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Biokinetics of Removal of BOD and COD from Domestic Sewage Using Fluidized Bed Bio-Reactor

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ABSTRACT - *The most harmful component of the wastewater i.e., the organic content can generally be removed in biological methods of wastewater treatment. Out of many Bio reactors that are in use to treat the wastewater, Fluidized Bed Bio Reactors (FBBR) are nowadays widely used keeping their advantages relative to the other types. An attempt has been made in the present work, to study the removal of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) from municipal wastewater using a laboratory scale model of fluidized bed bioreactor. An experimental setup is fabricated with three Acrylic glass columns of uniform dia. 6.9 cm and length 120cm. The MBBR media (plastic), Pumice stones, and Foam Pieces of uniform shape and size are considered as three different bed materials. An arrangement for sending compressed air is provided at the bottom of the columns. Municipal wastewater is taken as stock solution for conducting the study. The experiment is conducted for over 2 to 3 weeks at daily intervals, till the reactor gets stabilized and a maximum and uniform rate of percent removal of BOD and COD is obtained. The experimental data is analyzed and the results are presented in suitable formats. The Bio-kinetic study involving reaction rate kinetics and microbial growth kinetics are conducted for the zero order, first order, and second order rate of reactions. From the experimental results it is observed that the bio-kinetic reactions taking place in the reactor confirm to First order rate of reactions. Also, it is observed that Foam Pieces is proved to be a good alternative material when compared with that of the commercially available MBBR media which is made up of plastic.*

Keywords – *BOD,COD,FBBR,Growth Kinetics, Reaction kinetics*

I. INTRODUCTION

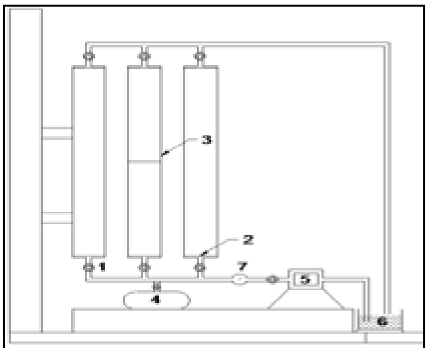
Municipal wastewater treatment plant is a facility designed to receive the waste from domestic and commercial sources and to remove materials that damage water quality and affect public health and safety when discharged into water receiving systems. Conventional wastewater treatment processes consists of a combination of physical, chemical, and biological processes and operations to remove solids, organic matter, and other harmful material from wastewater. Wastewater treatment involving physical, chemical and biological unit processes is carried out in vessels or tanks commonly known as reactors. Reactors that work by growing cells are known as Bio-Reactors. The fluidized bed bioreactor is similar to the packed bed reactor in many respects, but the packing material is expanded by the upward movement of fluid through the bed. The expanded porosity of the fluidized bed packing material can be varied by controlling the flow rate of the fluid. The fluidized media provides an extremely large surface area on which a film of microorganisms can grow and produce a large inventory of biomass in a small rector volume. The result of this biological growth is a system capable of high degradative performance for target contaminants in a relatively small and economical reactor volume.

In the past, designs of biological wastewater treatment processes were based on the empirical parameters developed by experience, which included hydraulic loading, organic loading and retention time. Nowadays, the design utilizes empirical as well as rational parameters based on biological kinetic equations. These equations describe growth of biological solids, substrate utilization rates, food-to-microorganisms ratio, and the mean cell residence time. Reactor volume, substrate utilization, biomass growth, and the effluent quality can be calculated from these equations [9] . Biokinetic coefficients used in the design of Bio-reactors include specific growth rate (μ), maximum rate of substrate utilization per unit mass of microorganisms (k), half velocity constant (k_s), maximum cell yield (Y), and endogenous decay coefficient (k_d) [10]

II. EXPERIMENTAL SETUP

A laboratory scale FBBR is constructed for experimental purpose consisting of three Acrylic glass columns of 120cm height and 6.9cm dia each arranged parallel to each other with valves at top and bottom of the columns to regulate the flow through them, as shown in Fig1. A flow meter is arranged on inlet pipe to measure rate of flow, flexible pipes of 1 inch dia. are used as inlet and outlet pipes, and wire mesh is provided to separate the inlet and outlet zones. An arrangement for sending compressed air is provided at the bottom of the columns.

