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Mathematical Modelling For Rotating Biological Contactor for Treatment of Grey wastewater

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Abstract

The laboratory model of the two-stage Rotating Biological Contactor (RBC) used in the present study is a modified one, with a provision to vary the speed of rotating blades. Grey wastewater was used to study the performance of the modified rotating biological contactor. The reactor had four rotating blades in each stage, having 300 mm x100 mm x 10 mm, attached perpendicular to the shaft. The experiment was conducted for different influent COD loads and different speeds of rotating blades. Mathematical Models, Kornegay models, and Hudson models were used to evaluate the kinetic coefficients to describe RBC kinetics for treating greywater.

Keywords: *RBC; rotating blades; Greywater; COD; OLR.*

I. INTRODUCTION

Water usage in an Indian residential building is 4% for drinking, 4% for cooking, 41% for bathing, 22% for toilet flushing, and 15% for laundry, 14% for cleaning, sprinkling, and another miscellaneous purpose. Wastewater segregation and treatment for reuse has become the best wastewater management option. Increasing the greywater reuse by lowering freshwater use for irrigation is an important step towards a better environment and resource management.

Greywater is a part of used household water that has not come into contact with toilet waste. Greywater produced can vary across each household according to the number of household occupants, ages, lifestyles, and health and water use patterns. It contains waste that a household would normally wash down in drains. This content can vary between households across different days and is dependent on daily household activities. Generally, greywater contains soap, shampoo, toothpaste, cooking oils, laundry detergents, hair and cleaning products. Characteristics of grey wastewater (1).

A physical model of rotating biological contactor (RBC) was used to study its performance for achieving desirable characteristics for reusing the treated greywater in agriculture and landscape developments.

II. EXPERIMENTAL SET-UP

The experimental model has been designed based on empirical, as a laboratory-scale RBC for an effective volume of 30 liters (In three compartments: two stages of rotating contactors and a settling tank in the third compartment). A specialty Nylon wire mesh spread on both sides of all the blades to impart enhanced biofilm area. The blade rotations are arranged in the opposite direction to the liquor flow, tangentially. The shafts of each stage are connected suitably to a gear motor assembly. The speed of rotating blades is 3, 4.5, and 6rpm. The schematic diagram of the experimental set-up of the modified Rotating biological contactor is presented in **Figure.1**. The greywater analysis is presented in **Table.1.**

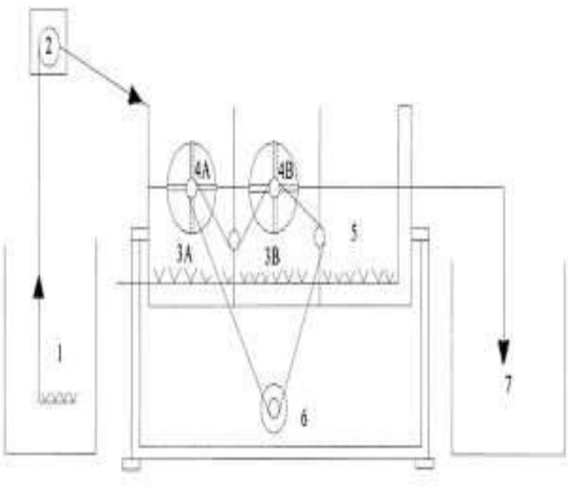

Figure-1. Schematic Diagram of Experimental Setup (RBC-105 L Capacity)

1. Grey water Mixing - Supply Tank
2. Peristaltic Pump; Miclins / 15pp
3A,3B - Stages of RBC
4A,4B - Rotating Contactors
5.Clarifier
6.Geared Motor- pulley assembly;1HP
7.Treated Grey water

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Table: 1 Greywater analysis

Parameter	Unit	Domestic grey wastewater
pH	-	6.5-8.5
Suspended solids	mg/l	90-400
BOD_5	mg/l	150-400
COD	mg/l	260-900
TDS	mg/l	200-1000
Oil & Grease	mg/l	10-20
Total phosphorus	mg/l	5-30
Total Nitrogen	mg/l	40-50

