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Substrate Removal Kinetics for Anaerobic Hybrid Reactor (AHR) Treating Dairy Industrial Wastewater

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Abstract: Anaerobic Hybrid Reactor (AHR) is one of the most commonly used high rate reactors for treating the domestic and industrial wastewater which offers the advantages of Up flow Anaerobic Sludge Blanket Reactor (UASBR) and Up flow Anaerobic Filter Reactor (UAFR) in a single reactor. In the present study determination of kinetic constants of the AHR was aimed by conducting experimental studies on a laboratory scale Anaerobic Hybrid Reactor(AHR) using different shapes of Poly Propylene Inter Media in the AHR and the dairy industrial wastewater as substrate. The mathematical equations Grau second-order model and Stover Kincannon model were found appropriate models for the design of Anaerobic Hybrid Reactors (AHRs).

Key Words: - Anaerobic Hybrid Reactor (AHR), Kinetic Constants, Inert Media, Dairy Wastewater, Organic Loading Rate (OLR), Substrate

I. INTRODUCTION

Generally in the industrial bio reactors design like application of specific unit operations, optimization and control of wastewater treatment operations, etc often mathematical modeling is used. There are plenty of equations to assess and design the large scale industrial bio reactors. The Anaerobic Hybrid Reactor (AHR) is one of the most commonly used high rate reactors for treating the domestic and industrial wastewater which offers the advantages of Up flow Anaerobic Sludge Blanket Reactor (UASBR) and Up flow Anaerobic Filter Reactor (UAFR), in a single reactor. The Anaerobic Hybrid Reactor (AHR) which combines an anaerobic filter region (Fixed Biomass) at top and an up flow sludge bed region at bottom (Suspended Biomass) [1].The performance of the AHR could be enhanced considerably by means of designing the suitable inert media for filter region [10]. The microbial attachment on the inert media will depend on several factors among them surface roughness, porosity, surface area of the inert media and also adopting suitable depth of media packing ratio inside the AHR are worth notable.

With this background in the present study an effort has been made to treat the dairy waste water (substrate) in an AHR with suitably designed Poly Propylene (PP) inert media with different shapes as well. Also from the Anaerobic Hybrid Reactor performance results, various mathematical models including first order kinetics model, Grau Second order kinetic model and Stover-Kincannon hypothesis were applied in order to find out the bio kinetic constants for the AHR, which will be highly useful in the design of AHR and also for developing the equations to predict the effluent substrate concentration, microbial concentration at any given time from the reactor. [6].

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In this study, the mathematical equations like Guru second-order kinetic model, Stover Kincannon model, were applied to the AHR. and found that the Garu second order model and the Stover/Kincannon model gave higher correlation of 98 and 99%, respectively. Therefore, these models could be used in designing of the Anaerobic Hybrid Reactors (AHR).

II. MATERIALS

A .Model Anaerobic Hybrid Reactor (AHR)

In this study, a laboratory scale model Anaerobic Hybrid Reactor was designed. The laboratory scale glass made Anaerobic Hybrid Reactor used for the present work and its characteristics were shown in the Figure-1 and Table-1 respectively

Table1-Physical properties of the model AHR

Sl No	Physical properties of AHR	
1	Total height of the reactor	0.36 m
2	Height of sludge bed	0.04 m
3	Height of filter region	0.05 m
4	Height of liquid	0.16 m
5	Diameter	0.14 m
6	Total volume of the reactor	0.004 m^3
7	Volume of liquid	0.0025 m^3
8	Volume of filter bed	0.0007 m^3
9	Volume of sludge bed -	0.0006 m^3

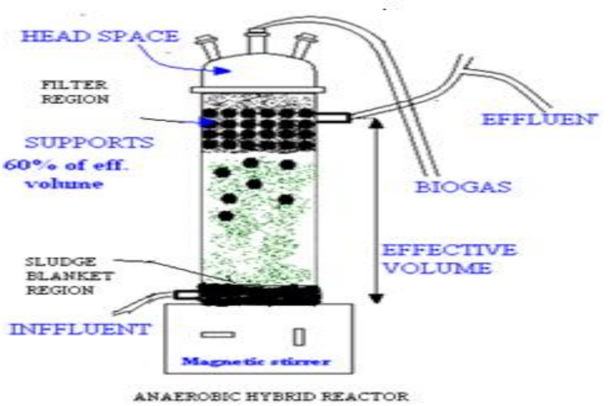

Fig.1- Anaerobic Hybrid Reactor (AHR)

B. Different Models of Inert Media

The inert media usage in the AHR will enhance the performance of reactor. Since the type of the inert media used for biomass fixation in the AHRs is an important parameter with respect to the performance of the reactor, while designing the inert media, shape, size,

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surface roughness, porosity and the specific surface area are given importance.

