

Biodegradation Kinetics in Bioaugmented Extended Aeration Reactors for Latex Effluent

MOHD OMAR AB. KADIR^{*}, NORLI ISMAIL^{**}, NIK FUAAD NIK ABLLAH^{**} AND NIK NORULAINI NIK AB. RAHMAN^{***}

A bioaugmented extended aeration reactor was used for the treatment of latex concentrate effluent with an average chemical oxygen demand (COD) of 10 240 mg/l. Biokinetic parameters were determined and they were as follows: half velocity constant = 285.3 mg/l; maximum substrate utilisation rate = 9.29 day⁻¹; yield coefficient = 0.0225 mg volatile suspended solids produced/mg substrate consumed; endogenous decay coefficient = 0.0122 day⁻¹ and maximum specific growth rate = 0.21 day⁻¹. A maximum of 96.9% COD removal was observed at a F/M ratio of 1.0 day⁻¹.

Rubber processing factories are among the major contributors to the environmental problem especially so since the latex concentrate effluent which generally contains high biochemical oxygen demand (BOD) (5000–6000 mg/l), chemical oxygen demand (COD) up to 10 000 mg/l, suspended solids (SS) (883 mg/l) and ammonia nitrogen (AN) (5000 mg/l).

The waste-water stream consists of excess field latex effluent, stabilisers such as ammonia, sodium sulphite or formaldehyde added to prevent premature coagulation of the field latex. Skim latex is a by-product in the processing of field latex concentrate after centrifugation and is the most polluting waste¹. The skim latex serum contains high ammonia, sulphate, organic and inorganic substrates which form the major pollutants of a latex concentrate factory.

Proper treatment of rubber processing waste for removal of organic pollutants is essential to minimise detrimental impact on the environment. It has been reported that biological waste treatment may be a valuable method for reducing the organic pollutants from latex concentrate effluent. A number of investigators examined the treatment of rubber processing waste by lagooning method¹.

Currently a new technology known as bioremediation technic appears as an improvement method to treat either contaminated soil, ground-water, surface water or waste water². A specific term called bioaugmentation refers to the addition of specific exogenous bacteria to enhance the reduction of the organic or inorganic pollutant especially in waste water treatment.

^{*} School of Industrial Technology, University of Science Malaysia, 11800 Penang

^{**} School of Housing, Building and Planning, University of Science Malaysia, 11800 Penang

^{***} School of Distance Education, University of Science Malaysia, 11800 Penang

[#] Corresponding author

A lot of research has been successfully done using the bioaugmentation technic such as the addition of *Pseudomonas putida* PRS 2015 pAC 27 to activated sludge systems for enhanced degradation of 3-chlorobenzoate (3-CB) The addition was 10% of the total biomass and resulted in successful 3-CB degradation³ Studies on the addition of a par-chlorophenol (4-CP) degrading culture to a non-acclimated chemostat showed that the bioaugmented system successfully removed more than 96 percent 4-CP⁴

It has generally been assumed that the growth of mixed cultures in complex organic wastes would be similar to the growth of pure cultures, so the Monod equation which has been used successfully in studying the kinetics of pure cultures of bacteria utilising simple substrates can be used to study the aerobic digestion of complex organic materials Biokinetic parameters are valuable in designing and scale up of a continuous treatment process⁵ whereby evaluation of the biokinetic constants has its significance with respect to understanding the capabilities of the microorganisms in the degradation process as well as in the operation of biological reactors

The objectives of this study were to determine the treatability of latex concentrate effluent and to determine bio-kinetic parameters of the waste water using bioaugmented extended aeration reactors

MATERIALS AND METHODS

Treatment System

Aerobic pilot scale system was constructed using fibre glass materials The system comprises of 0.5 m diameter cylindrical tank separated into two parts which were equalisation tank (EQT) (0.7 m long) and extended aeration tank

(EAT) (0.5 m long) The samples were aerated in EAT for 24 h and 20 h Both ends are capped with 0.1 m cover and the clarifier was a hopper type with dimensions 0.45 m diameter and 0.6 m high The 24 h – 20 h retention time in the clarifier allowed suspended solids to be settled and therefore will remove it Schematic diagram of the reactor is shown in *Figure 1*

Sampling and Waste Water Compositions

Latex effluent samples were collected from a local company from their raw mixed latex effluent before entering the rubber trap (B) as shown in *Figure 2* Mixed latex effluent was a mixture of the two processing mixture steps Once from field latex washing process, processing platform and from the lorry tanker after washing the tank and the other is after de-ammoniation of skim latex