About 15 litres of sample from the domestic municipal wastewater treatment plant located in port area, Visakhapatnam is collected each day and diluted to 1:4 concentrations and is used as stock solution for experimentation. A 5 litre capacity plastic jar with open top is used for biomass acclimatization. A concentrated solution is prepared by crushing tomatoes in the jar and mixing with small amount of water and the wet and dry sludge collected from domestic sewage plant. The ingredients are mixed thoroughly everyday for aerobic growth of microorganisms. The process is continued for a week and the slurry obtained at the end in the jar is introduced in to the experimental columns which act as seed for biomass acclimatization on bed particles in the columns.



1. Valve 2.STainless Steel Mesh
3. Acrylic Glass Column 120 cm long
4. Air Compressor 5. 0.5 HP Motor
6. Stock Solution 7. Flow meter

Fig.1 Experimental Setup

III. METHODOLOGY

The acclimatized biomass is transferred to the experimental columns and the columns are filled with water for three days before the start of experiment, and then the experiment is started by pumping the effluent taken from the municipal wastewater treatment plant. The BOD and COD values of the effluent before pumping are determined. The samples from outlet of the experimental columns are collected at intervals of 30min, 60min, 90 min and the respective BOD & COD values are determined. Simultaneously, the rate of flow is measured. The same experiment is carried out with different bed materials. The process is continued till the constant percentage removals of BOD and COD are obtained.

IV. ANALYSIS OF SAMPLES

The influent and effluent samples are analyzed for BOD & COD values using standard methods. i.e., by D.O test and standard reflux method respectively.

V. REACTION RATE CONSTANTS

Reaction rate coefficients are determined using the experimental results obtained, in the method of integration. The method of integration involves the substitution of the measured data on the amount of reactant remaining at various times into the integrated form of the rate expression. Plots of the integrated forms of the reaction rate expressions used to determine the reaction rate coefficients are as follows

Zero Order Reaction:

$$r_c = dc/dt = k$$

Integrated form is

$C_{eff} = {}_{Ci}-(k*t)$ --------- (Eq.1)

K is determined by plotting graphically (C_i-C_{eff}) versus t

First Order Reaction:

$$r_c = dc/dt = k_c$$

Integrated form is

$C_{eff} = C_i*e^{(-k*t)}$ --------- (Eq.2)

K is determined by plotting graphically $-\ln(C_i/C_{eff})$ versus t

Second Order Reaction:

$$r_c = dc/dt = k_c^2$$

Integrated form is

$$C_{eff}=(C_i/(1-k*Ci*t)) \qquad \text{--------- (Eq.3)}$$

K is determined by plotting graphically $(C_i-C_{eff})/(C_i*C_{eff})$ versus t
where

C_i = influent concentration (mg/L)
C_{eff} = effluent concentration (mg/L)
t = Duration (days)

VI. MICROBIAL GROWTH CONSTANTS

The specific substrate utilization rate, (dF/dt)/X represents the "food -to-micro-organisms ratio", substrate utilization rate (U), or, the "process loading factor", when considered on a finite mass and time basis.

$$U =(\Delta F/\Delta t)/X_m \qquad \text{--------- (Eq.4)}$$

in which $\Delta F/ \Delta t$ = amount of food utilized "per unit time of Δ t",
Xm = mass of the active micro-organisms in the reactor. Using above Eqs., reduces to the following form:

$$1/ \theta_c = Y.U - k_d \qquad \text{--------- (Eq.5)}$$

And the specific growth rate 'μ' is obtained by the equation

$$\mu = (\Delta X/\Delta t)/X_m \qquad \text{--------- (Eq.6)}$$

The above Equation is the basic or the controlling equation in any biological reactor of this type.
Finally, the following equation can be used to find the micro organism decay coefficient

$$C_{eff} = C_i - X(1+k_d\, \theta_c) /Y \qquad \text{--------- (Eq.7)}$$

Where

C_{eff} = concentration of the effluent, mg/l
C_i = concentration of the influent, mg/l
X = microbial mass concentration
k_d = micro organism decay coefficient
θ_c = mean cell residence time.

VII. RESULTS AND DISCUSSIONS

Experiments are conducted using the methodology explained above with commercially available MBBR media (plastic), Pumice stones, and Foam Pieces as bed materials, and the sewage samples collected from municipal wastewater treatment plant Port area, Visakhapatnam. The percentage removals of BOD and COD in the sewage sample at different operation times using MBBR Media (Plastic),Pumice Stones and Foam Pieces as bed materials are shown vide Fig 2 to 7. The Maximum Percent Removals of BOD and COD using different bed materials are presented in following Table 1.

