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Kinetic Evaluation of Fixed Film Fixed Bed Anaerobic Reactor by Using Dairy Wastewater

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Abstract: A diphasic Anaerobic Reactor model (FFFB) was studied for treating Dairy wastewater. The experiment was conducted for different COD loading and different flow rates. The COD reduction efficiency was observed for 58.82% to 70.8%. The models prescribed by[1,2 and 3] model were used to estimate the process kinetic parameters. The evaluated kinetic parameters are listed.

Keywords: Diphasic reactor · Kinetic parameters · Acidogenic · Methanogenic · FFFB reactor

INTRODUCTION

Dairy plant wastewaters are generally high strength wastes containing soluble, colloidal and suspended solids with high concentration of biochemical oxygen demand [1]. Anaerobic decomposition is a biologically mediated process indigenous to nature and capable of being simulated for treating high strength wastes [2]. Though the capital cost is higher the net operating cost of the system turns out to be either significantly less whereas the operating cost for aerobic process increases with increase in their strength [3]. Therefore for high strength industrial wastewaters, anaerobic treatment process has long been economically attractive [4]. The development of processes with higher volumetric load capacity has gradually increased the interest in treating more wastes in anaerobic processes [5]. Reuse and energy conservation have become the words of the day and anaerobic processes have emerged with a new potential [6]. With the new interest came new approaches, of which the anaerobic fixed film fixed bed reactor have assumed greater significance in treating high as well as medium strength wastewater [7]. A laboratory scale model of FFFBAR mainly involved operating the reactors at various combinations of HRT and influent COD concentration. The data generated were used to determine the process kinetic values for substrate biomass.

EXPERIMENTAL METHODOLOGY

The experiment was initiated using domestic wastewater. The reactor was observed to attain the steady state conditions after 60 days with an average COD removal of 76 %.Three random samples were obtained from M/s. Hat sun Agro Industries Private Ltd., Kari Patti, Salem district, Tamil Nadu, India and were analyzed for specific parameters.

The real time wastewater was introduced in reactor with an overall average VLR of 6.50 Kg COD/m^3.day and in stages, mixed with domestic wastewater, in proportion of 20%, 40%, 60% and 100%. The performance of the reactor was studied and the steady-state conditions were observed to attain with COD reduction for an average value of 65 % after 30 days.

The synthetic dairy effluent is prepared using milk powder (Amulya brand) and introduced after the process stabilization.

The model reactor was operated under different conditions

I) Volumetric Loading Rates:
In A.R.: 4.77 Kg COD/m^3.day to 55.908. Kg COD/m^3.day
In M.R.: 1.279 Kg COD/m^3.day to 16.614 Kg COD/m^3.day
Overall: 1.26 Kg COD/m^3.day to 14.81 Kg COD/m^3.day

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II) Average influent COD, mg/lit: 8000, 8996, 9956, 10976, 11981.

III) Hydraulic Retention Time (HRT) in hours:

Acedogenic reactor: 40.712, 20.356, 10.178, 6.785 and 5.089.

Methanogenic reactor: 113.09, 56.548, 28.274, 18.849 and 14.137

MATHEMATICAL MODELS

Dewalle and Chian [8] Model: The anaerobic process of treatment in the phased out FFFB reactors viz., acidogenic and methanogenic is well explained by many. Though not directly, the substrate utilization kinetics can be deduced from the given model equations with required modifications.

Dewalle and Chian [8] provided the Model as differential equations using Fick's law of molecular diffusion as

$$\frac{dF}{dt} = -AD\frac{ds}{dz}$$

This can be applied independently for acidogenic and methanogenic reactors, in series and also considering it as one process (anaerobic FFFB reactor in two phases).

When substrate concentration is > k_S, the above equation can be stated as

$$\frac{1}{V}\cdot\frac{dF}{dt} = (K\,A/V)\sqrt{Se}$$

While the substrate concentration is < k_S, the equation can be restated as

$$\frac{1}{V}\cdot\frac{dF}{dt} = (K\,A/V)\,Se$$

Where

$(k\ A/v)Se$ = substrate removal rate constant

$\frac{1}{v}\frac{df}{dt}$ = Loading rate expressed in kg COD/m^3/day

Ks = Half velocity constant in Kg/m^3.

