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Startup of Moving Bed Biofilm Reactor for Leachate Treatment

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The tremendous increase in population in the last few decades has resulted in massive unmanageable solid waste products across the country. The leachate produced during decomposition of solid waste can be treated using conventional systems but proves to be uneconomical and requires a long duration thus leading to environmental unsustainability. However, recent advancements in wastewater treatment have emerged with moving bed biofilm reactor (MBBR) and is gaining popularity around the globe. The system is economical as it requires less land area while treating high quantum of wastewater in short time duration. The present study has been carried out with an objective to treat the landfill leachate using laboratory-scale aerobic MBBR system. The microorganisms were acclimatized for leachate degradation by feeding the reactor with varying composition of glucose and leachate with a COD inlet concentration of 1000 mg/L at HRT of 21 h. In Phase-I of the study, the reactor was operated with 100% glucose and resulted in 95 % COD removal with 90% TSS removal. In Phase-II of the reactor operation with inlet feed containing 75% glucose and 25% leachate resulted in 93% COD removal with 89% TSS removal. In Phase-III of the study duration, the reactor when fedwith 50% glucose and 50% leachate resulted in 91% of COD removal and 91% of TSS removal. However, on the 100th day of the study, the reactor was switched to 100% leachate and under pseudo steady state a COD removal of 84% and with TSS removal of 92% was being assessed. The kinetic parameters including sludge growth rate, decay coefficient and sludge yield were assessed in each step of the study. The results from the present study indicate that MBBR is an efficient technology that can remove 84 %of CODand92% TSS from leachate efficiently and effectively with a sustainable method.

Keywords: Chemical Oxygen Demand, Hydraulic retention time, Moving bed biofilm reactor, Total suspended solids

1 Introduction

Leachate is one of the prominent environmental issues caused during the disposal of municipal solid waste (MSW) on landfill sites. The quality and quantity in terms of MSW generation are subjected to generally depend upon such wastes lifestyle, population type, the extent of industrial area, food habits people, living standards, and day to day activities in the area. Municipal solid waste disposed of in landfill includes non-hazardous wastes from a variety of sources such as households, industries, restaurants, medical facilities, and schools. Many MSW landfill site also accepts contaminated soils from gasoline spills. The leachate emanating from moderndesigned engineered landfill is collected and treated on-site by physical, chemical, biological, or combined treatment systems[1-2]. It is reported that a total amount of 12.7 billion tonnes of waste was generated across the globe in the year 2000. It is predicted that the total waste generated is likely to increase to 19 billion tonnes in 2025[3.] The groundwater generally affected by leachate produced depends on the characteristics of the produced waste and daily generated leachate. Landfill leachate generation and leachate dispersion also depend on the amount of rainfall it receives, the hydraulic gradient, and the geology of the area. In the case of Delhi, the capital of India out of the total waste generated approximately 5533 (tons per day) TPD comprising 50.3% is disposed of on landfill sites while 47.3% accounting for 5193.57 TPD is treated biologically, chemically, and physically[4] The reclaimed water can be utilized in domestic, industrial, and agricultural usage, thereby contributing to sustainability and circular economy [3-4]. The moving bed bioreactor (MBBR) system is such an advanced method for treating different types of wastewater with very high efficiency in terms of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) removal. This treatment method is designed to leverage the benefits of both the activated sludge process and biofilter processes. It utilizes both suspended biomass and attached biomass processes collectively to effectively remove organic and inorganic contaminants from the wastewater. Therefore, MBBR system is quite a popular choice for treating municipal

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and industrial wastewater, as it consumes less energy. It effectively removes a broad range of contaminants, including organic matter, nitrogen, and phosphorus. In view of the above facts, a study is being planned with the objective to treat the produced landfill leachate of the Delhi region using the MBBR system and to assess the biokinetics of the leachate treatment system.