Table 1 The maximum percentage removals of BOD and COD at different operation times and for different bed materials

S.No	Bed material	Acclimatization/Experimental duration (days)	Operation time(minutes)	Maximum percentage removal	
				BOD	COD
1	MBBR media(Plastic)	15	30	75.74	57.12
		15	60	77.16	61.35
		15	90	81.42	67.02
2	Pumice stones	14	30	75.56	59.23
		14	60	78.13	67.25
		14	90	83.11	75.16
3	Foam Pieces	12	30	80.10	69.08
		12	60	83.08	72.31
		12	90	85.03	78.51

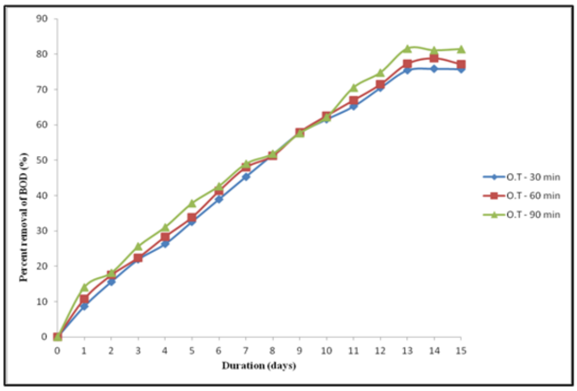


Fig:2 Percentage removal of BOD using MBBR Media(Plastic)

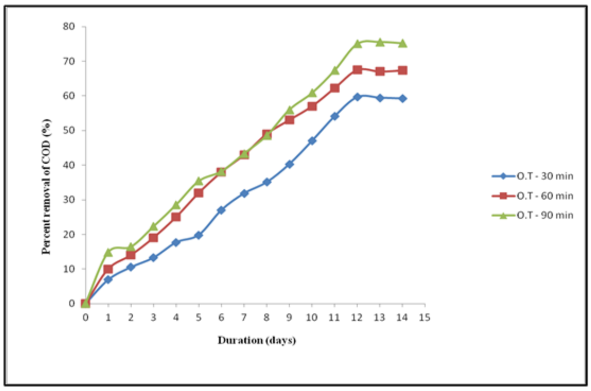


Fig:5 Percentage removal of COD using MBBR Media(Plastic)

