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To Study the Application of Elliptical Media in MBBR for the Removal of COD in Wastewater at Low Hydraulic Retention Time

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Abstract- This study was done for the efficacious treatment of high Chemical Oxygen Demand (COD) content in waste water at low Hydraulic Retention Time (HRT) using low cost elliptical biomedia by Moving Bed Biofilm Reactor (MBBR). It was accomplished by sequence of experiments to identify the outcome of process at different media filling rate at a detention time of one day and one week. To prophesy the biomass escalation, the Monod kinetics was applied in a 10 litre oxygenated reactor. HRT and filling ratio were appraised for the effective rate of COD removal. This work introduces the concept of using low cost biomedia for high COD waste reduction at low HRT in MBBR which is substitute for traditional costly biomedia. Performance of reactor was observed in terms of COD removal. Chemical Kinetics of system has also been studied in order to predict the substrate utilization rate as well as growth rate of microorganisms in MBBR. The average rate of substrate uptake (K) and half saturation constant (Ks) were identified as 17.16 d^{-1} and 400 mgL^{-1} respectively. 70% COD removal has procured with seven day waste. In addition to this, the endogenous decay coefficient of 0.985 d^{-1} was calculated.

Keywords-Bio-carriers, Chemical Oxygen Demand (COD), Hydraulic Retention Time (HRT), Kinetic Model, Moving Bed Biofilm Reactor (MBBR).

NOMENCLATURE

Q	volumetric flow rate of wastewater, ml/ min
So	influent substrate concentration, mgL^{-1}
S	effluent substrate concentration, mgL^{-1}
U	specific substrate uptake/ utilization rate, $time^{-1}$
V	volume of reactor, l
X	biomass concentration, mgL^{-1}
K	maximum rate of substrate uptake, $time^{-1}$
Ks	Monod constant
Y	yield coefficient
K_d	decay coefficient, d^{-1}
E	removal efficiency, %

I. INTRODUCTION

The presence of organic matter and nutrients in the environment has unfavourable effects on both human and aquatic life [1-4]. Hence, in order to reduce the organic load (COD) of discharged wastewater in natural water bodies, different wastewater treatment applications have been used all over the world, one of which is the effectual technology of treatment through Moving Bed Biofilm Reactor (MBBR) [5]. It is an advanced aerobic wastewater treatment process having virtue of both attached and suspended growth systems. Plastic media are used in this process, on the surface of which microorganisms attach and grow [6]. In an aerobic process, microorganisms that are in contact with the wastewater, are exposed to either air or oxygen. The microorganisms consume the organic matter and wastewater, so biomass is engendered [7]. Biofilm develops on the surface of small carrier elements moving inside the reactor. Biofilm growing within the internal structure of bio carriers degrade dissolved pollutants in the wastewater. The principle of MBBR is to immobilize biomass on carrier, eliminating the need for sludge

settling and return in a continuous operation system [8]. The benefits of this system compared to a suspended growth one are: higher biomass concentration, lesser sensitivity to toxic compounds, lack of long sludge settling period [9], less prone to the process upsets from poorly settling biomass [10], cost effectiveness [11] and greater efficiency to reduce COD [12].
In MBBR, up to 90% COD and 95% BOD removal is achievable [13]. Controlled biomass retention, improved effluent quality and decreased water footprint are the characteristics of MBBR used in treatment plants [14].

Kinetics of MBBR
The MBBR process is unique from the point of view of the kinetics. The kinetic model contribute to the understanding, determination and assessment of organic matter degradation in a biological reactor. Biofilm kinetics can help to describe the substrate removal rate and the parameters which could affect the transport phenomenon in microbial films [15]. Hence it is important to study the mechanism that control the process**.** To describe the overall kinetics of biofilm reactor Monod model is explained below:-

The rate of substrate utilization is described by following equation:-

$$\mathrm{U} = \mathrm{KSe} = \frac{Q(\mathrm{So}-\mathrm{Se})}{XV} \qquad (1)$$

Where Q is the volumetric flow rate of wastewater (ml/ min), So is influent substrate concentration (mgL^{-1}), Se is effluent substrate concentration (mgL^{-1}), X is biomass concentration in the aeration tank (mgL^{-1}), V is volume of reactor (L), U is specific substrate uptake/ utilization rate (time) and K is substrate uptake constant, mass. Time /maximum rate of substrate utilization per unit mass of biomass (k) mg COD/ mg MLVSS.