2 Materials and Methods

The model MBBR with a gross volume of 28 L was fabricated using a Perspex glass sheet and utilized for the treatment of leachate. For the development of biofilm growth, the polyethylene PE 06 type were used for biofilm growth. The present study was carried out in Laboratory of Environmental Engineering established in Department of Civil Engineering at Netaji Subhas University of Technology West Campus, Jaffarpur, New Delhi, India. K1 media of 500m^2/m^3 specific surface area(SSA) and biosphere balls of 800m^2/m^3 SSA were used for the development of attached microorganisms that help in biofilm growth. *Guet al.* (2014) in a study recommend that the filling ratio of the media concerning the reactor volume should be kept 50% for optimum organic load removal efficiency [7]. For carrying out the aeration process the diffused aeration system with perforated plates was placed at the bottom of the tank. Javid *et al.* (2013) and Biase *et al.* (2016) have reported startup phase of a reactor for wastewater treatment to be 127 days in their study [8-9]. During the startup, activated sludge from a real-scale 20 MGD sewage treatment plant located in Dwarka, New Delhi was used for seeding the reactor. The influent total COD fed to the reactor was kept 1000 ± 25 mg/L mg/L during the entire startup phase duration with HRT of 21 h. Each phase of the process continued until pseudo-steady state conditions were achieved. After the successful completion of the startup phase, the reactor was fed with 100% leachate wastewater on day 100. This indicated that the startup process had been accomplished efficiently.

2.1 Leachate characteristics

The leachate used as a substrate in the present study was collected at regular intervals of time from a nearby landfill site located in south Delhi Okhla region. Before the startup of the experimental study the physicho-chemical characteristics of the collected leachate in terms of pH, mixed liquor volatile suspended solid (MLVSS) COD, BOD, and mixed liquor suspended solids (MLSS) was determined, and obtained results are summarized in Table 1. The leachate is difficult to degrade because it contains a high concentration of toxicants and chemicals that inhibits biological activity and thereby retards the biodegradation process. Therefore, to acclimatize the microorganisms in the reactor, 100 % glucose-based synthetic wastewater was used at the start. Thereafter, the reactor was stepwise switched to 100 % leachate while decreasing the glucose concentration to 0%. However, the COD concentration in the influent was maintained at 1000 ±20 mg/L throughout. For maintaining the pH value of 7.0 to 8.0 the influent was feed buffer with sodium hydrogen carbonate.

2.2 Microbial growth kinetics

The Monod model was utilized for the estimation of kinetic parameters in terms of yield and decay coefficient.The kinetic coefficients, viz., Y and K_d were calculated using Equation (i)

$$\frac{1}{\theta_C} = YU - K_d \qquad ... (1)$$

Where θ_C represents cell age or solid retention time, Y represents the yield coefficient ofbiomass as the slope of the curve in mg VSS/mg COD, K_d represents the endogenous decay or death coefficient for heterotrophic organisms as the intercept of the curve in d^{-1}and Urepresents the specific substrate utilization rate[10]. TheKs and k values have been computed from the 1/S vs 1/ U plots. The intercept of the obtained curve provides the *1/k* value while the slope of the curve provides the *Ks/k* value and values of both the coefficients can be assessed by the obtained values. Eq. (ii) was used to calculate the kinetic coefficients Ks and k.

Table 1 — Physicho-chemical characteristics of leachate and seed sludge used in present study

Leachate Characteristics	
Parameter	Value
pH	8.8
Chemical oxygen Demand COD (mg/L)	19000-22000
Total solids TS (mg/L)	49000-50000
Total suspended solids TSS (mg/L)	21000-22000
Total dissolved solids TDS (mg/L)	27500-28000
Biochemical Oxygen Demand (mg/L)	7000-7500
Seed Sludge	
Volatile suspended solids VSS (g/L)	12.09
Total suspended solids TSS (g/L)	15.5
VSS/TSS	0.78
Colour	Black

$$\frac{1}{U} = \frac{K_S}{k}\frac{1}{S} + \frac{1}{k} \quad \text{... (2)}$$

Where, S_0 COD concentration at the inlet of the reactor in mg/L, K_S for heterotrophic biomass, Maximum half-velocity constant in mg COD/L, μmax for heterotrophic biomass Maximum specific growth rate in d^{-1}, k for heterotrophic biomass specific substrate utilization rate in mg COD/mg VSS. d the maximum specific bacterial growth rate is related to the maximum specific substrate utilization rate as follows. μmax was calculated using the equation below

