this study were made of polypropylene with a density of 870 kg/m3. It is irregular in shape with an average diameter of 10 mm and surface area of 390mm2/mm3. The wastewater was treated in an IFBBR at various initial substrate concentrations (2250, 4475, 6730 and 8910 mg COD/L) for different hydraulic retention time (40, 32, 24, 16 and 8h). Experiments were carried out at an optimum bed height of 80 cm and an airflow rate of 62.50 cc/s (Rajasimman and Karthikeyan, 2006). The pH of the wastewater was maintained at 6.0. The data obtained from the continuous degradation was used to fit the various kinetic models.

RESULTS AND DISCUSSION

The biodegradation kinetics was studied for the continuous degradation of

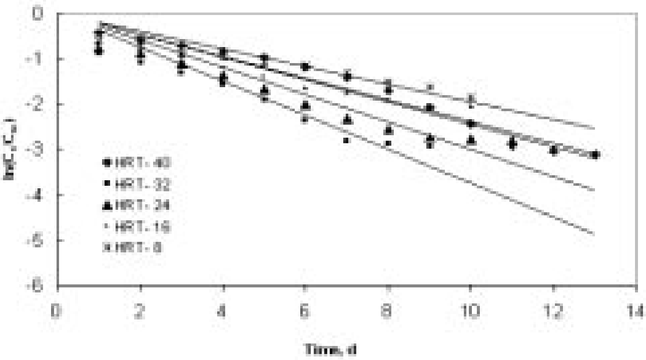


Fig. 1 First Order Model in continuous degradation kinetics for the initial substrate concentration of 2250 mg/L

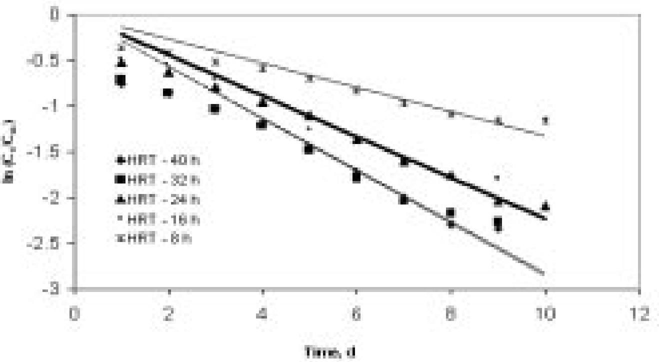


Fig. 2 First Order Model in continuous degradation kinetics for the initial substrate concentration of 4475 mg/L

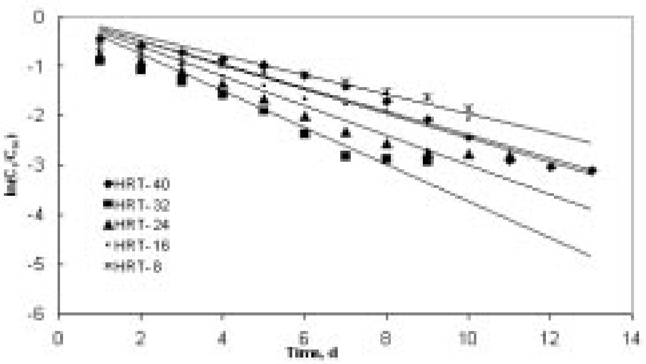


Fig. 3 First Order Model in continuous degradation kinetics for the initial substrate concentration of 6730 mg/L

starch wastewater at different initial substrate concentration and various hydraulic retention time. The experimental data obtained from IFBBR were fitted to the First order, Diffusional and Singh kinetic models.

The application of the first order model to the COD reduction at different

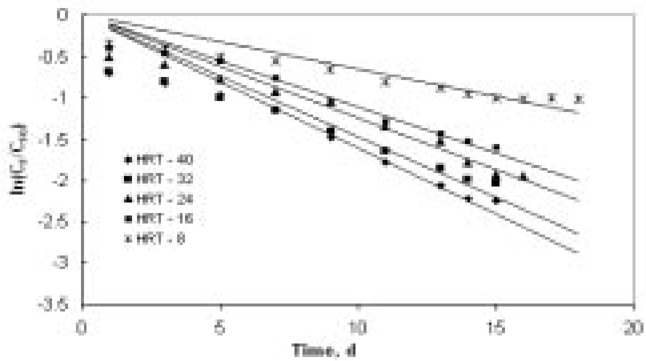


Fig. 4 First Order Model in continuous degradation kinetics for the initial substrate concentration of 8910 mg/L