Treatment Process

Thirty litres of raw latex effluent of known BOD and COD concentration was allowed to homogenise in a standard FRP tank The sample was pumped into the EAT using a masterflex pump (Model no 7568-10) at a flow rate of 12, 6, 1.9, 1.0, and 0.5 l/hr, respectively In the EAT the waste was aerated for 2, 4, 12, 24 and 48 h, respectively Air was supplied using air diffuser (Model no SA 130 EX Lot no 905, National air pump) at a rate of 1.5 mg/l – 3.0 mg/l dissolved oxygen Two sets of fine sparger were used to aerate the extended aeration tank There was no recycled sludge and the system was operated for a month in order to achieve the required mixed liquor suspended solids (MLSS) of 4000 mg/l–6500 mg/l A constant concentration of MLVSS was maintained by estimating MLVSS concentration daily and withdrawing calculated amount of sludge when required

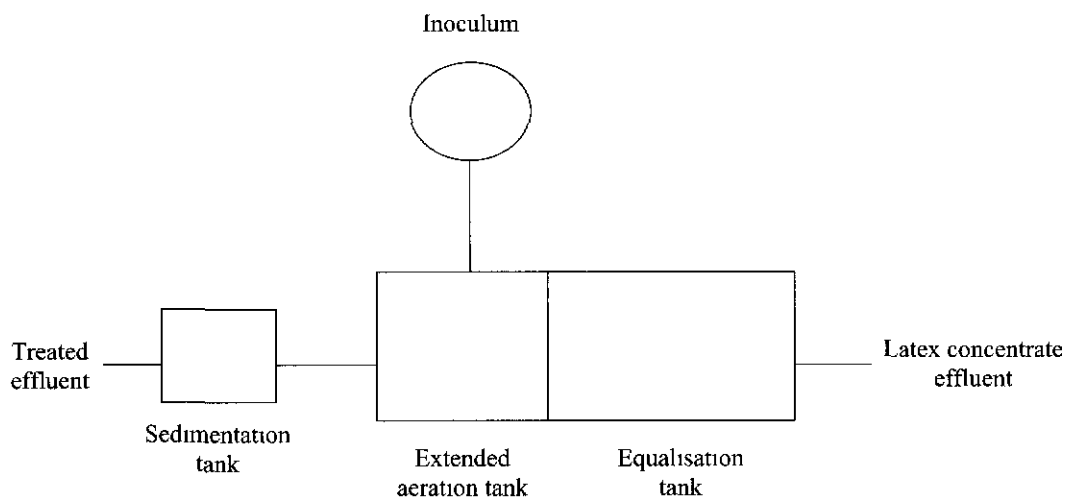


Figure 1 Schematic diagram of the bioaugmented reactor

An experimental run was performed at an average daily temperature of $29^{\circ}\text{C} \pm 1^{\circ}\text{C}$. There was no oxygen supplied in the equalisation tank. A heterogeneous mixture of bacteria was used to enhance the loading reduction of the tested parameters. The bacteria was filled up in a ten-litre aspirator bottle and placed above the EAT. The inoculum were applied in drips, set at six-second interval per drip at a concentration of 44.0 mg/l for each of the experiment.

The treated effluent from EAT was passed through the pipe to the clarifier. Data was collected every day for each experiments in replications. Analysis of BOD_3 and COD concentrations were determined as above. Sample for analysis was collected from initial and final concentration of the tested parameter for performance assessment of the system.

The treated MLSS from EAT was passed through the pipe to the clarifier. Sample was collected every day for each experiments in three replicates. The collected sample was

immediately preserved in refrigerator at 4°C . The sample was then analysed for the BOD_3 and COD values.

Operational Problems

During the operational period, clearance of the porous stones in the EAT and masterflex transferring the waste flow must be done every month in order to prevent the sludge clogging. Flow-rate of the system was checked every two days to ensure constant flow-rate as shown in Table 1. MLSS was measured everyday for sludge settleability determination and maintaining the required MLSS.

Inoculum

The heterogeneous culture of *Bacillus sp*⁶ was used in this study. The inoculum was stored in the refrigerator at 4°C for preservation until it was ready to use. The concentrated inoculum was diluted with water to 22 mg/l (w/v) prior to application.