The different shapes of the inert media designed using poly propylene(PP) were shown in Fig-2.While conducting experimental study four laboratory scale AHRs with different shapes of inert media (PP material) namely Model-1, Model-2, Model-3, Model -4 were filled with dairy waste as substrate and were observed for the performance. Since, the PP material is inert in nature; it retains the attachment of biomass on it and considerably reduces the washout of biomass at the outlet.

Model-1 Model-2
Model-3 Model-4

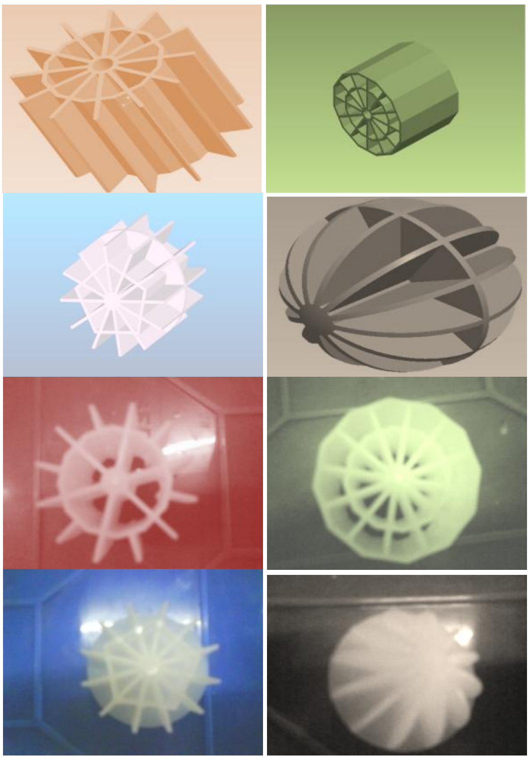

Figure 2- Different Models of Inert Media

S.No	Parameters	Model-1	Model-2	Model-3	Model-4
1	Material	PP	PP	PP	PP
2	Height (mm)	30	30	30	30
3	Diameter (mm)	30	36	36	30
4	Specific surface area (m^2/m^3)	234	388	304	366
5	Weight (g)	7.54	11.48	8.64	8.86
6	Number of medias per liter	19	17	19	43

Table - 2 Characteristics of PP Inert Media with different size and shape

C. Substrate (Dairy Industry Wastewater*)*

The dairy wastewater samples were collected and stored as per the standard procedure regularly from "Aavin" dairy industry located in Coimbatore, Tamil Nadu, India.The characteristics of the dairy industrial wastewater were analyzed in the laboratory as per the standard methods for the examination of water and wastewater (1992)[8]

and its characteristics were tabulated in Table-3. The collected wastewater from the dairy industry were prepared (4,5) in the laboratory to feed into the Anaerobic Hybrid Reactor

pH	6.4 -7.1
Alkalinity	10 mg/L
Total COD (CODt)	2.5 - 3.3g/L
Soluble COD(CODs)	1.3 - 1.6g/L
Total Solids (TS)	1.3 - 1.4g/L
Total Suspended Solids(TSS)	0.63 - 0.73g/L
Total Dissolved Solids (TDS)	0.67 g/L
Total Fixed Solids	0.60 g/L

Table 3 - Characteristics of dairy waste water

D. Inoculums and Seed Sludge

In order to enhance of the startup period and to induct the microbial culture in the Anaerobic Hybrid Reactor (AHR) 10% of the effective volume of the reactors was fed with seed sludge (VSS concentration of the sludge was approximately 45 g/L) [2]. The sludge was collected from the successfully operating distillery wastewater treatment plant from M/s Sakthi distilleries company limited, Appakoodal, Erode, TamilNadu, India.