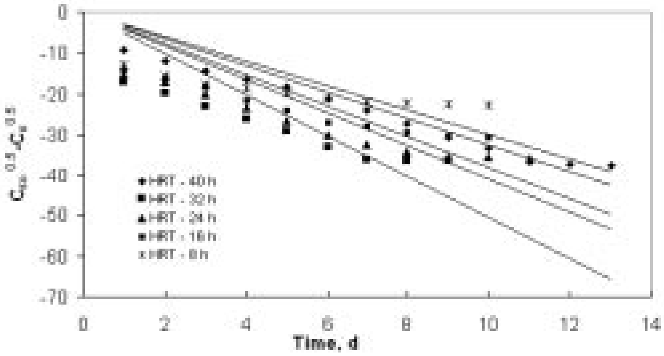


Fig. 5 Diffusional Model in continuous degradation kinetics for the initial substrate concentration of 2250 mg/L

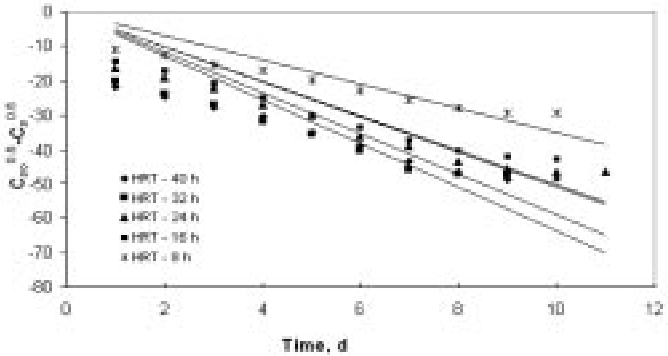


Fig. 6 Diffusional Model in continuous degradation kinetics for the initial substrate concentration of 4475 mg/L

initial substrate concentration was shown in Figures 1 to 4. The values of the kinetic parameter present in the continuous model for all initial substrate concentrations were estimated from the slope of the best-fit lines and it was given in Table 1. The values of the rate constant and higher values of R2 (>0.90) prove

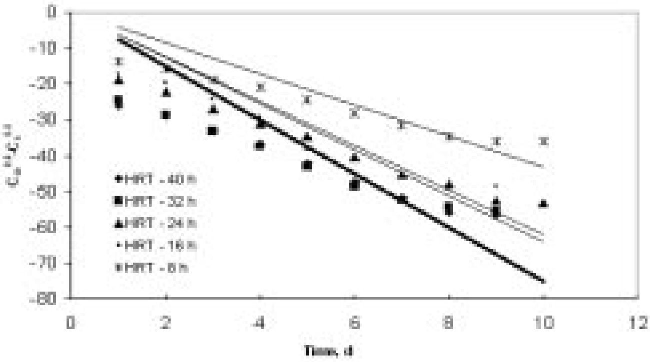
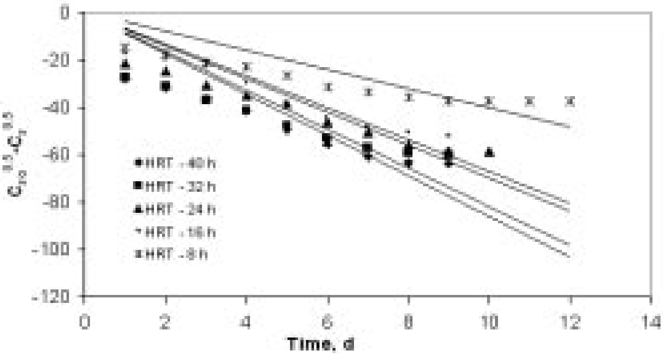


Fig. 7 Diffusional Model in continuous degradation Kknetics for the initial substrate concentration of 6730 mg/L



Fi.g 8 Diffusional Model in continuous degradation kinetics for the initial substrate concentration of 8910 mg/L

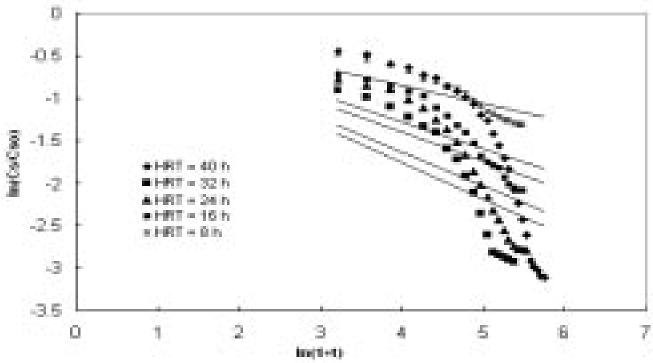


Fig. 9 Singh Model in continuous degradation kinetics for the initial substrate concentration of 2250 mg/L

the ability of this model in describing the degradation kinetics of starch industry wastewater in an inverse fluidized bed bioreactor. As the initial substrate concentration increases, the first order rate constant decreases and this can be ascribed to a growing importance of the recalcitrant fraction in reducing the