III. METHODOLOGY

A two-stage RBC followed by a settling tank was envisaged as the modified RBC in the present study. Real-time greywater samples were daily collected from a residential building complex for experimenting. The raw greywater was pumped at a pre-determined rate to the model by a peristaltic pump. The model was run for five different average influent substrate concentrations measured as COD (248,294,347,395 and 448 mg/l). Each stream was fed into the model for five different hydraulic flow rates (13.2, 10.5, 7.01, 5.3, and 4.4 l/h). Each combination of these two was conducted on three different rotating blades' speeds (3, 4.5, and 6 rpm). In total, the experiment was conducted for 75 combinations of these three operating variables, according to the Standard Methods (APHA, AWWA, WEF 1998) (5). An increase in the rotational speed shows you decreased in removal percentage of COD.

IV. MATHEMATICAL MODELING

Mathematical modeling is an important preliminary step for implementing the wastewater treatment processes guiding systems.

A. KORNEGAY MODEL

The first model ever formulated on full-fledged RBC was made by Kornegay and Andrews (1975).

The Kornegay kinetic model is essential to a steady-state model, assuming complete mixing in the reactor.

$$\frac{Q}{S_o - S_e} = \frac{PAS_e}{(K_s + S_e)} + \frac{((\mu_{\max})_s / Y_s) X_s V S_e}{(K_s + S_e)}$$

(Attached growth) (Suspended growth)

Where

Q = Hydraulic flow rate, 1/day

S_o = Influent substrate concentration, mg.COD/l

S_e = Effluent substrate concentration, mg.COD/l

P = Area capacity constant, g.COD/m^2/day

A = Total surface area of rotating discs, m^2

K_s = Saturation constant, mg.COD/l

μ_{max} = Maximum specific growth rate, day

X_s = Active biomass per unit volume of attached growth, mg/l

Y_s = Yield coefficient for suspended growth

In this equation, the first component on the LHS is contributed by treatment due to the attached growth of microorganisms in the discs. The second component on the RHS is contributed by treatment due to the suspended growth of microorganisms in the reactor's mixed liquor. The model is deduced to the following state for solving it mathematically for establishing P area capacity constant and K_s, saturation constant of the modified RBC of the present study. The above equation may then be written as:

$$S_e\left[1 - \frac{(\mu_{\max} / Y_s) X_s V_s}{Q(S_0 - S_e)}\right] = P\frac{AS_e}{Q(S_o - S_e)} - K_s$$

So, the area capacity constant P as the slope of the line and saturation constant K_s as Y-intercept can be calculated by plotting graph for

$$S_e\left[1 - \frac{(\mu_{\max} / Y_s) X_s V_s}{Q(S_0 - S_e)}\right] \text{ versus } S_e\frac{AS_e}{Q(S_o - S_e)}$$

in Y and X axis respectively.

The plot between X and Y is drawn as the best fit line using statistical tools, and the estimation of biokinetic constants P and K_s is shown in **Fig 2.**

The modified RBC plant's experimental results in treating grey water are used to evaluate the biokinetic constants like P and K_s. As the experiments were conducted based on COD, biokinetic constants, P and K_s, are evaluated only based on the COD of the greywater samples, independently.

Statistical package, namely SPSS, was used to draw the best fit line and calculate correlation coefficients shown in **Fig. 2.**

From **Fig.2**. The slope of the line and y-intercept is calculated. The existing correlation value was found to describe the suitability of the model in representing the modified RBC.

The area capacity constant P is 26 mg. COD m^2/l/ day and saturation constant K_s is 36 mg. COD/l for greywater. The correlation coefficient of 0.9807 indicates the Kornegay model's suitability in representing the present model on modified RBC.

B. HUDSON MODEL

Hudson et al. (1976) have developed a mathematical model for RBC. This model is based on the assumption of the plug flow regime and Monod's kinetic growth function of microorganisms.