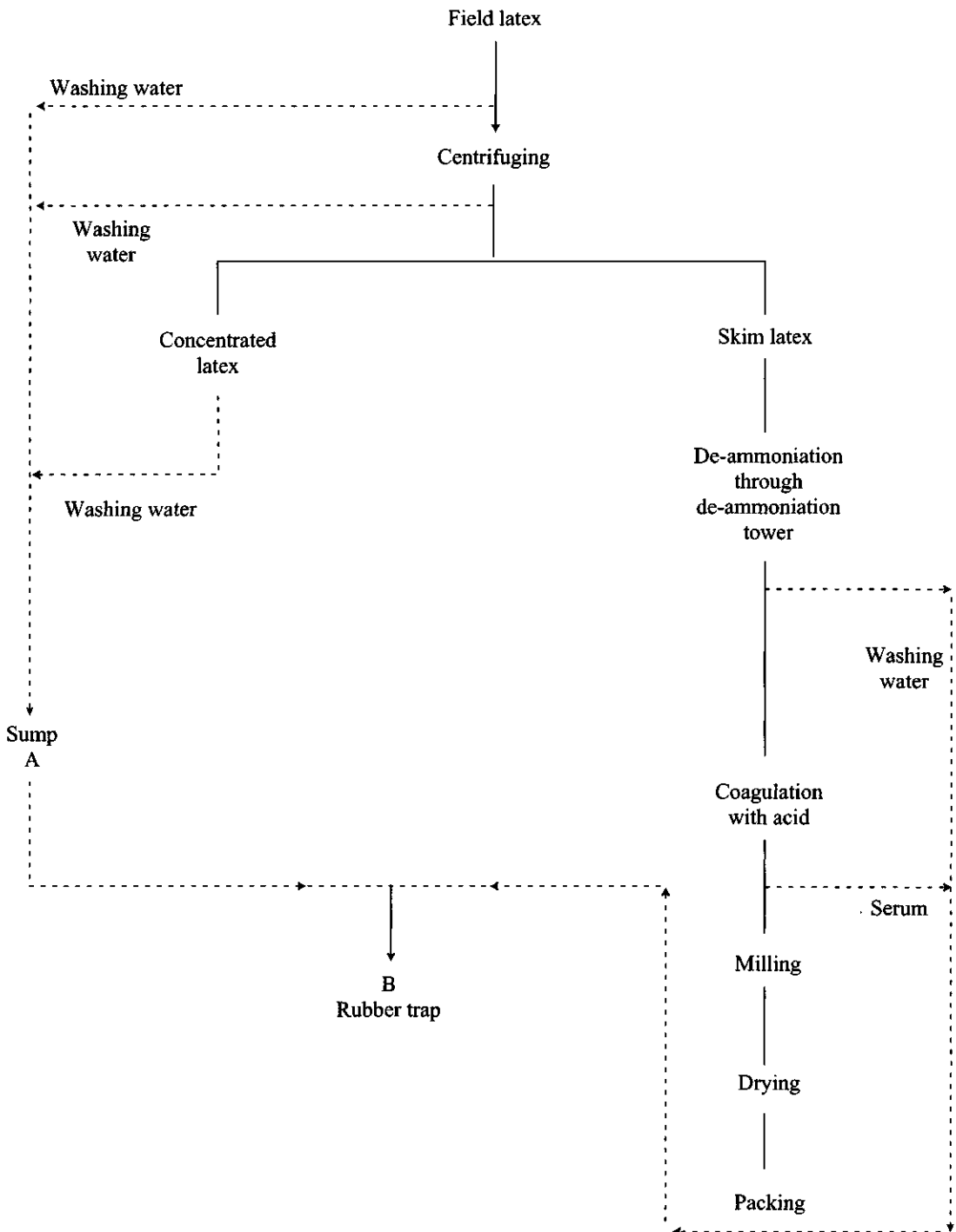


Figure 2. Latex processing flow chart.

TABLE 1 PERFORMANCE SUMMARY (EXPERIMENTAL DATA)

Run no	Influent average	Effluent average	MLVSS (mg/l)		Flow rate	HRT (θ)
	COD, S_0 (mg/l)	COD, S_e (mg/l)	X_T	X_0	Q (ml/min)	t/hr
1	10240	2754 0	3904 0	3725 3	200 0	2
2	10240	1420 0	2928 2	3800 0	100 0	4
3	10240	687 0	3473 8	3200 0	31 6	12
4	10240	448 0	4371 4	4200 0	16 6	24
5	10240	308 0	4855 1	4759 0	8 3	48

Analytical Method

The latex effluent was analysed for various parameters such as BOD₃, COD and MLVSS (mixed liquor volatile suspended solids) using the APHA techniques⁷. The pH was constantly monitored using Orion Research, Model SA 210 pH meter. Sample of mixed liquor from the EAT was taken, and the volatile solids were termed MLVSS.