The specific substrate utilization rate can also be represented by:-

$$\mathrm{U} = \frac{KSeX}{Ks+Se} \qquad (2)$$

Where k is maximum rate of substrate uptake $time^{-1}$ and Ks is Monod constant i.e. half-saturation constant, mass $volume^{-1}$ (mgL^{-1})
Yield coefficient (Y) is defined as the mass of cells produced per unit mass of substrate utilized.

$$\mathrm{Y} = \frac{mg\ MLVSS}{mg\ COD} \qquad (3)$$

The biomass is known as mixed liquor volatile suspended solids (MLVSS) that is the biomass grown from the utilized substrate.
Decay coefficient (K_d)

$$\mathrm{Kd} = \frac{mg\ MLVSS}{mg\ MLVSS\ .d} \qquad (4)$$

The removal efficiency (E) is defined on the basis of substrate removal (COD) and is given by:-

$$\mathrm{E} = \frac{\mathrm{So}-\mathrm{S}}{S} \qquad (5)$$

Presently, wastewater treatment plants based on MBBR are operated with high sludge retention time & costly media. This research study is intended to evaluate the performance of a laboratory scale MBBR, using low cost bio carrier for the treatment of high COD content wastewater at low HRT. Kinetics of the reactor has been analysed by Monod Model.

Paper is organised as follows: Section I contains introduction of MBBR and Monod kinetics Model, section II gives brief description about related work in MBBR, section III describes experimental setup, materials and methodology used, section IV includes result & discussion, section V concludes paper with future scope.

II. RELATED WORK

A study done on MBBR concluded that typical biofilm concentrations range from 3000 to 4000 g TSS/m^3, which is closer to the values obtained in activated sludge processes with high sludge retention time. It was observed that, since the volumetric removal rate in the MBBR was several times higher than that in the activated sludge process, the biomass in the former were much more viable.

Another work concluded that traditional systems such as trickling filters were not volume effective. Mechanical failure has been a common problem with rotating biological contractors and it has been challenging to distribute the load evenly over the entire carrier surface in fixed media submerged bio filters. MBBR, with biofilm processes for wastewater treatment, has exhibited improved performance compared to traditional biofilm systems.

A study on the design of MBBR reported that geometry of bio carriers (size and shape), materials for construction have been carefully considered to maximize performance of MBBR. This was a major difference from the activated sludge process, where treatment performance was more directly tied to reactor volume. In the MBBR, surface area could be increased by designing carriers with a higher specific surface area or by adding greater quantity of carriers to a reactor volume. This offered flexibility for future treatment capacity upgrades without requiring the construction of additional reactors.

A research on MBBR studied the effect of Dissolved Oxygen (DO) and influent ratio of Chemical Oxygen Demand to Nitrogen (COD/N) ratio on biological nitrogen removal from synthetic wastewater. It was observed that in moving bed biofilm reactors (MBBRs), by conducting partial nitrification process in pilot-plant configuration for 300 days, maintained with operational conditions of (500 mg COD/l, 35.7 mg NH4-N/l, 7.14 mg PO4-P/l, HRT=20 h, Qr/Q=3), fluctuations in the concentration of DO had no negative influence on COD removal rate. Moreover complete soluble organic carbon removal, in excess of 99% efficiency, occurred in the total MBBRs system.

III. MATERIALS AND EXPERIMENTAL APPROACH

Synthetic wastewater prepared in the laboratory with the help of organics and nutrients, was filled in a 10 litre plastic reactor with biomass (slurry) concentration of 2mg at room temperature. This waste water was used in all stages of the experiment with constant composition. The biofilm media used in experiment is white coloured plastic media with external grooves. Influent and effluent flow rate were set at 10 ml /min. Initial concentration of waste was 1200 mgL^{-1} COD.
The experiment investigated the effect of media filling ratio, COD removal rate and low hydraulic retention time (HRT) on the performance of MBBR.