The model can be stated as follows

$$Q/(S_0 - S_e) = K_s/\mu_v . \frac{In\left(S_0 / S_e\right)}{\left(S_0 - S_e\right)} + \frac{1}{\mu_v}$$

Where

Q = Hydraulic flow rate, 1/day

S_0 = Influent substrate concentration, mg.COD/l

S_e = Effluent substrate concentration, mg.COD/l

K_s = Saturation constant, mg.COD/l

μ_v = Specific growth rate, mg.COD/hr

The values of biokinetic coefficients, Ks and μ_v, were estimated by plotting a graph of $Q/(S_0 - S_e)$ versus $\frac{In\left(S_0 / S_e\right)}{\left(S_0 - S_e\right)}$. The intercept gives $1/\mu_v$, and the slope of the graph gives K_s/μ_v. The values of K_s and μ_v can be estimated from the slope and intercept values.

The experimental data were used to plot the best fit line based on the Hudson model. The best fit line is shown in **Fig. 3.**

The μ_v and K_s values were calculated from the intercept and slope of the best fit line. The μ_v and K_s values are drawn based on COD, as the study model's treatment process is studied based on COD removal.

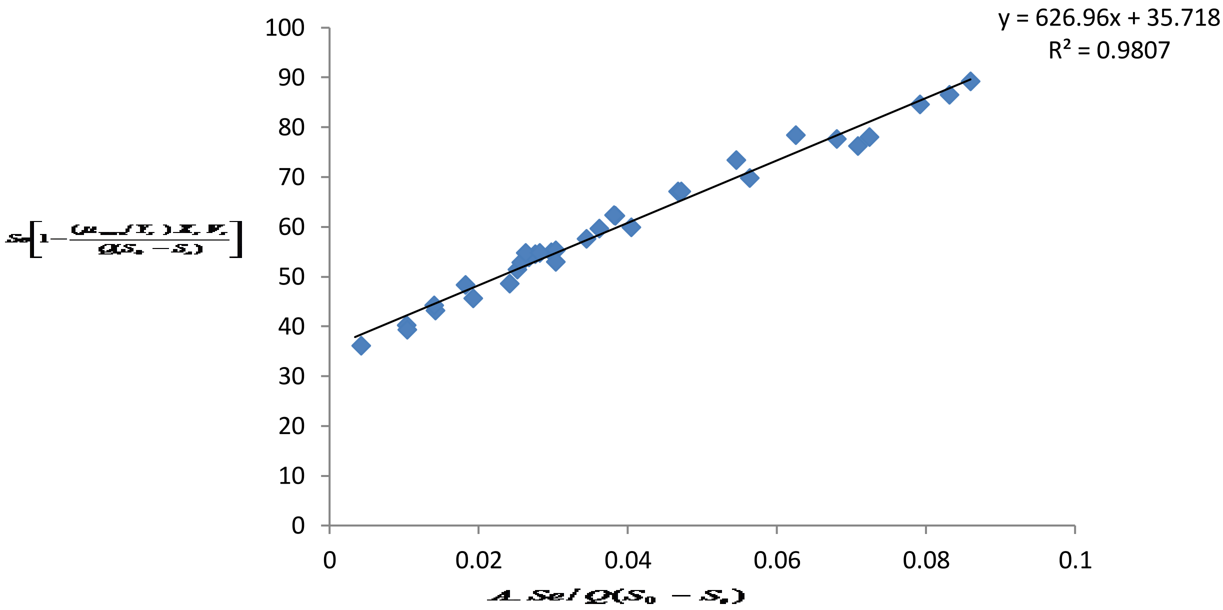
The values of μ_v and K_s for treating greywater effluent are 32 mg. COD / lit/ day and 56 mg COD /lit respectively. The correlation coefficient of 0.887 indicates that the Hudson model represents the kinetics of the modified RBC's substrate utilization for treating greywater effluent.