The volatile suspended solids indicate the amount of microorganisms in the biological system. MLVSS used as biomass of the bacteria was used in the study. The statement was an agreement with the studies⁸ for the activated sludge reactor which stated that the mixed liquor from the activated sludge reactor was the source of biomass for the experiments.

RESULTS AND DISCUSSION

The influent characteristics were as follows: average COD = 10 240 mg/l, BOD₃ = 5100 mg/l, suspended solids = 1800 mg/l and pH 5.5–6.5. Performance summary data are given in Table 1 and Table 2.

In Figure 3 effluent COD was plotted against hydraulic retention time. An exponential decrease of effluent COD was observed with

increase in hydraulic retention time similar to the results obtained on treatment of dairy waste water⁹. Figure 4 (logarithmic) shows the increase in removal efficiency with increase in retention time.

In Figures 5 and 6 specific substrate removal (q) was plotted against effluent COD concentration. It was observed that a rectangular hyperbolic better fits the points (Figure 6) than the straight line (Figure 5). The statement was verified by the values of R^2 for both of the figures (Figures 5 and 6). Values of R^2 (0.9251) for Figure 5 was low compared to value of R^2 (0.9994) for Figure 6. It showed that about 99.9% of COD effluent in Figure 6 was influencing a specific substrate utilisation rate (q) and the rest (0.1%) was influenced by other factors. Therefore it could be predicted that substrate removal rate follows Michaelis-Menten relationship better than the first order reaction kinetics.

The selection of any one model for practical application, may be based upon a curve-fitting approach. This does not provide proof of theoretical validity of any particular kinetic model. The approach offers support for practical application rather than a proof of the Monod equation in reactors employing heterogeneous population as the Monod model has extensively been used.

TABLE 2 PERFORMANCE SUMMARY (CALCULATED DATA)

Specific substrate utilisation rate $q = S_0 - S_e / xt$ mg COD removal/d mg MLVSS	$1/q$ day ⁻¹	Specific growth rate, μ day ⁻¹	$1/(S_e - S_n)$ mg/l	$F/M = S_0 / tx$ day ⁻¹	% COD removed
23.2	0.043	0.56	0.004	31.5	73.1
13.5	0.074	0.20	0.00087	15.7	86.1
5.5	0.18	0.16	0.0024	5.89	93.2
2.2	0.45	0.04	0.0057	2.3	95.6
1.0	1.0	0.01	0.03	1.0	96.9

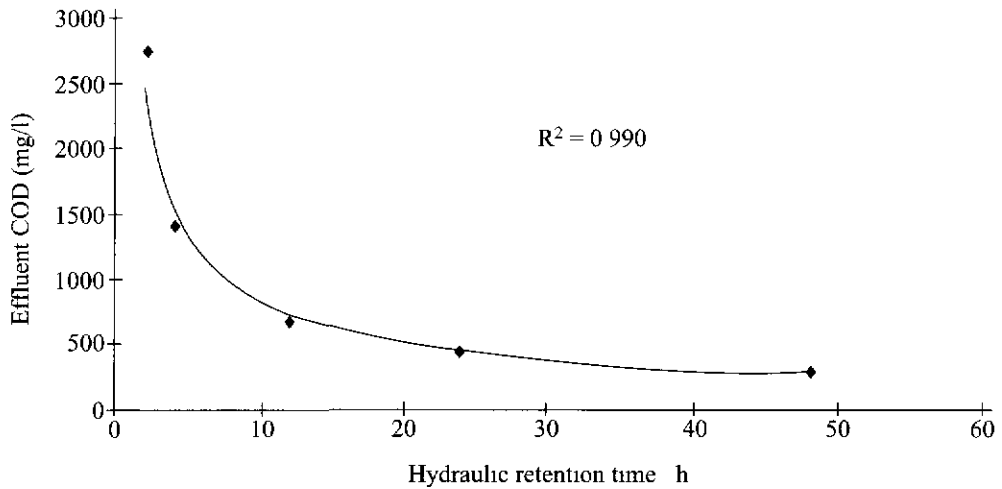


Figure 3 Effect of hydraulic retention time on effluent COD

for the estimation of biokinetic constants for bacterial growth on non-inhibitory substrate^{10 11} and for inhibitory substrates^{12 13}