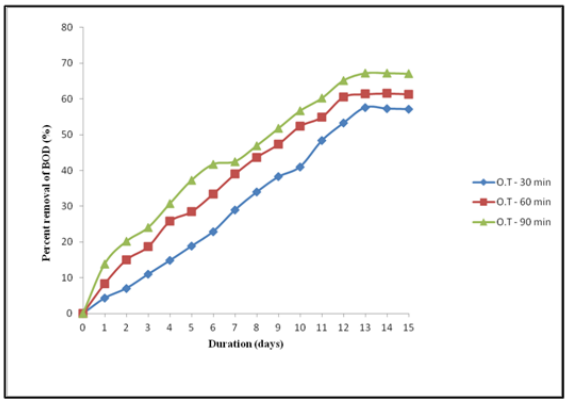


Fig:3 Percentage removal of BOD using Pumice Stones

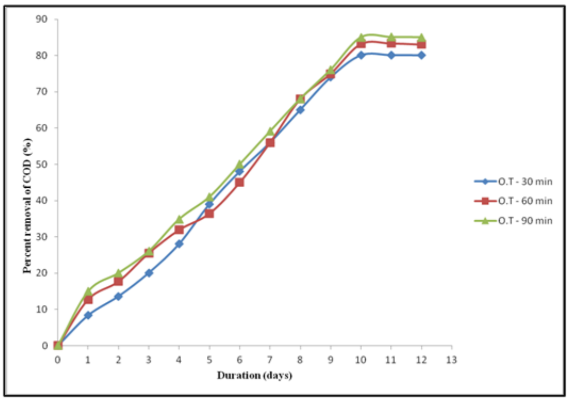


Fig:6 Percentage removal of COD using Pumice Stones

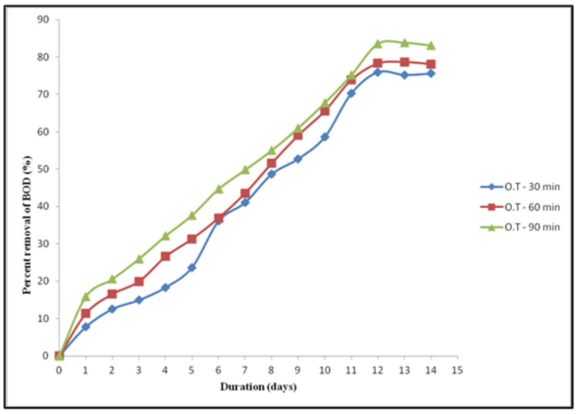


Fig:4 Percentage removal of BOD using Foam Pieces

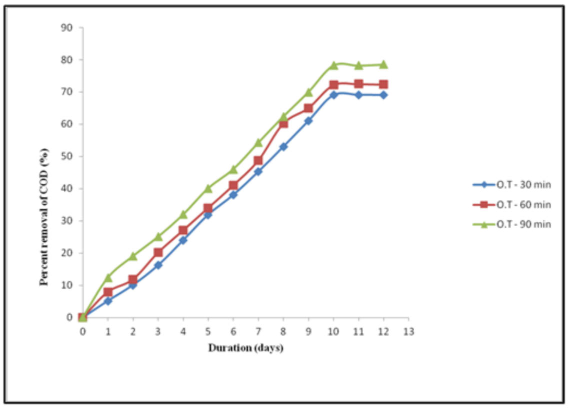


Fig:7 Percentage removal of COD using Foam Pieces

Maximum percentage removals are obtained when Foam Pieces are used as bed material. Also, the experimental duration/acclimatization period of the reactor is found to be less, with Foam Pieces as bed material. From Table 1, it is observed that the maximum percentage removal for BOD is found to be 85.03%, 83.11%, 81.42% for the bed materials Foam Pieces, Pumice stones, and commercially available MBBR media respectively, at an operation time of 90 minutes. Similarly, the maximum percentage removals of COD are found to be 78.51%, 75.16%, 67.02% respectively, for the bed materials in the same order. The experimental duration/the acclimatization period is found to be 12, 14, and 15 days against the bed materials Foam Pieces, Pumice stones, and commercially available MBBR media (plastic) respectively. From these results it is observed that, Foam Pieces is found to be a good alternative for the commercially available MBBR media (plastic) which are made up of plastic material.

VIII. STUDY ON REACTION RATE KINETICS

The study on Reaction Rate Coefficients is conducted as explained in the topic V, where three different reaction rate models are taken into consideration viz., Zero order, First order and Second order reaction. After analyzing the values, Plots of the integrated forms of the reaction rate expressions (Eqns 1,2,3) are used to determine the reaction rate coefficients 'k'. The reaction rate kinetics of the experimental programme confirms to first order reaction rate kinetics.. The reaction rate coefficients (k) obtained for the first order reaction rate of the experimental programme conducted with three different bed materials ranged from 0.01 day-1 to 0.15 day^{-1} and are shown vide Fig 8 to 13. These are in agreement with the earlier experimental works [1, 10, 11 and 13]. At the same time coefficients are found to be more for the experiment with Foam Pieces as bed material.

IX. STUDY ON MICROBIAL GROWTH KINETICS

The study of Microbial growth kinetics as explained in the Topic VI is conducted and the microbial decay coefficients (k_d) are obtained from graphs, using the specific growth rates (μ) and specific substrate utilization rates (U) which are calculated using the equations 4 to 7. The Microbial Decay Coefficients (k_d) for the removal of BOD and COD using different bed materials is presented in Table 2 below. It is observed that, the microbial decay coefficient (k_d) are found to be increasing against the following order of bed materials. i.e., Pumice stones, MBBR media (plastic), and Foam Pieces for different operation times and at the end of the acclimatization period. Maximum microbial decay coefficient 'kd' values are obtained when Foam Pieces is used as bed material when compared to Pumice stones and MBBR media (plastic). Also the Microbial decay coefficients are well in agreement with earlier works[8].

Table 2 The Microbial Decay Coefficients (kd) for the removal of BOD and COD using different bed materials.