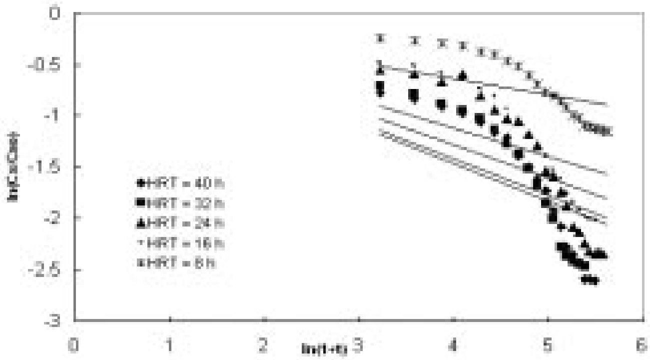


Fig 10 Singh Model in continuous degradation kinetics for the initial substrate concentration of 4475 mg/L

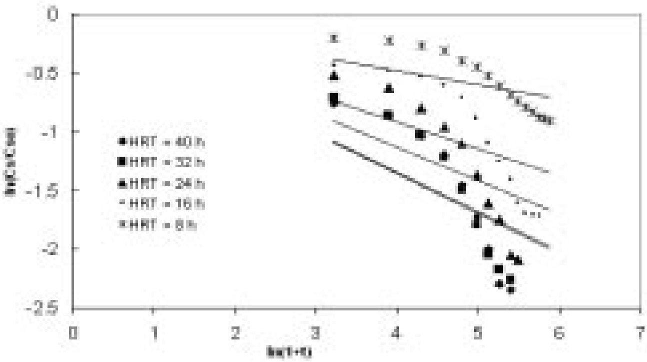


Fig.11 Singh Model in continuous degradation kinetics for the initial substrate concentration of 6730 mg/L

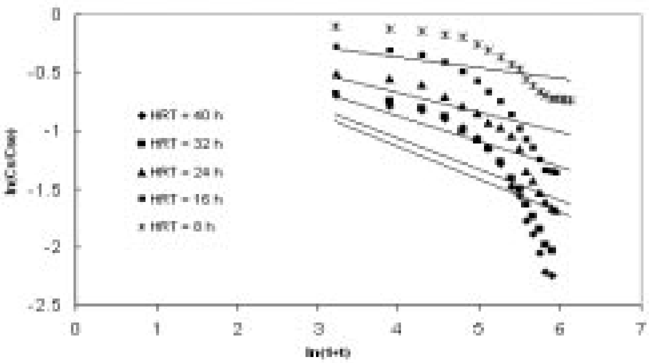


Fig. 12 Singh Model in continuous degradation kinetics for the initial substrate concentration of 8910 mg/L

diffusivity of biodegradable substance. In addition, high values of R2 obtained with the first order model makes the model more valid in representing the continuous degradation of starch wastewater.

The experimental data obtained from the inverse fluidized bed reactor were

Table 1
Kinetics Constants in the First Order Model

Initial Substrate Concentration, mg COD/L	Kinetic Constant	Hydraulic Retention Time, h				
		40	32	24	16	8
2250	k_I, h^{-1}	0.2378	0.3731	0.2993	0.2447	0.1962
	R2	0.9646	0.8619	0.8643	0.7057	0.6895
4475	k_I, h^{-1}	0.2855	0.2828	0.2238	0.2226	0.1331
	R^2	0.8638	0.8454	0.9427	0.9308	0.8379
6730	k_I, h^{-1}	0.2882	0.3049	0.2493	0.2232	0.1319
	R^2	0.8829	0.9022	0.9590	0.9483	0.8466
8910	k_I, h^{-1}	0.1602	0.1472	0.1248	0.1108	0.0652
	R^2	0.8437	0.7391	0.9051	0.9374	0.7110