In Figure 6 the intercept on X-axis obtained is equal to 275.0 mg/l COD, about 2.5% of 10 240 mg/l initial COD (COD was used as an indicator for substrate concentration) When it was compared to the study of dairy waste⁹, it

was found that about 188.27 mg/l non-biodegradable portion of substrate was obtained This is equal to 36.2% of the COD initial concentration (520 mg/l) It indicates that only a small (2.5%) portion of the non-biodegradable substrate was left compared to 36.2% of the non-biodegradable portion for dairy waste It demonstrates that the coupled system of extended aeration and

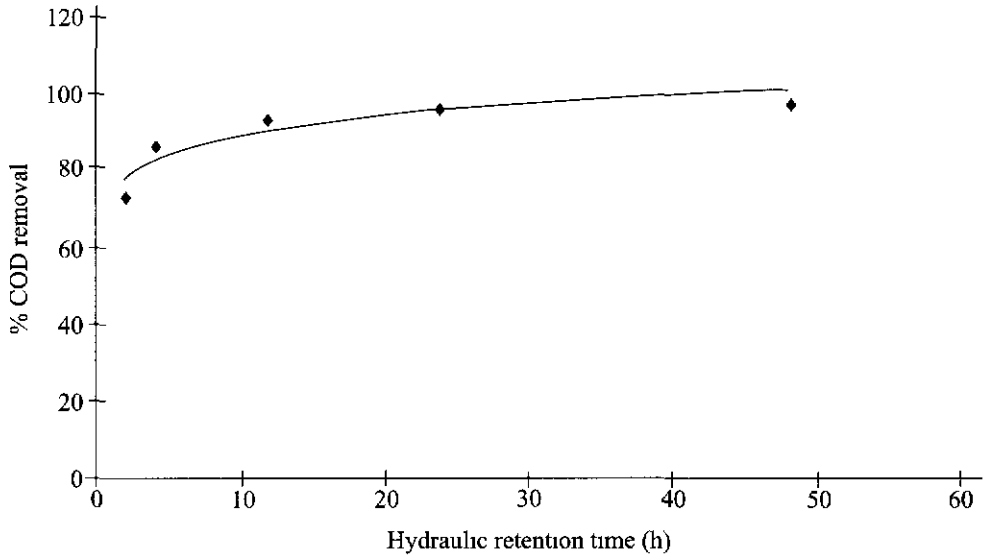


Figure 4 Effect of hydraulic retention time on removal efficiency

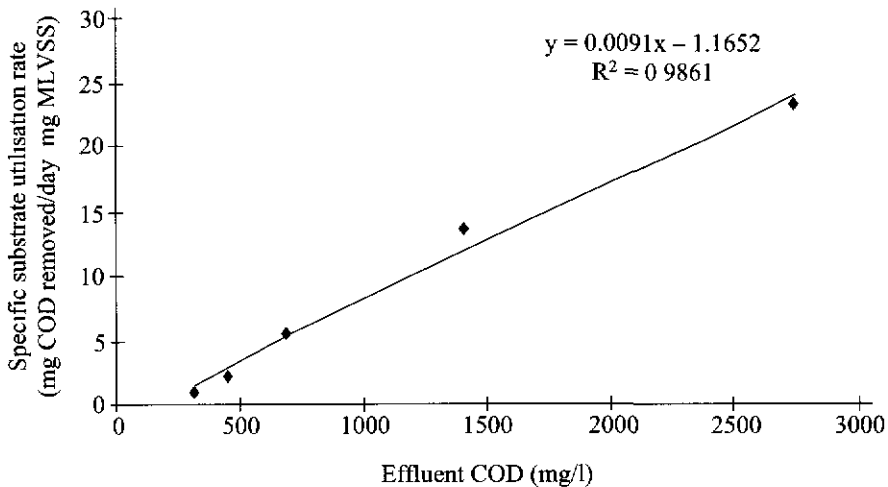


Figure 5 Plot of specific substrate utilisation rate vs effluent COD

bioaugmentation can degrade about 36.18% of the non-biodegradable substrate in mixed latex effluent compared to dairy processing waste. Concomitantly it was proved that the

coupled technique enhanced reductions of the biodegradable portion of the pollutants by 97.5%. The concentration of non-biodegradable COD is estimated by application