S.No	Bed material	Operation time (minutes)	Microbial Decay Coefficient (k_d), day^{-1}	
			BOD	COD
1	MBBR Media (Plastic)	30	0.0034	0.1532
		60	0.0038	0.1012
		90	0.0044	0.0216
2	Pumice stones	30	0.0023	0.0697
		60	0.0027	0.0194
		90	0.0032	0.0381
3	Foam Pieces	30	0.0075	0.2395
		60	0.0073	0.1179
		90	0.0073	0.0134

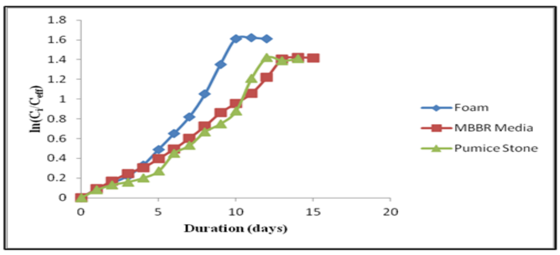


Fig 8 First Order Kinetics for the removal of BOD at OT 30 Min

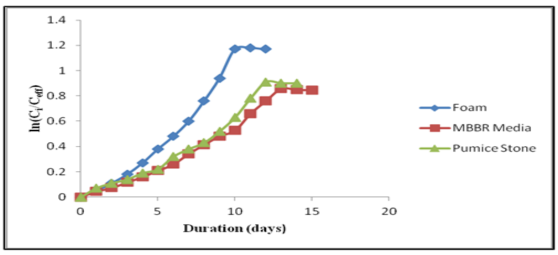


Fig 11 First Order Kinetics for the removal of COD at OT 30 Min

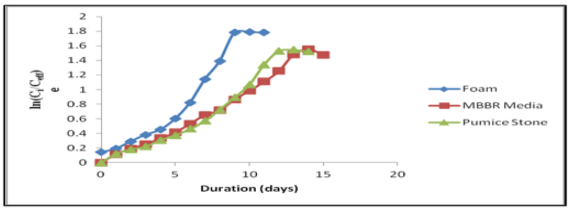


Fig 9 First Order Kinetics for the removal of BOD at OT 60 Min

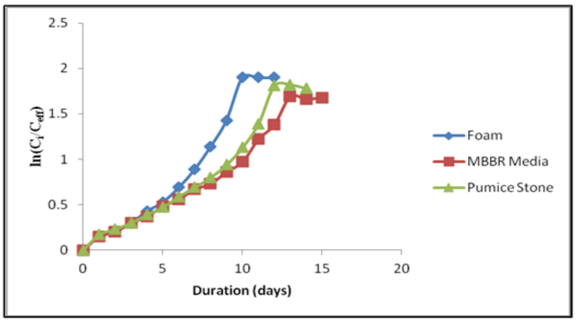


Fig 10 First Order Kinetics for the removal of BOD at OT 90 Min

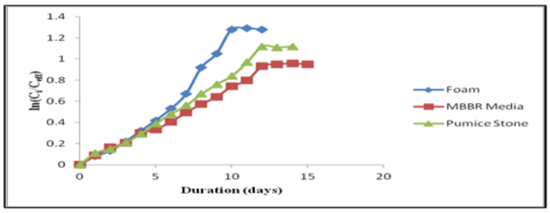


Fig 12 First Order Kinetics for the removal of COD at OT 60 Min

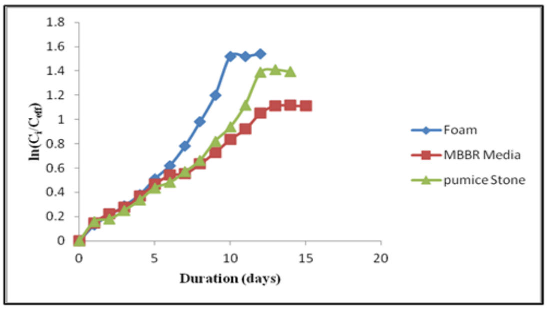


Fig 13 First Order Kinetics for the removal of COD at OT 90 Min

X. CONCLUSIONS

1) The acclimatization periods of the bio reactor are found to be 15, 14 and 12 days against the usage of commercially available MBBR media (plastic), Pumice stones and Foam Pieces as bed materials respectively.
2) The maximum percent removal of BOD and COD are found to be more against Foam Pieces as a bed material,at an operation time of 90 minutes and at the end of the acclimatization period.
3) The reaction rate kinetics of the experimental programme confirms to first order reaction rate kinetics and the reaction rate coefficients (k) obtained are in agreement with the earlier experimental works.
4) The microbial decay coefficient (k_d) are found to be increasing against the following order of bed materials. i.e., Pumice stones, MBBR media (plastic), and Foam Pieces for different operation times and at the end of the acclimatization period and the values obtained for BOD and COD are in agreement with the earlier experimental works.
5) Therefore, it can be concluded that, Foam Pieces can be used as a better alternative against the commercially available MBBR media (plastic) for the removal of both BOD and COD in floating bed bio-reactors.

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