Table 2
Kinetics Constants in the Diffusional Model

Initial Substrate Concentration, mg COD/L	Kinetic Constant	Hydraulic Retention Time, h				
		40	32	24	16	8
2250	k_D, mg COD $^{0.5}$/	6.5848	10.137	8.25	7.6814	6.025
	L0.5hR^2	0.8843	0.0581	0.1279	-0.1501	-3.3116
4475	$k_{D,}$ mg COD $^{0.5}$/	11.8354	12.742	10.2268	10.1082	6.9722
	L0.5hR^2	0.2048	0.3621	0.6297	0.6986	0.6193
6730	$k_{D,}$ mg COD $^{0.5}$/	15.0578	15.011	12.407	12.8118	8.6152
	L0.5hR^2	0.2089	0.1885	0.6507	0.7072	0.5983
8910	$k_{D,}$ mg COD $^{0.5}$/	17.1864	16.387	13.9094	13.3996	8.023
	L0.5hR^2	0.3453	0.1045	0.6411	0.8118	0.2118

Table 3
Kinetics Constants in the Singh Model

Initial Substrate Concentration, mg COD/L	Kinetic Constant	Hydraulic Retention Time, h				
		40	32	24	16	8
2250	$k_{S,}$ h^{-1}	0.3475	0.4388	0.4061	0.3185	0.2113
	R^2	0.3880	0.5541	0.5562	0.6467	0.7337
4475	$k_{S,}$ h^{-1}	0.3679	0.3557	0.3219	0.2805	0.1595
	R^2	0.5458	0.5329	0.4952	0.5144	0.5063
6730	$k_{S,}$ h^{-1}	0.2830	0.2664	0.2178	0.1671	0.0911
	R^2	0.5494	0.6129	0.5729	0.4884	0.4564
8910	k_S, h^{-1}	0.3381	0.3361	0.2828	0.2286	0.1193
	R^2	0.5704	0.5971	0.5317	0.4977	0.5376

represented by the Diffusional model in Figure 5 to Figure 8. The kinetic rate constants and R2 values obtained from graph were shown in Table 2. The biodegradation rate does not depend on diffusion phenomenon. Hence, Diffusional model failed miserably in representing the continuous biodegradation of starch wastewater in IFBBR. This fact is also complimented by the poor values of R2 obtained with the half order model.

Figures 9 to 12 shows the data obtained from IFBBR represented by the Singh model. The rate constant and R2 values were obtained from the best-fit lines and it was presented in Table 3. Even though the values of rate constant decreases with increase in concentration the R2 values were found to be low. Hence the Singh model fails to describe the continuous degradation of starch industry wastewater in the present study.

CONCLUSION

In the present study, three bio kinetic models namely First order, Diffusional and Singh model were applied to the data obtained from an Inverse Fluidized Bed bioreactor treating starch industry wastewater. From the results it was observed that the First order model fits the data well with high R2 values, whereas the other two models fails to explain the present degradation study.

Nomenclature

CSO – Initial substrate concentration, mg COD / L
CS – Substrate concentration, mg COD / L
t – Degradation time, h
kI – First Order rate constant, h-1
kD – Rate constant for Diffusional model, mg COD 0.5 / L0.5h
kSi – Rate constant for Singh Model, h-1

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News -
Global partnership award is launched

A women's network in India is collaborating with British engineers and a French water compnay to improve water delivery to impoverished urban areas. In Ecudor, a consortium of European companies is working with the government and coffee farmers to ensure that the pesticides don't contaminate water supplies. In South Africa, a small business owner is working with wome's cooperatives and the government to test-market solar technology in rural areas.

Such innovative partnerships are the focus of a global award programme launched by UNEP and other groups in January at the World Social Forum in Mumbai, India and the World Economic forum in Davos, Switzerland. The SEED Awards for "Supporting Entrepreneurs in Environment and Development" will reward people and organizations that work in partnership to devise innovative strategies for the sustainable use of natural resources.

The awards will be given for partneship proposals that show great promise and could serve as modesl. The partners - community groups, businesses, worker organizations, local authoritiies and the like- will receieve support in developing business plans, sekking funding and setting up partnerships.

"Partnerships between NGOs, governments and companies are generating new ideas on how to balance economic, social and environmental needs in a sustainable way', says Miguel Araujo of IUCN-the World Conservation Union, another of the sponsoring organizations. "However, not many people know about their success, why they are important, or how partnerships may be useful in their own communities."

The SEED Awards will be presented every two years. Other groups involved in the inititave are the Stakeholder Forum for Our Common Future, the United Nations Development Programme, Partnerships Cenral, the Global Public Policy Institute, the German government and the United Nations Global Compact office.

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