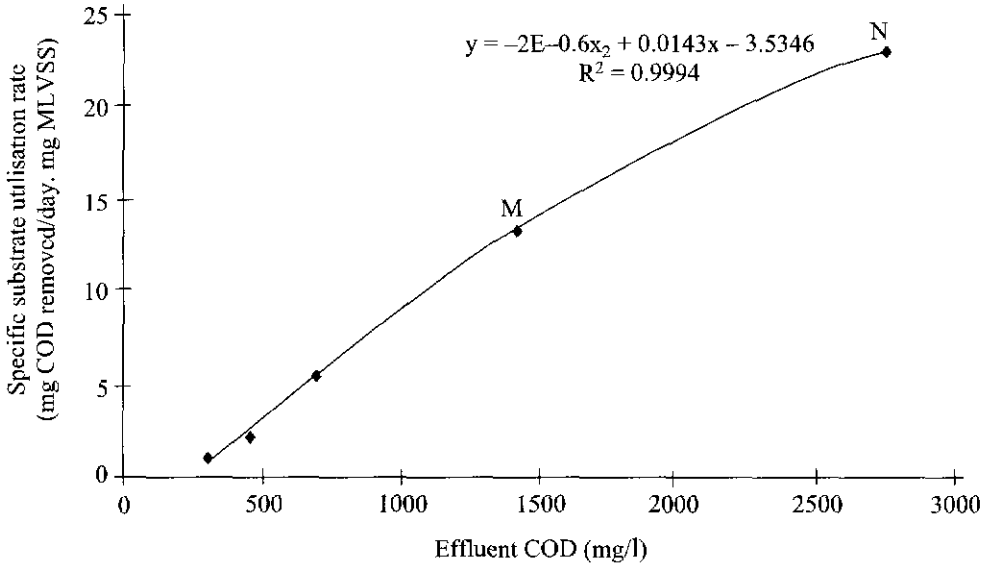


Figure 6 Michaelis-Menten plot of specific substrate utilisation rate vs. effluent COD

of the specific growth rate (μ) where the specific rate of substrate removal (q) will be zero when the concentration of biodegradable substrate is zero¹⁴.

The possibility of zero non-biodegradable portion was based on the natural characterisation of the waste. In this case, latex effluent normally consists of process water, proteins, sugar and lipids¹⁵. Aside from the bacteria used there were also hydrogen and carbon which attack the aromatic rings through the degradative pathway¹⁶.

In Figure 7, $1/q$ was plotted against $1/S_e$. This is a Lineweaver-Burk Plot which follows the following equation:

$$\frac{1}{q} = \frac{K_s}{q_{max}} \cdot \frac{1}{(S_e - S_n)} + \frac{1}{q_{max}} \quad \dots 1$$

where,

K_s = half velocity constant (mg/l)

q_{max} = maximum substrate utilisation rate

q = specific substrate utilisation rate

S_n = non-biodegradable portion of substrate.

From the slope and intercept the value of K_s and q_{max} was found out. $K_s = 285.3$ mg/l and $q_{max} = 9.29 \text{ day}^{-1}$. A maximum substrate utilisation rate for this system was 9.29 day^{-1} compared to 0.199 day^{-1} as obtained in the study of dairy effluent treatment⁹. This indicates that about 9.29 mg COD removed per mg MLVSS within a day compared to only 0.199 mg COD removed per mg MLVSS within one day for dairy processing effluent. The capabilities of inoculum in removing COD of 9.29 mg COD per mg MLVSS within a day proved the effectiveness of using the exogenous bacteria in enhancing the pollutant's degradation rate.

In Figure 8, specific substrate utilisation rate (q) was plotted against specific growth rate (μ). From the equation below, yield coefficient (Y) and endogenous decay coefficient (K_d) was obtained:

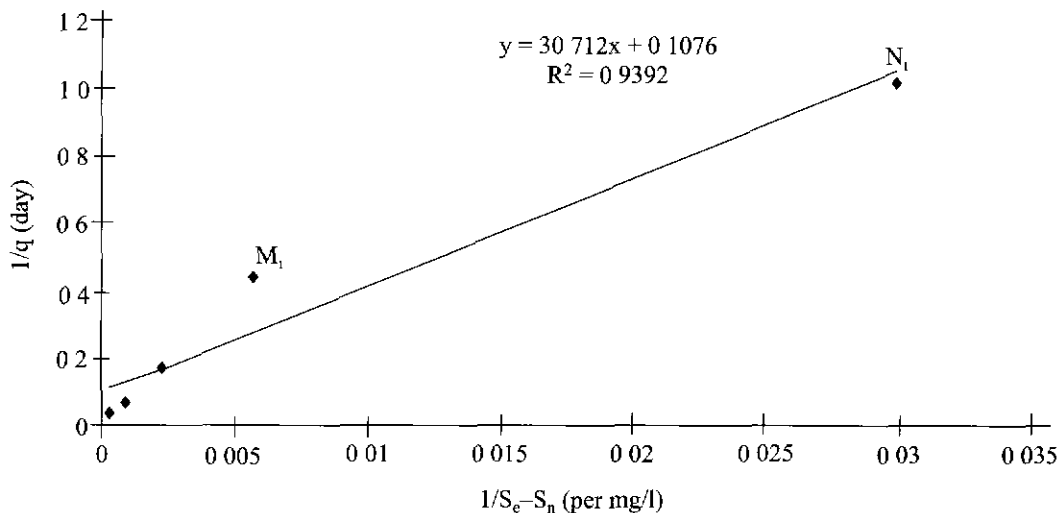


Figure 7 Lineweaver-Burk plot of $1/q$ vs $1/(S_e - S_n)$

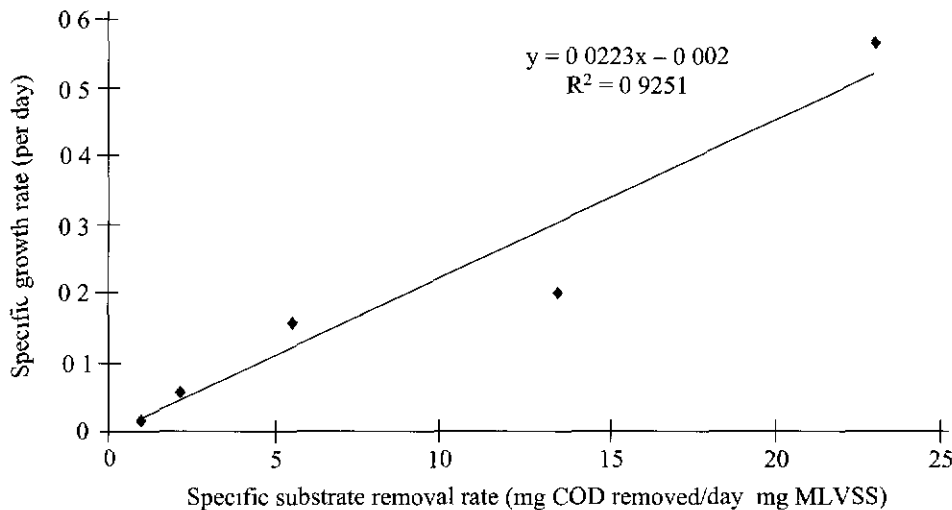


Figure 8 Specific growth rate vs specific substrate removal rate

$$\mu = Y_q - K_d$$

2

MLVSS/mg substrate The values of Y and q_{max} were used to predict the maximum growth rate

where, Y = yield coefficient and K_d = endogenous decay coefficient The values of $K_d = 0.0122 \text{ day}^{-1}$ and $Y = 0.0225 \text{ mg}$

The value of μ_{max} from the study was obtained as 0.21 day^{-1} compared to 0.149 day^{-1} achieved

in dairy waste treatment. The μ_{\max} value of 0.21 day^{-1} showed that the growth rate of the inoculum was rapid compared to 0.149 day^{-1} for the bacteria which exist in the dairy processing effluent. The rapid growth rate of the bacteria will enhance the reduction of the pollutants even though the initial COD concentration in latex effluent was high ($10\,240 \text{ mg/l}$) compared to 520 mg/l COD in dairy processing effluent⁹.

In *Figure 9*, percent removal of COD was plotted against F/M ratio. It was observed that with the decrease in F/M ratio, percent COD removal increases up to a limit. A maximum of 96.9 percent removal was observed at a F/M ratio of 1.0 day^{-1} .

CONCLUSION

The following conclusions were drawn from the foregoing study:

- For continuous stirred tank reactor, the percent removal of COD increases with increasing hydraulic retention time.

- The values of kinetic coefficients were as follows:

$$K_y = 285.3 \text{ mg/l}; K_d = 0.0122 \text{ day}^{-1};$$

$$Y = 0.0225 \text{ mg VSS produced/mg substrate consumed};$$

$$\mu_{\max} = 0.21 \text{ day}^{-1}.$$

- A maximum of 96.9 percent removal of COD was observed at a F/M ratio 1.0 day^{-1} .
- Good treatment efficiency cannot be achieved without raising HRT.

Date of receipt: December 1998

Date of acceptance: August 1999

REFERENCES

1. NORDIN ABD. KADIR BAKTI (1997) Effluent Management in the Rubber Product Manufacturing Industry. *Journal of Ensearch.* **10(1)**, 67-72.
2. YEOH, B.G., CHEE, K.S., PHANG, S.M., ZAID, I., AZNI, I. AND MAKETAB, M.