$$\mu_{max} = kY \quad \text{... (3)}$$

3 Results and Discussions

In the beginning, the reactor was filled with 50% of activated sludge obtained from a 20 MGD real-scale sewage treatment plant located in New Delhi having TSS concentration of 15.5 g/L. The major nutrients in the form of NH_4Cl and K_2HPO_4 were used as sources of phosphorus and nitrogen. The pH of the influent of the reactor was kept between 7.0 to 8.5 for the entire study duration. The physicochemical parameters including pH, COD, BOD, TSS, and VSS were monitored regularly. The reactor startup is being carried out in five phases. Initially, the reactor had glucose-based synthetic wastewater containing 100% glucose as substrate and gradually it is shifted phase-wise to a concomitant increase in leachate concentration from 0 to 100%. The influent COD_{total} in the reactor feed was maintained at 1000 ± 20 mg/L throughout the study. However, any change in the reactor operation conditions was made till the reactor attained the pseudo-steady state conditions (PSS). The obtained results are shown in Table 2. The bio-kinetic coefficients (Y), K_d as endogenous decay coefficient, K_S as the maximum half-velocity constant, μ_{max} as the maximum specific growth rate of microorganisms, and k as the specific substrate utilization rate of the substrate have been evaluated in each phase of the study. The computed biokinetic coefficient values in each phase of the study was compared with the available literature which are presented in Table 3. The schematic of the experimental setup of laboratory scale MBBR has been shown in Fig. 1.

Table 2 — Operational parameters of the MBBR for leachate treatment

Phase	Days	Influent COD (mg/L)	Effluent COD (mg/L)	COD Removal Efficiency (%)	Influent TSS (mg/L)	Effluent TSS (mg/L)	TSS Removal Efficiency (%)
Phase - 1 (Glucose:100%)	1	1020	840	17.65	1015	877	13.60
	4	1015	714	29.66	1005	750	25.37
	7	980	653	33.37	980	600	38.78
	10	1020	406	60.20	1020	547	46.37
	13	1000	218	78.20	1050	420	60.00
	16	975	193.3	80.17	980	213	78.27
	19	973	147.2	84.87	970	200	79.38
	22	1020	123.4	87.90	1000	140	86.00
	25	1180	55	95.34	1050	110	89.52
Phase -2 (Glucose: 75% & Leachate: 25%)	28	1000	738	26.20	1120	754	32.68
	31	912	635	30.37	1100	623	43.36
	34	1018	421	58.64	1080	543	49.72
	38	1014	290	71.40	1050	412	60.76
	41	973	188	80.68	1070	318	70.28
	44	934	144	84.58	1020	258	74.71
	47	1020	124	87.84	1015	198	80.49
	50	1000	113	88.70	1017	108	89.38
	53	1005	71	92.94	1005	106	89.45

Table 3 — Summary of kinetic coefficients reported in literature and computed in present study

Substrate	Y (mg VSS/ mg Codd)	Ks (mgCOD/L)	K_d (d^{-1})	μ_{max} (d^{-1})	K (mgCOD/mgVSS.d)
Glucose based wastewater[11]	0.52-0.62	11-181	0.025-0.48	7.4-18.5	-
Municipal wastewater[11]	0.46-0.60	250-3720	0.05-0.16	5.6-8.1	-
Municipal wastewater[12]	0.3-0.6	10-60	0.06-0.15	0.6-6	2-10
Textile dye wastewater[13]	0.141-0.043	53-168	0.011-0.23	0.002-0.009	0.024-0.128
Glucose:100% (Present study)	0.56	111	0.015	0.20	0.35
Glucose: 75% &Leachate:25% (Present study)	0.59	152	0.044	0.31	0.52