E. Performance of the AHR- Analytical Methods

The performance of the AHRs was evaluated by monitoring routine test according to the Standard Methods for Examination of Water and Wastewater (1992) [8] at inlet and outlet of the reactors. The biomass entrapped in to each support was quantified gravimetrically by weighing the oven-dried supports at 105°C for 24 h and the specific biomass activity was determined as described by Thanikal et al[9]. The total volatile solids (TVS) content of the solids was measured using procedures outlined in Standard Methods (1992) .

III. METHODOLOGY

A. Operating strategy

Experiments were performed in four laboratory scale Upflow Anaerobic Hybrid Reactors (AHRs) with an effective volume of four liters capacity with intermittent agitation. Initially, the reactor was fed with dairy waste water at low Organic Loading Rate (OLR) of 0.5 g COD/L.d and Hydraulic Retention Time (HRT) of 5.64 days. All the reactors were operated at room temperature and the OLR was increased by increasing the feed flow rate while maintaining almost constant COD concentrations in the feed [4].The treatment efficiencies of the lab scale AHRs were evaluated for different Hydraulic Retention Time and the Organic Loading Rates for 165 days of operation with dairy waste water as substrate.

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The experimental protocol was designed to examine the effect of organic loading rate and the COD removal efficiency of 80% which was considered as a threshold level in the present study for the operation of reactors.

Efforts were made to maintain constant influent COD concentration (S_o) while the OLR was gradually increased by the decreasing the Hydraulic retention time [(5)]

B .Performance evaluation of anaerobic hybrid reactor with respect to COD_s RemovalOrganic Loading Rate (OLR) and Hydraulic Retention Time (HRT)

The performance of four lab-scales up flow anaerobic hybrid reactors of about 4 liters capacity packed with low-density polypropylene (PP inert media) with different shape and specific surface area were investigated for the treatment of dairy waste water as substrate. The Reactor 1 was filled with Model-1, Reactor 2 was filled with Model-2, Reactor 3was filled with Model-3, and Reactor 4 was filled with Model-4. In all the reactors were operated at room temperature with the operating condition of intermittent agitation at the rate of 100rpm for 15 minutes in every four hour cycle with 60% of the reactor volume of inert media inside the reactor.

All the four reactors were started with low Organic Loading Rate (OLR) of 0.5 g COD/L.d. with HRT of 5.64 days along with four different shapes of inert media. The COD_s reduction with respect to OLR and time for all the four reactors were given in the Figure 3.4,5.6 respectively. From the graph it was found that all the reactors took an appreciable time of 12 to 15 days for acclimatization with the fed dairy waste water during this period, the COD_s removal efficiencies were less than the threshold of 80% and the biomass washout at the reactor outlet were more. Once, the reactors got acclimatized, the COD_s removal efficiency was more than the threshold of 80% and the biomass washout was almost negligible at the outlet of the reactors. Though all the reactors were operated for 165 days, the maximum OLR with COD_s 80% removal were achieved in between the 140 to 145 of operation hence, the OLR with a threshold of COD_s removal was taken as the maximum OLR that could be treated by the AHRs with the respective inert media. At the end of 165 days of operation, the AHR_{31} attained the maximum OLR of 6.36 gCOD/L.d with HRT 0.38 days, the AHR_{32} attained the maximum OLR of 6.06 gCOD/L.d with HRT of 0.40 days, the AHR_{33} attained the OLR of 6.50gCOD/L.d with HRT of 0.37 days and the AHR_{34} attained the maximum OLR in 6.36 with HRT of 0.38 days for the CODs removal efficiency of 80%.