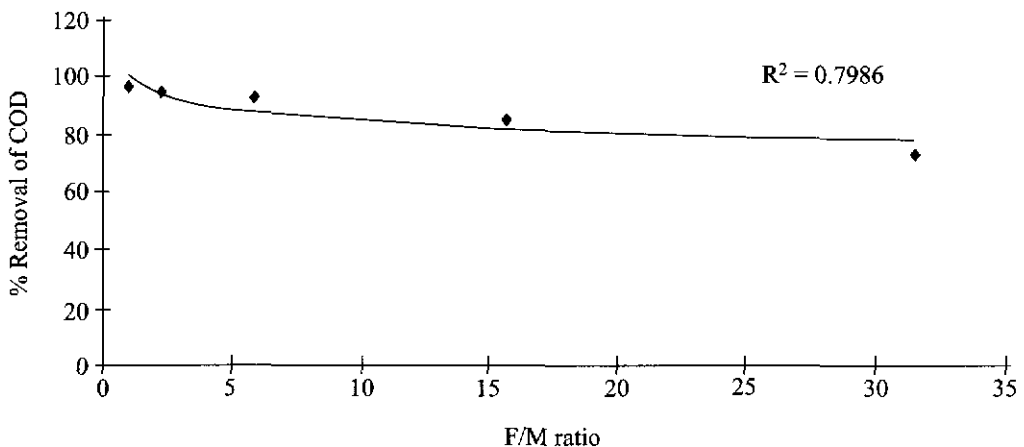


Figure 9. Effect of F/M on COD removal efficiency

- (1993) Biological Removal of Heavy Metals *Waste Management in Malaysia Current Status and Prospect for Bioremediation* Kuala Lumpur Ministry of Science, Technology and the Environment
- 3 WILDERER, P A , BUBIO, M A AND DAVIDS, C (1991) Impact of the Addition of Pure Cultures on the Performance of Mixed Culture Reactors *Wat Res* , **25**, 1307-1313
- 4 KENNEDY, M S , GRAMMAS, J AND ARBUCKEL, W B (1990) Para-chlorophenol Degradation Using Bioaugmentation *Res J Wat Pollut Control Fed* , **62**, 227-232
- 5 KUMARAN, P AND PARUCHURI, Y L (1997) Kinetics of Phenol Biotransformation *Wat Res* , **31(1)**, 11-22
- 6 BAUGH, C L (1996) *Custom Biologic Increment* Florida, USA
- 7 APHA (1980) *Standard Method for the Examination of Water and Wastewater*, 5th (ed) Washington, D C American Public Health Association
- 8 SLADE, A H AND DARE, P H (1993) Measuring Maximum Specific Growth Rate and Half Saturation Coefficient for Activated Sludge Systems Using a Freeze Concentration Technique *Wat Res* , **27(12)**, 1793-1795
- 9 BHATTACHARYA D , RAY, L , GHOSH, A K AND CHATTOPADHYAY, P (1994) Activated Sludge Treatment of Dairy Wastewater — Determination of Kinetic Parameters in Continuous Stirred Tank Reactor *Research and Industry*, **39**, 43-47
- 10 EDWARD, H L (1970) The influence of High Rate Substrate Concentration on Microbial Kinetics *Biotechnol Bioengg* , **12**, 679-712
- 11 JONES, F C (1923) History of Crude Rubber *Journal of India Rubber*, **66(219)**, 328
- 12 GAUDY, A F , ROZICH, A R AND GAUDY, E T (1986) Activated Sludge Process Models for Treatment of Toxic and Non-toxic Wastes *Environ Sci Technol* , **12**, 123-137
- 13 COLVIN, R J AND ROZICH, A R (1986) Phenol Growth Kinetics of the Heterogeneous Population in a Two Stage Continuous Culture System. *J Wat Pollut Control Fed* , **58**, 326-332
- 14 GRADY, C P L AND LIM, H C (1980) *Biological Wastewater Treatment Theory and Applications* New York Marcell Dekter, Inc
- 15 IBRAHIM, A (1983) Improved Anaerobic Digestion of Rubber Effluent Using the Upflow Anaerobic Filter *Planters' Conference*, 17-19 October, Kuala Lumpur
- 16 KUMARAN, P AND PARACHURI, Y L (1997) Kinetics of Phenol Biotransformation. *Wat Res* , **31(1)**, 11-22