The plot of COD loading rate versus the effluent concentration is made to study the substrate utilization for the FFFB diphasic reactor model and as well independently for acidogenic and methanogenic reactors.

The plots of drawn curves are shown in the Fig 1, 2 and 3.

Mccarty and Young [9] Model: The hydraulic retention time, over which the substrate is maintained in the vicinity or contact with the bio film, could influence the treatment efficiency than any other parameter. Certain inhibitory factors in the substrate utilization could be overrun by increasing HRT of the process.

McCarty and Young [9] provided a relationship between substrate removal and hydraulic retention time as

$$Es = 100\ (1 - a / \varnothing)$$

Where Es = substrate removal

a = Probability constant or theoretical HRT at which efficiency Would be zero (Critical HRT)

$\varnothing$ = Hydraulic retention time

The equation provides the concept that as HRT increases to infinity, the substrate removal efficiency would approach 100%

Anyhow, COD removal at 100% is hypothetical as the residual refractory of microbial stabilization will always keep some amount of COD in the system or in the effluent therefore a modified version of the model is proposed as

$$Es = Es\ m\ (1 - a/\varnothing)$$

Where

m = Maximum organic removal (COD removal)

The plot was drawn for substrate removal efficiency versus HRT

The drawn curves are shown in Fig. 4, 5 and 6 for the acidogenic, methanognic and overall FFFB diphasic digester respectively.

The results confirmed that 100% treatment or COD removal can not be achieved even for longer HRT as large as infinity. This is essentially because of refractory organics present in the biodegradable dairy waste streams.

The experiment result on the model is assessed to give 18.327% as maximum COD removal in the acedogenic reactor for the HRT of 0.2120 days and 51.726% for methanogenic reactor for the HRT of 0.589 days. The model as the whole, performing as FFFB diphasic digester, the maximum COD removal is 60.33% for a HRT of 0.8011 days.

Dewalle and Chian [8] model

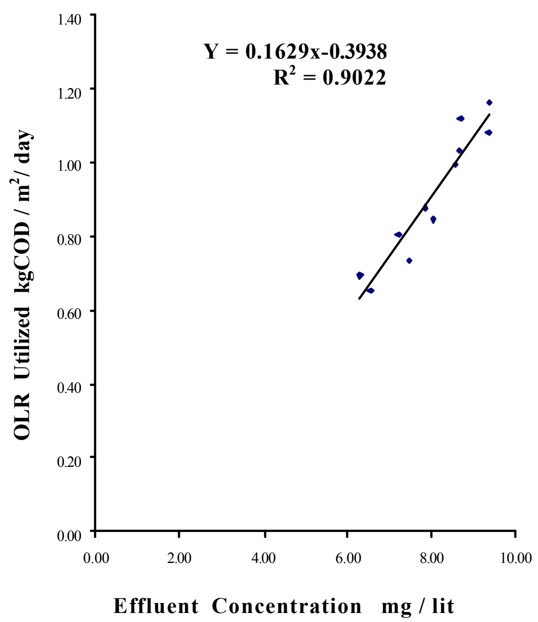

Fig. 1: OLR Vs Effluent Concentration [Acedogenic Reactor]

Dewalle and Chian [8] model

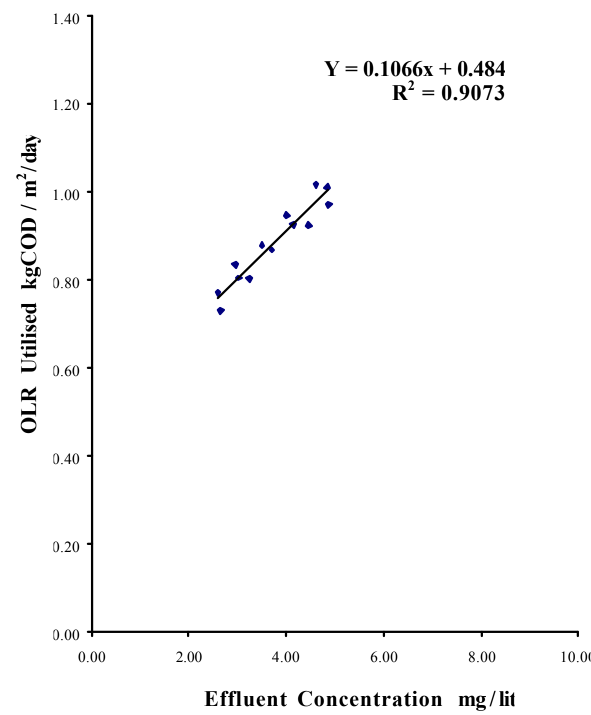

Fig. 3: OLR Vs Effluent Concentration [Diphasic Reactor]