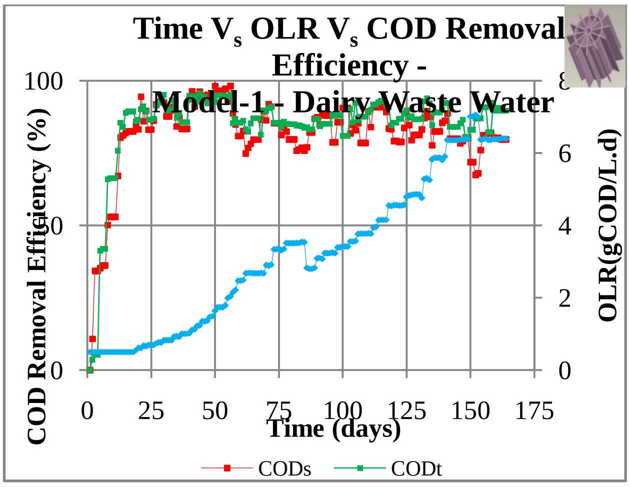

Figure 3 - Model-1 -Time V_s OLR V_s COD removal efficiency

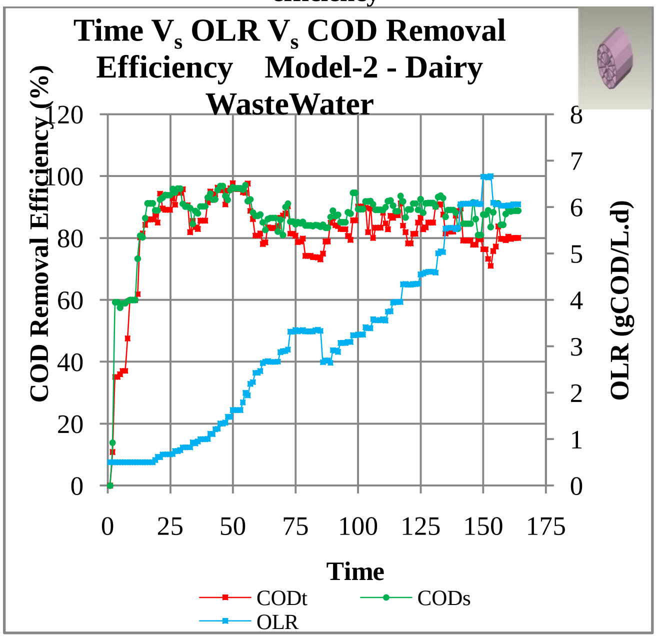

Figure 4- Model – 2 Time V_s OLR V_s COD removal efficiency

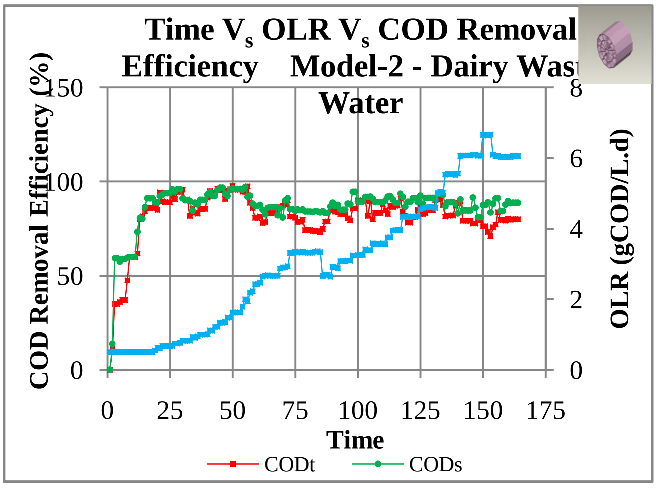

Figure 5- Model – 3 Time V_s OLR V_s COD removal efficiency

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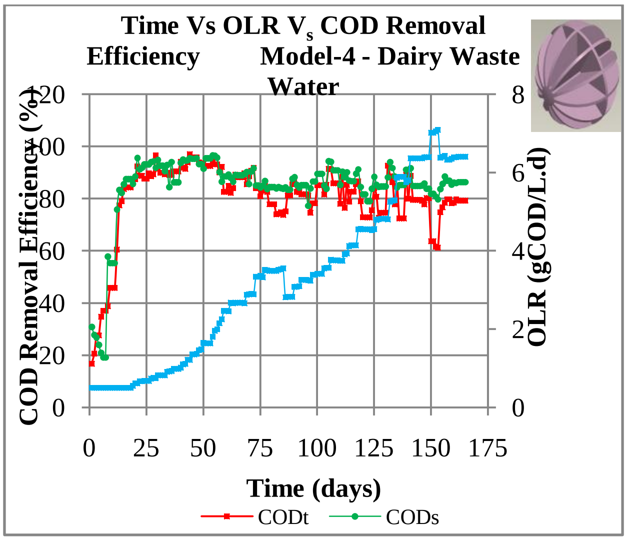