The MBBR was set up in the Laboratory. A 10L cylindrical shaped vessel, built of plastic, with height 28cm and average diameter 25cm was used to treat 10L synthetic wastewater every day. Aerator and motor were located inside the reactor to supply oxygen to the microbial mass for biological activity and mixing the carriers. Water flowed through pipes from influent storage tank through the column and downwards to the effluent storage tank by the effect of gravity. The schematic of experimental setup used in shown in Figure 1 and the actual photograph of reactor & bio- carrier is shown in Figure -2.

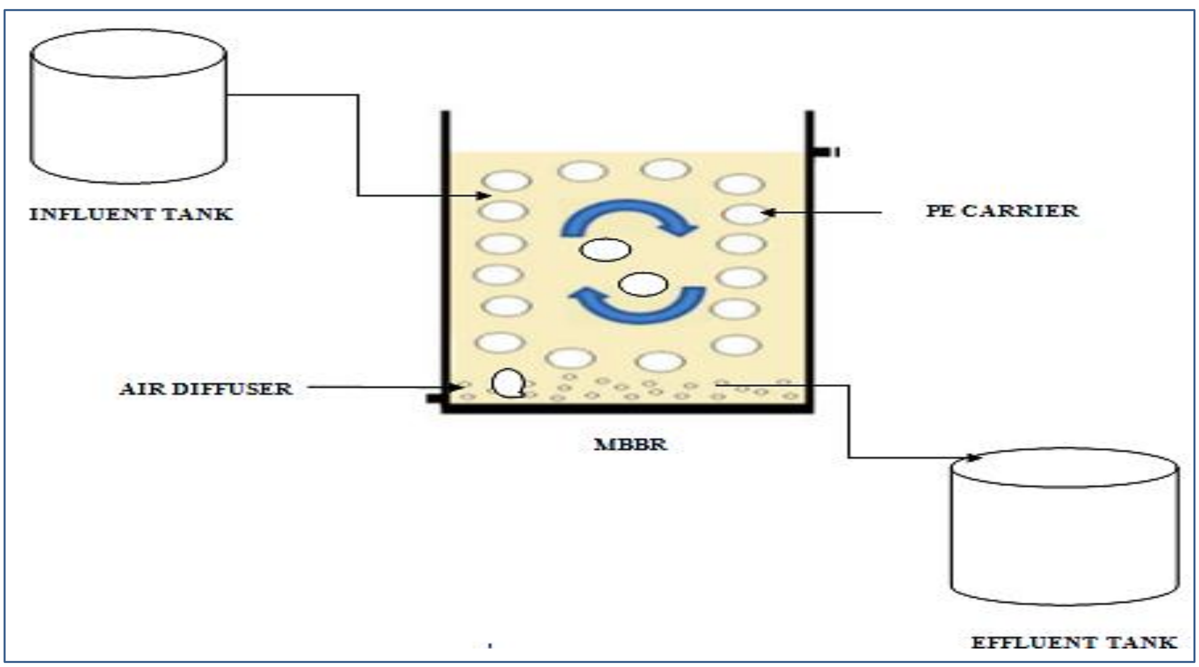

Figure 1: Schematic of Laboratory scale MBBR for high COD wastewater

Figure 2: Real Photograph of Moving bed biofilm reactor with Bio Carrier

The biofilm media used in experiment is white coloured plastic media with external grooves. These suspended media carriers were used in the reactor to provide the surface area for accommodation and better growth of microorganisms. The bio carrier specifications are as per Table-1.