Dewalle and Chian [8] model

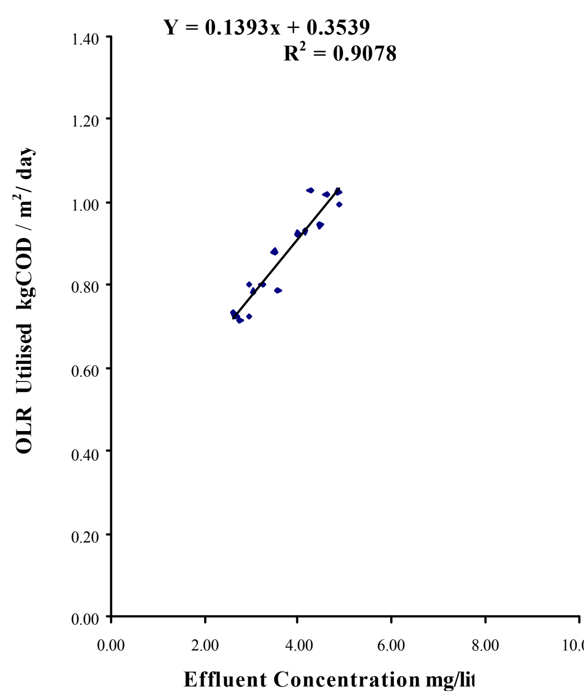

Fig. 2: OLR Vs Effluent Concentration [Methanogenic Reactor]

McCarty and Young [9] model

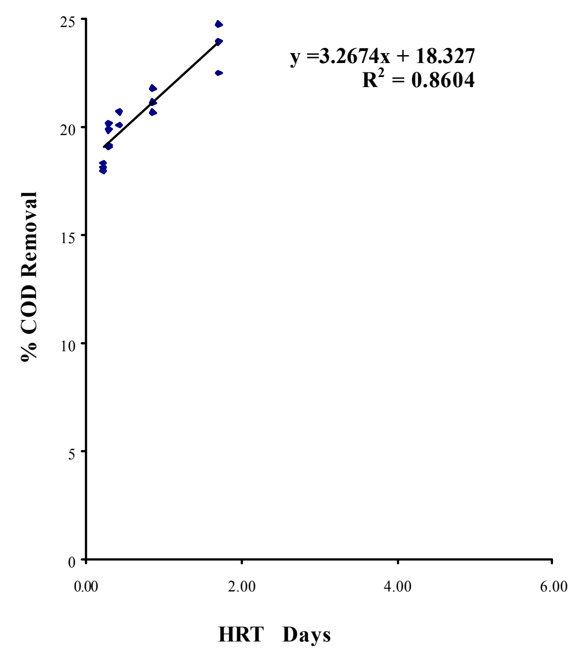

Fig. 4: % COD Removal Vs HRT [Acedogenic Reactor]

McCarty and Young [9] model

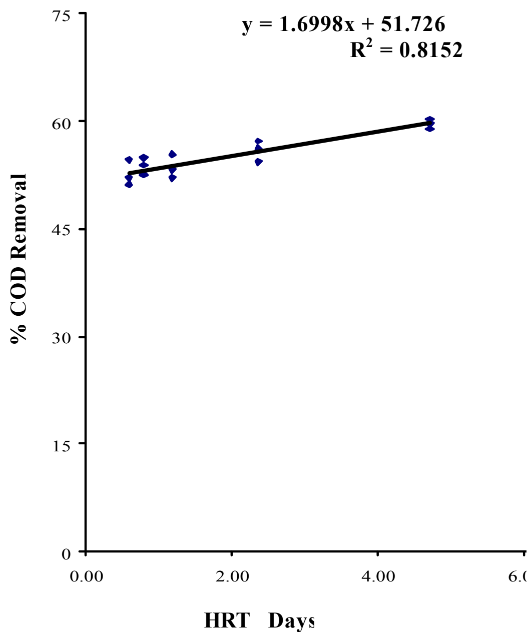

Fig. 5: % COD Removal Vs HRT [Methanogenic Reactor]