Figure 6 Model- 4 Time V$_s$ OLR V$_s$ COD removal efficiency

C. Role of inert media on reactor performance

The use of PP inert media with different shapes was highly helpful in retaining the biomass inside the reactor. From the graph of OLR V$_s$ COD removal graph (Figure 4.40, 4.41, 4.42, 4.43) it was evident that the PP inert media (Modle-1, Model-2, Model-3, Model-4) was filtering the biomass washout from the reactors and hence improved the Solids Retention Time (SRT) in the reactors[3]. The increased solid retention time will obviously increases the Organic Loading Rate (OLR) and reduces the Hydraulic Retention Time. Though all the four models of PP inert media were helped in the performance of the AHRs for the threshold 80% COD$_s$ removal efficiency, the AHR filled with Model-2 performed significantly when compared to AHRs filled with Model-1, Model-3, and Model-4 respectively. The AHR$_{32}$ with Model-2 obtained the maximum OLR of 6.05 gCOD/L.d with HRT 0.45 days when dairy waste water was used as substrate. Similarly, from the Table 4.32 (the data given in the Table 4.32 is only partial)the biomass quantification and biomass activity for the AHR$_{32}$ packed with Model-2 inert media were also high and hence the Model-2 inert media made up of PP material was chosen as the best media. In the phase IV the role of PP-Model-2 inert media will be studied for the performance of AHRs with different industrial waste waters.

D. Quantification of Biomass of the Reactors and their Specific Biomass Activity

The performance of the four lab-scales AHRs of 4 liter capacity packed with inert media made up of four different shapes of polypropylene material had been completed for treatment of dairy waste water. At the end of the experiment all the four reactors reached the maximum OLR 6.36,6.06,6.5 and 6.36 gCOD/L.d with the HRT of 0.38,0.4,0.37 and 0.38 days respectively. Similarly the biomass activity for all the four reactors were found to be 1.5, 0.82, 0.9, 1.11 gCOD/gVSS.d respectively.

IV. APPLICATION OF MATHEMATICAL MODELS TO THE ANAEROBIC HYBRID REACTOR

A.Grau second order model to predict effluent substrate concentration

The base equation used for the determination of effluent substrate concentration by the Grau second model is given below [7]

$$S_e = S_o\left(1 - \frac{\theta}{a+b\theta}\right) \qquad 4.1$$

The Grau Second order substrate removal model was applied to all the four AHRs. From the experimental results a graph was drawn on HRT Vs HRT/E to find the substrate removal efficiency of the reactors. The respective graph for all the four reactors were given in the Figure 5, 6.7.and 8. Similarly, for all the four reactors the predicted equation for substrate removal concentration and the bio kinetic coefficient were given in the Table 4.