Table 1: Bio - carrier specifications

Parameters	**Specifications**
Material	Plastic
Shape	Ellipsoidal with external grooves
Colour	White
Total Surface Area (cm^2)	21.8286
Specific Surface Area (cm^2 / cm^3)	43.65
Length (cm)	1.155
Breadth (cm)	0.89
Height (cm)	0.69
Thickness (cm)	0.05
Net Volume (m^3)	0.5
Weight (gm)	0.49
Density (gm/ cm^3)	0.98
Specific Gravity	0.98

Batch tests were initiated at a specified waste water concentration and ended at different concentration using same residence times. To initiate biological growth and development of biofilm, reactor was inoculated with biomass. Initially the reactor was acclimatized for seven days. According to filling ratio without media, 5%, 10% & 20% carries were added into 10 L reactor in different phases. In each phase, when reactor was acclimatized for 2 hours and 7 days, samples were collected at an interval of 2 hr and 1 day respectively during all stages of experiment. Analysis was done for COD, alkalinity, MLVSS and Oxygen Uptake Rate (OUR) by standard methods [16]. Effect of bio carriers media on OUR was investigated at different filling ratios. DO is a key substrate for ensuring microbial growth. The dissolved oxygen level kept above 2 mgL^{-1} during experiment. The oxygen used for respiration can be determined by measuring the decrease in oxygen levels in the process, when no air is supplied. By calculating the slope of the oxygen concentration curve versus time, the OUR was calculated. Ambient condition was maintained throughout the experiment.

IV. RESULTS AND DISCUSSIONS

For the diminution of organic pollutants in wastewater, aerobic process was employed. Biodegradation and oxidation of organic compounds were achieved through biological process. Bacterial growth, COD removal and retention time are the critical influential parameters, which were carefully observed.

For decrease in the DO concentration from an initial value DO_1 to a lower value DO_2, the corresponding OUR (expressed in mgL^{-1}h^{-1}**)** is calculated as:

$$\text{OUR} = \frac{DO1 - DO2}{t2 - t1}$$

Where, t_2- t_1 is time difference at an interval of 30 min.

Table 2 & 3, represents the calculated COD values at different media filling rate for retention time of one day and one week respectively. It was analysed that**,** at 5% of carrier filling rate, carriers were moving uniformly in 10L reactor and gave acclamatory surface area for microbial growth. As a result, higher COD removal efficiency was achieved at 5% filling rate as compared to that of 10% and 20% carrier filling rates. 70% efficiency of COD removal was also accomplished, which is within prescribed limit given by CPCB (250 mgL^{-1}). Figures 3 & 4 exhibit the time vs COD reduction profile of different media.

MBBR, capable of retaining considerable quantity of attached biomass, would provide successful performance and achieve appreciable COD removal. Thus, the higher value of OUR led to greater amount of attached biomass on media, which resulted in consumption of a greater substrate by this biofilm. From the information illustrated in Figure-5, maximum oxygen uptake rate was derived and found to be at 5% filling ratio, which was 1.5 mgL^{-1}h^{-1}.

Figure 6 represents kinetic model, which is similar to Monod rate model. Monod equation was filled with experimental data. Graph was plotted against specific substrate utilization rate & substrate to determine the order of Monod equation. The value obtained for the correlation coefficient (R^2) was 0.9954. The maximum rate of substrate uptake (K) was 333 d^{-1} and Monod constant Ks was 16.92 mgL^{-1}. The kinetic coefficient, which indicates maximum substrate utilization rate, was achieved at a maximum carrier filling rate of 5%. The higher value of K depicts that, when the substrate is used at its maximum rate, the bacteria also grow at their maximum rate. The large value of Ks represents that either the biomass grown on water has low affinity for substrate or the rate expression leads to the first order kinetics. Based on the experimental data the yield coefficient and endogenous decay coefficient were calculated as 0.059 and 0.985 d^{-1} respectively. The high decay coefficient values might be due to considerable decay of cells that occur as a result of endogenous respiration. The higher value of R^2 indicates that first order kinetics can be applied.