V. RESULTS AND DISCUSSION

After the RBC reactor was stabilized, synthetic wastewater was prepared and used for experimental study. An experiment was conducted to evaluate the RBC system in terms of COD removal. The reactor ran continuously for 45 days. Influent COD prepared were 248, 294, 347,395 and 448 mg/l. Initially, COD removal efficiency was poor; after some reactor period, steady state condition and removal efficiency were improved to 82.68%. The COD removal efficiency for varying OLR from 0.054 to 0.163 kg COD/m^2/day. The maximum COD removal was observed for 95.07% against an OLR of 0.234 kg.COD/m2.day, for the rotational speed of 3 rpm.

Fig. 2. KORNEGAY MODEL -Bio Kinetic Coefficients

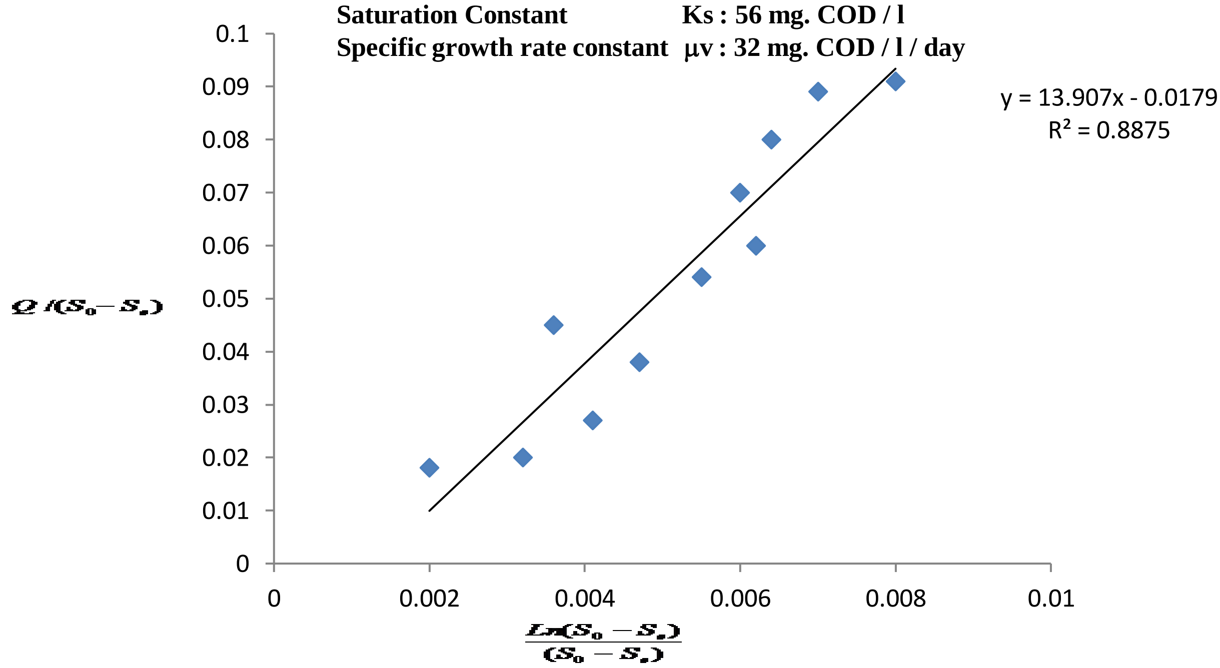
Saturation Constant Ks : 36 mg. COD / l
Area capacity constant P : 26 mg. COD / lit/ day



Correlation : 0.9807 at 0.01 level

Fig. 3. HUDSON MODEL - Bio Kinetic Coefficients

Saturation Constant Ks : 56 mg. COD / l
Specific growth rate constant µv : 32 mg. COD / l / day



Correlation : 0.887 at 0.01 level

VI. CONCLUSION

The optimum rotational speed of the blades is understood to be the lowest possible. Though 3 rpm of the blade rotational speed was optimum from the experiment results, it could still be lower in full-fledged, field-level RBC plants to better remove COD from the waste streams. The correlation coefficient r^2 was chosen as the criterion for choosing the most suitable model to represent organic matter removal kinetics. Considering this criterion, the Kornegay was more suitable than the Hudson model.

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