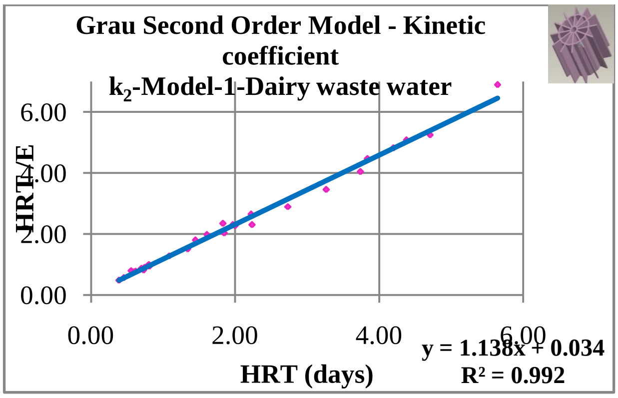

Figure 5-Model -1 –Grau second order Model

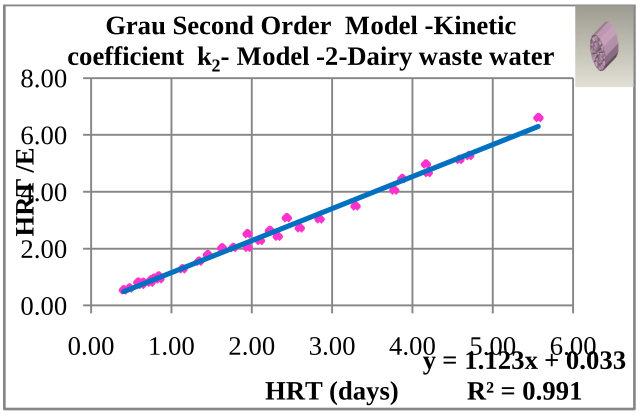

Figure 5 Model -2 – Grau second order Model

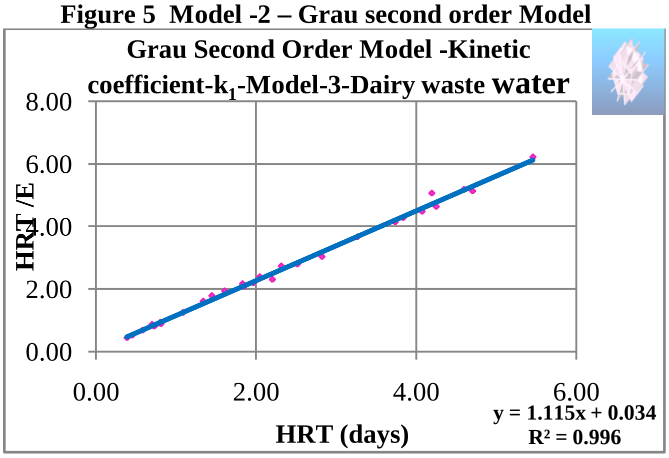

Figure 6 Model -3 – Grau second order Model

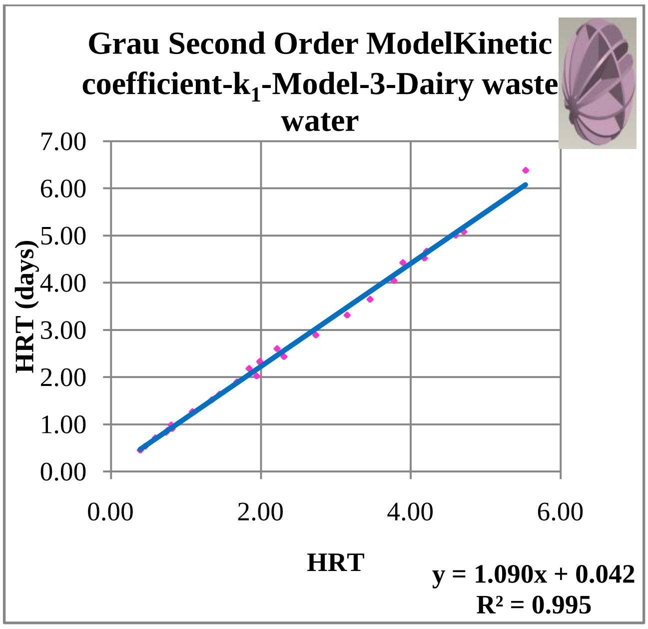

Figure 7 - Model-4 – Grau second order Model

Table-4 Kinetic coefficients and Substrate removal equation-Grau Second Order Model for Phase - III

Inert Media Using PP material	k_2 (per day)	Constants		Grau – Substrate removal equation
		a	b	
AHR_{31} – Model-1	13.38	0.034	1.138	$S_e = S_o\{1 - \theta/(a + b\theta)\}$
AHR_{32} – Model-2	7.67	0.033	7.67	
AHR_{33} – Model-3	8.15	0.034	1.115	
AHR_{34} – Model-4	8.03	0.042	1.090	

B. Modified Stover Kincannon model to predict effluent substrate concentration

The base equation used for the determination of effluent substrate concentration by the Stover Kincannon model is given below [9]

$$S_e = S_o - \frac{U_{max}\,S_o}{K_B + \left(\frac{QS_o}{V}\right)} \quad (4.2)$$

The modified Stover Kincannon model was applied to the all the four Anaerobic hybrid reactors (AHRs) and biokinetic constants were determined. The respective graph for the application of the Stover Kincannon model are and in the Figures 8,0,18,11respectively .The kinetic coefficients K_B , U_{max} for all the reactors calculated and tabulated in the Table 5