Table 2: Performance of Test at Different Filling Ratio at HRT 1 Day

S.No.	PARAMETER	TIME (In h)	WITHOUT MEDIA	5% MEDIA	10% MEDIA	20% MEDIA
1	COD (mgL^{-1})	Initial	1200	1160	1140	800
		2	640	480	880	320
		4	560	400	440	400
		6	450	320	320	560
		8	380	160	160	240
2	ALKALINITY (mgL-1)		339	368	433	328
3	OUR (mgL-1h-1)		0.5	1.5	0.2	0.9

Table 3: Performance of Test at Different Filling Ratio at HRT 1 Week

PARAMETER	TIME (In Days)	WITHOUT MEDIA	5% MEDIA	10% MEDIA	20% MEDIA
COD (mgL^{-1})	1	920	460	500	520
	2	840	420	440	440
	3	700	340	380	300
	4	640	200	180	160
ALKALINITY (mgL^{-1})		327	422	430	444

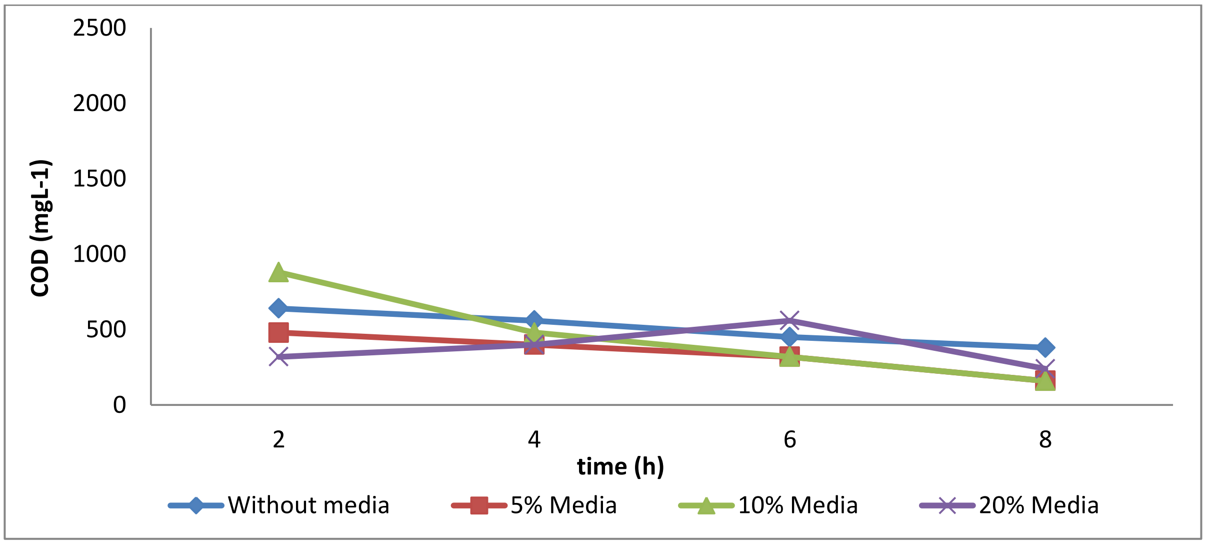

Figure 3: COD concentration profiles vs. time for different media at HRT 1 day

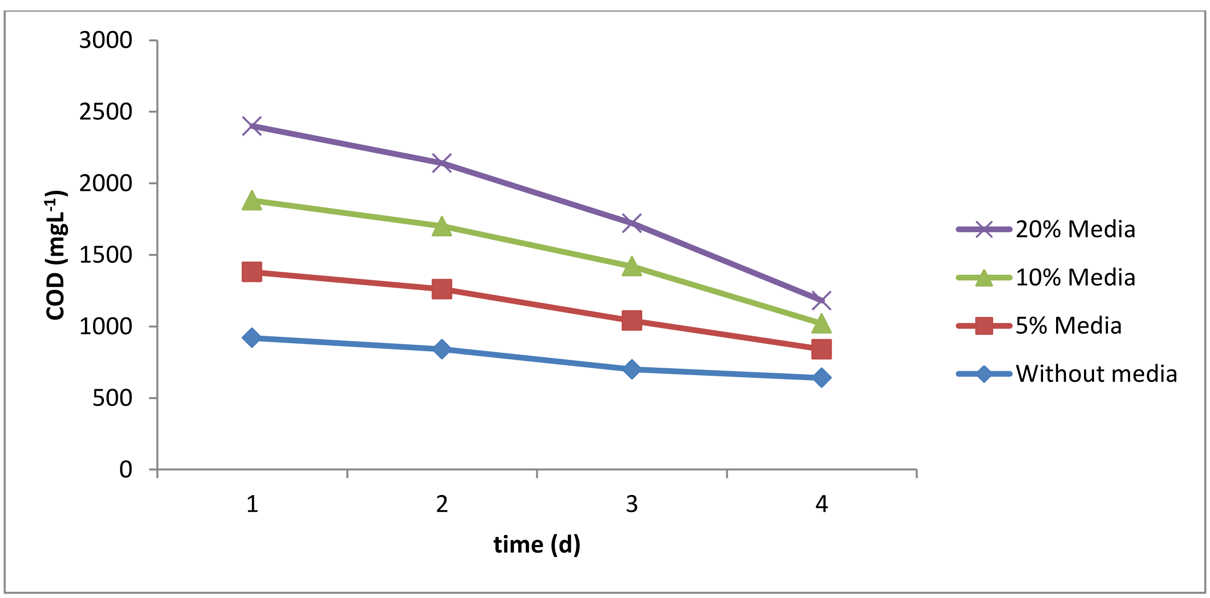

Figure 4*: COD concentration profiles vs. time for different media at HRT 7 day*