Stover *et al.* [10] model

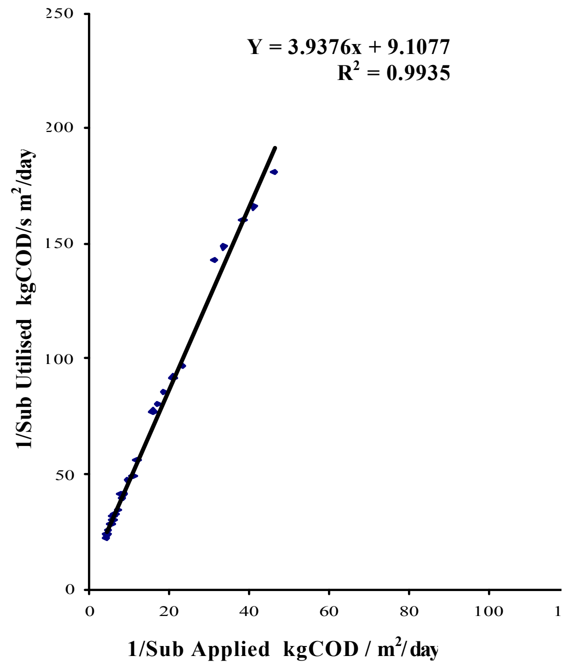

Fig. 7: 1/Sub Utilized Vs 1/Sub Applied [Acedogenic Reactor]

McCarty and Young [9] model

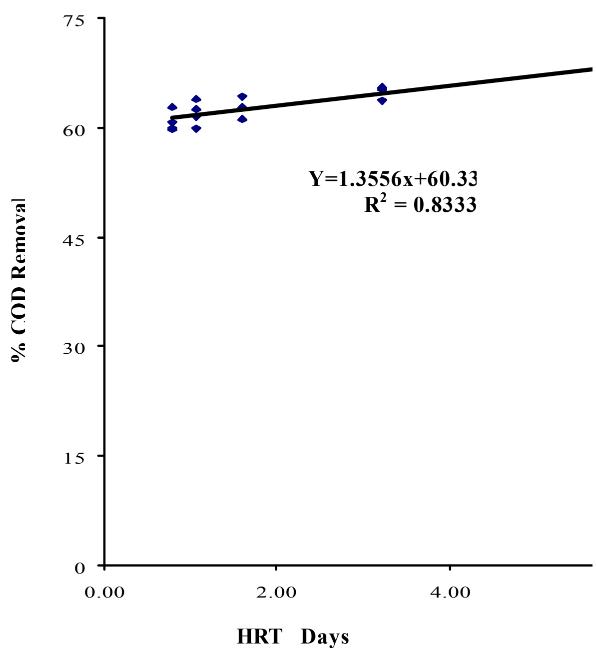

Fig. 6: % COD Removal Vs HRT [Diphasic Reactor]

Stover *et al* [10] model

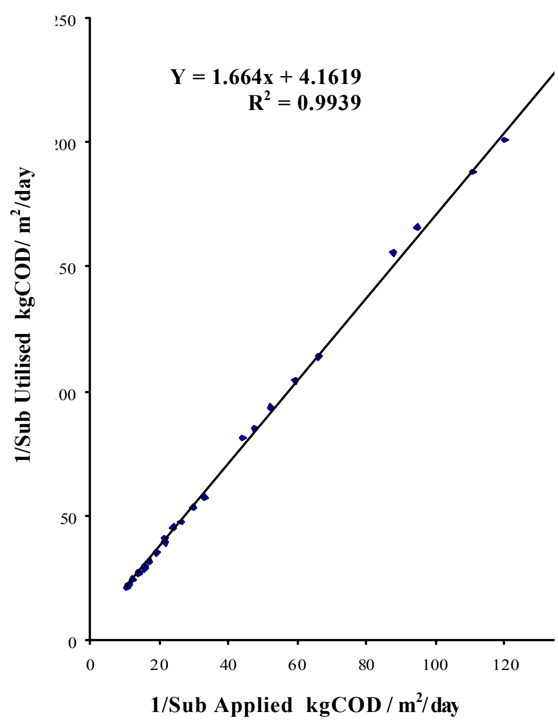

Fig. 8: 1/Sub Utilized Vs 1/Sub Applied [Methanogenic Reactor]