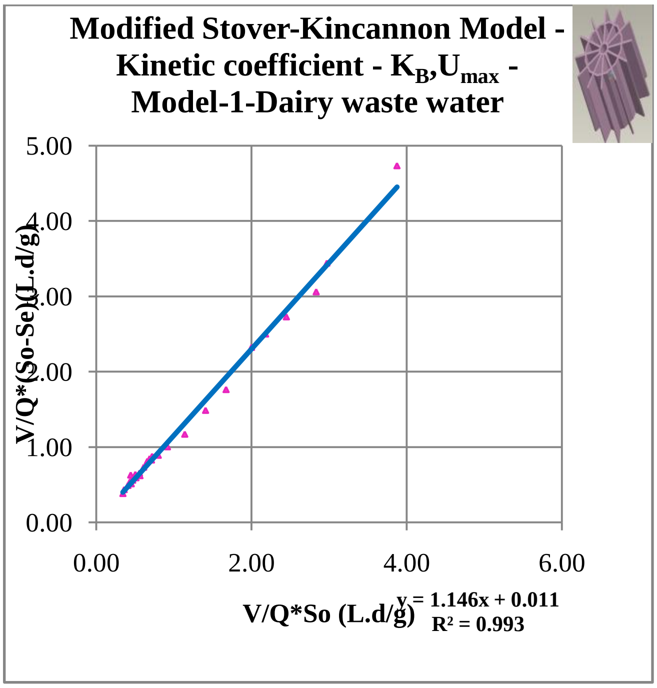

Figure 8-Model-1-Modified Stover Kincannon

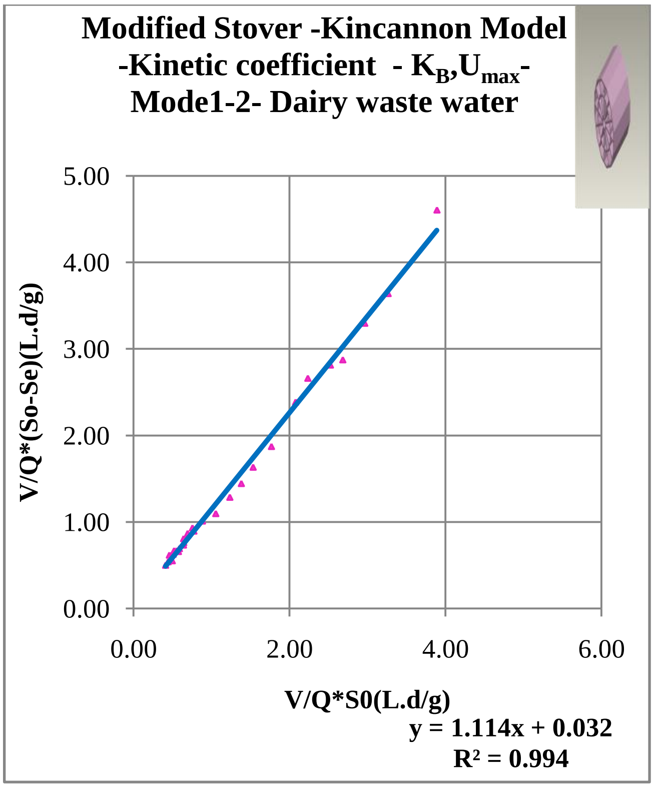

Figure 9 -Model-2-Modified Stover Kincannon

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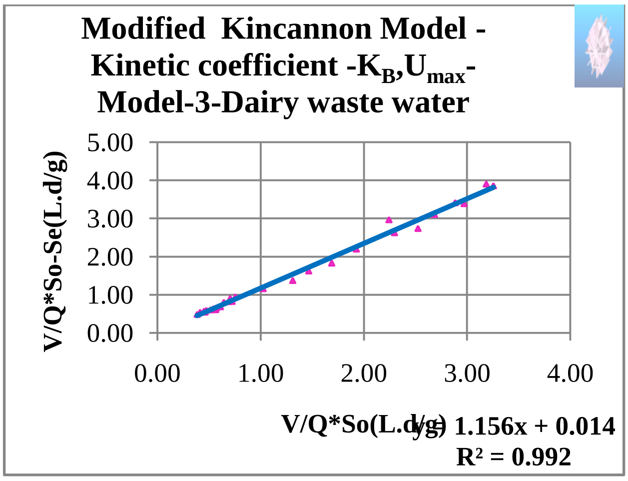