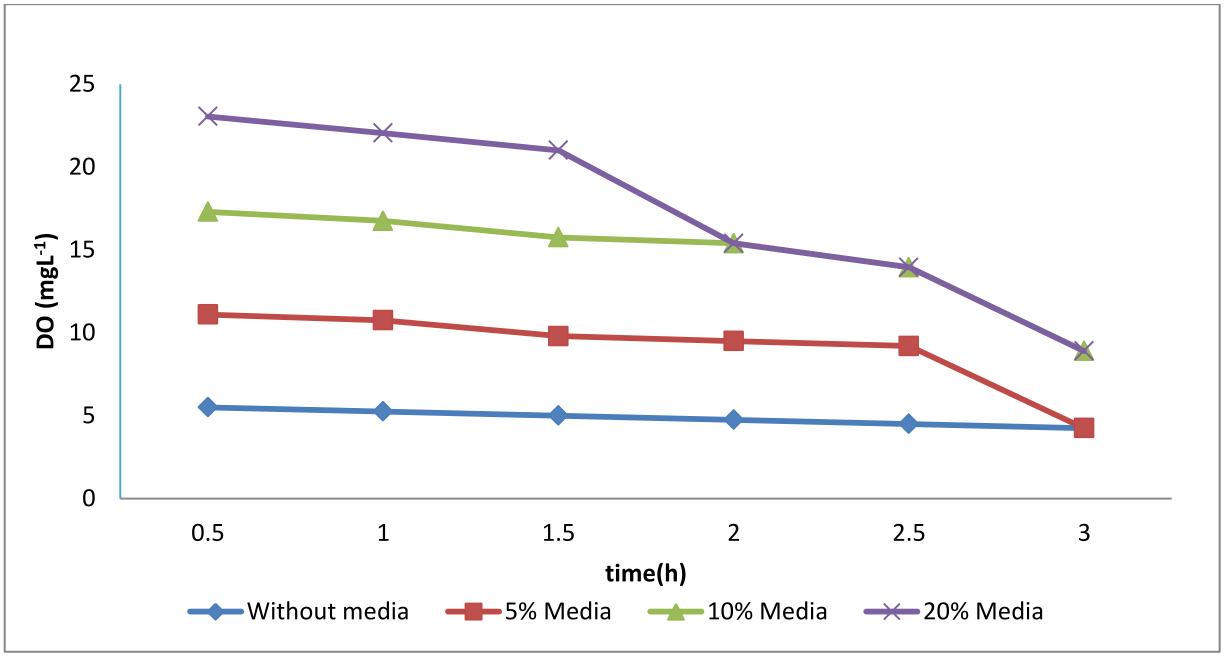

Figure 5: *Profiles of OUR as a function of time at different filling ratios*

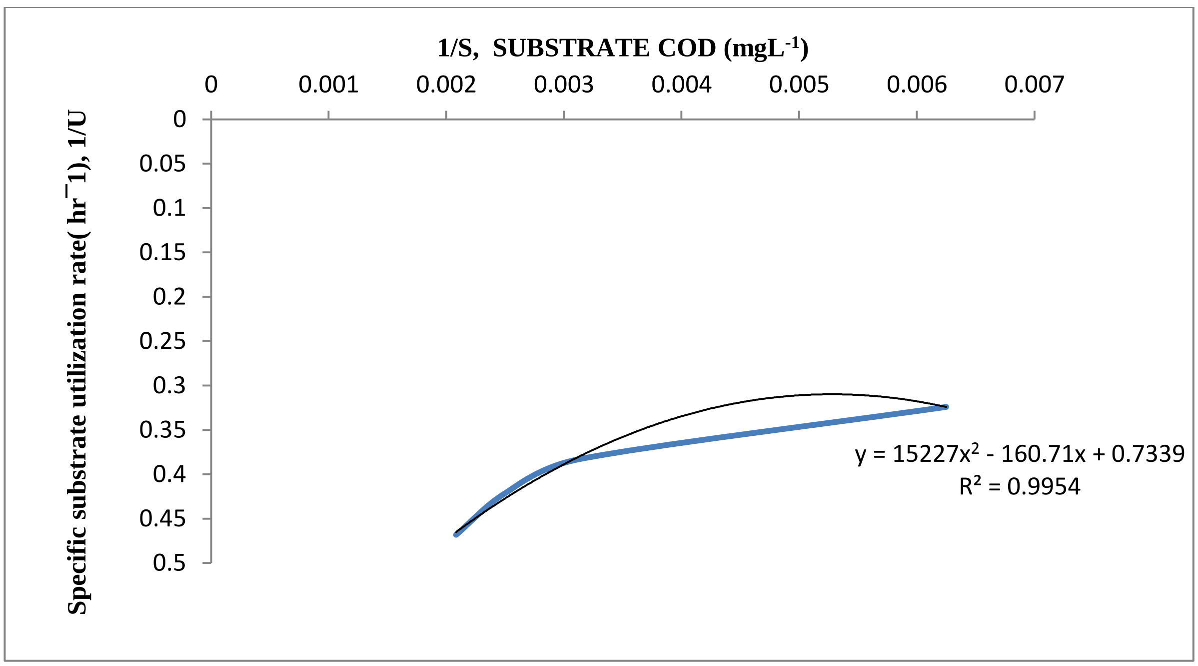

Figure 6: *Kinetic model for leaving substrate and utilization rate*

V. CONCLUSION & FUTURE SCOPE

The lab scale MBBR was used to study performance of different media for reduction of COD at low HRT. The experiments were conducted in series, in order to identify maximum COD reduction rate by different media filling ratios. 70% COD reduction was achieved at a retention time of 1 Week. 5% media filling gave appreciable reduction. Uptake rate was observed in range of 0.2 - 1.5 ($mgL^{-1}h^{-1}$), of which maximum uptake rate was shown by 5% media. The kinetic model for substrate utilization was introduced and Monod kinetic constants were calculated. The experimental data and the model was consistent. The Monod constant Ks and maximum rate of substrate uptake (K) were estimated at 16.92 mgL^{-1} and 333 d^{-1} respectively. The endogenous decay coefficient of 0.985 d^{-1} was calculated. This work concludes that low-cost polystyrene biomedia could be used in MBBR to substitute the expensive commercial biomedia. Even through a lab scale set up, MBBR was capable of retaining a considerable quantity of attached biomass, which provided successful performance and achieved appreciable COD removal. Future scope of this research study is to remark the effectiveness of MBBR with different low cost biomedia for treatment of highly polluted industrial/municipal wastewater.

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