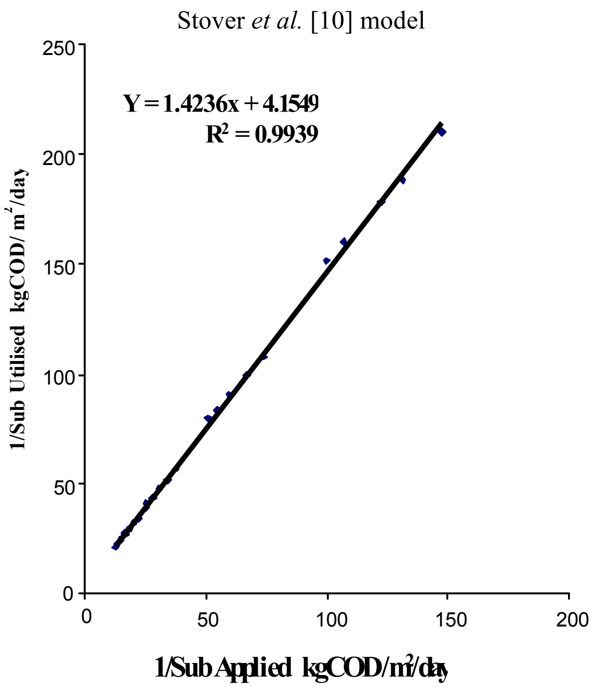

Fig. 9: 1/Sub Utilized Vs 1/Sub Applied [Diphasic Reactor]

The prediction of required HRT for 100% COD removal, as could be noted from the Fig. 4, 5 and 6 is 78.4 days for acedogenic reactor, 28.39 days for methanogenic reactor. As a whole, the FFFB diphasic digester, the required HRT for 100% COD removal is 29.26 days.

Stover *et Al* [10] Model: The COD applied is always influencing its removal pattern and efficiency, with limitations that are more specific to waste characteristics, biochemical process, biomass stabilization and treatment plant.

Stover *et al.,* [10] described a relationship of linear characteristics between the organic loading (applied) and organic loading (utilized).

The differential equations of the model could be stated as

$$\frac{1}{V}.\frac{dF}{dt} = \frac{\left(\frac{1}{V}\frac{dF}{dt}\right)_{\max}\left(Q\frac{S_i}{V}\right)}{k_B + (Q/SiV)}$$

Where

(1/V dF/dt) = Organic loading rate (utilized or removed)

Q Si/V = Mass substrate loading rate.

The experimental FFFB diphasic digester is envisaged to have a definite volume of biomass support fill (0.00452 + 0.01413) 0.01865 m^3 to offer the assured bio film area of (2.26+4.65) 6.91m^3. Hence, these organic rates, applied and removed, are assessed in terms of kg COD/m^2.day

The plots for reciprocal of substrate utilized versus reciprocal of substrate applied were drawn, for three conditions of the FFFB diphasic digester model viz., acidogenic, methanogenic and overall reactor. They are presented in Fig. 7, 8 and 9.

The plot gives a linear curve for the range of organic loading and as predicted by Stover *et al*., there by illustrating that the model can be fitted to the FFFB diphasic digester performance.

RESULTS AND DISCUSSION

- The COD reduction is a maximum of 70.40% while treating dairy effluent for a varying influent COD from 7850 to12100 mg/lit. The reduction of COD can be further enhanced with better operating conditions in a full-fledged FFFB diphasic anaerobic reactor for treating biodegradable industrial waste streams
- The maximum COD reduction in the acetogenic reactor is 25.56% for the OLR of 3.6 kg COD/ m^2/day and HLR of 0.5309 m^3/m^2.day
- The maximum COD reduction in the methanogenic reactor is 60.34% for the OLR of 1.897 kg COD/ m^2/day and HLR of 0.1910 m^3/m^2.day
- The maximum gas conversion ratio is 0.3190 m^3 of biogas per kg of COD removed.
- The Kinetics on substrate utilization was evaluated by the established mathematical models.

CONCLUSION

- Kinetic constants for substrate removal were determined using DeWalle and Chian [8] model
- McCarty model [9] has also been evaluated and modified to fit into the experimental condition
- As the Organic loading rate increases there will be a decline in the performance of the reactor system
- The maximum loading rates obtained from Stover *et al* [10] also validated

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