Figure 10 - Model-3-Modified Stover Kincannon Model- K_B, U_{max}

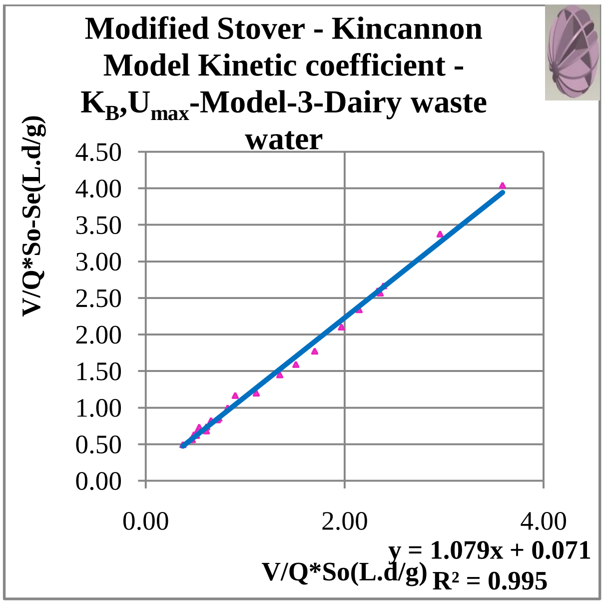

Figure 11-Model-4 – Modified Stover Kincannon Model

Table 5 Kinetic coefficients and Substrate removal equation-Modified Stover Kincannon Model – Phase - III

Inert Media Using PP material	Constants		Stover Kincannon substrate removal equation
	U_{max} (g/L.d)	K_B (g/L.d)	
AHR_{31} – Model-1	90.91	104.18	$S_e = S_o - \frac{U_{max} S_o}{K_B + \left(\frac{QS_o}{V}\right)}$
AHR_{32} – Model-2	31.25	34.81	
AHR_{33} – Model-3	71.43	82.57	
AHR_{34} – Model-4	14.08	15.19	

V. CONCLUSION

Treatment performance of the lab scale AHR was evaluated at different OLRs and HRTs using dairy waste water and the kinetic analysis of the reactor were carried out according to the experimental results. From the experimental study it was evident that the Anaerobic Hybrid Reactor could be effectively used for the treatment of dairy waste water treatment without clogging and short circuiting. All the four different shape inert media could effectively retain the biomass inside the AHR, thereby increasing the SRT and lowering biomass washout.AHR_{32}, with Model-2 as the inert media, recorded a daily OLR of 6.06 g COD/L with HRT of 0.4 days. The corresponding values for AHR_1, which was filled with Model-1, were 6.36 g COD/L and 0.38 days, for AHR_3, filled with Model -3, were 6.5 gCOD/L and 0.37 days and for AHR_4 filled with Model -4 were 6.36 gCOD/L and 0.38 days.Model-2 Polypropylene inert media turned out to be the most efficient inert medium with respect to achieve the threshold of 80% stipulated for lowering the COD.AHR_2 recorded the lowest daily biomass activity (0.82 g COD / g VSS), which was 1.5 g COD / g VSS for AHR_{31} , 1.1 g COD / g VSS for AHR_{33} and 0.9 g COD / g VSS for AHR_4.Comparing the Model-2 inert media with other models, it has got greater specific surface area and hence, improved biomass activity was found in the AHR_{32}. Therefore for the maximum OLR that could be treated, the biomass activity of the reactor and physical characteristics of the inert media, Model-2 was the best inert medium..The up flow anaerobic filter region of the AHR was highly helpful to minimize the escape of biomass from the system which increases the solids retention time inside the reactor and hence improves the overall efficiency of the Anaerobic Hybrid Reactor as well. In order to arrive the biogenetic modeling of the AHR, the Grau second order kinetic model and Stover-Kincannon model were used. From the above said model analysis both the models gave higher correlation of 0.994. Hence, these two models could be used in the design anaerobic hybrid reactors. Hence the results of kinetic studies obtained from the lab scale AHR could be used for estimating the treatment efficiency of the anaerobic hybrid full scale reactors as well with the similar operating conditions in the field.

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