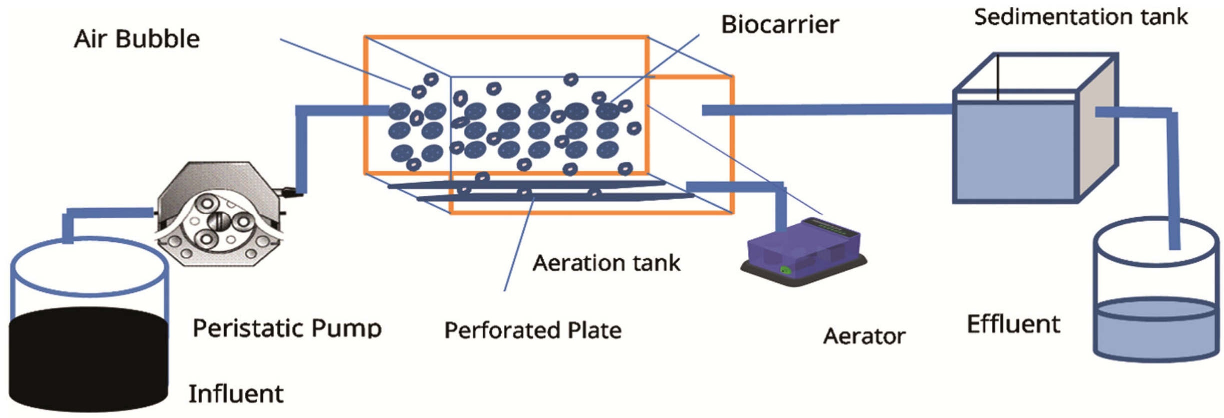

Fig. 1 — Experimental setup of moving bed bioreactor used in the present study.

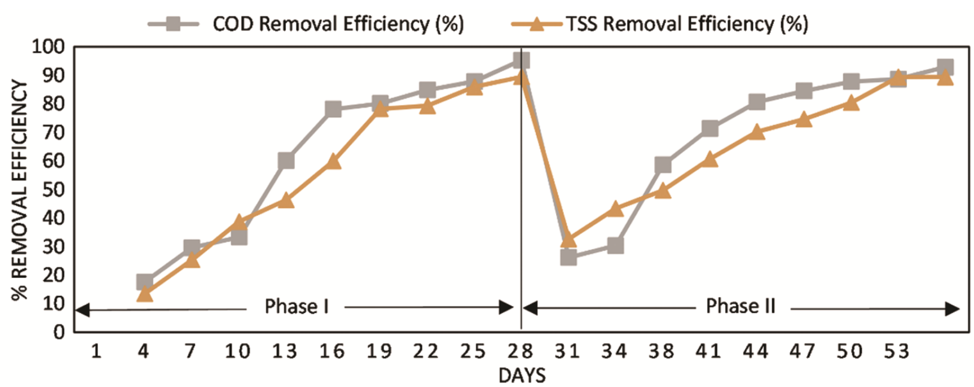

Fig. 2 — Temporal variation of percent COD removal and TSS removal efficiency.

Phase- I: Day 1-27 (Feed with 100%glucose)

In this phase, the reactor was operated in a batch mode for 25 days for appropriate growth and enhancement of biomass on the media. A perusal of the data from Table 2 signifies the COD removal efficiency varying from 17 to 95% with TSS removal increment from 13 to 90%. After 44 days period, the variation in effluent COD was observed to be negligible thereby signifying the reactor towards PSS conditions with visible biofilm growth over media. The highest MLSS concentration in the reactor during this period was found to be 4523 mg/L. The temporal variation of percent COD removal and TSS removal efficiency has been shown in Fig. 2.

During reactor operation, the biokinetic coefficients in terms of K_d, k, Y and K_s of Phase-I with 100% glucose were determined and is depicted through Fig. 3(a-b). The K_d was computed to be 0.015 d^{-1} whereas the Yvalue was computed to be 0.56 mg VSS/mg COD. d. The high yield value thus indicatesthe high mass formation of biomass and the efficiency of microorganisms towards glucose as a readily degradable substrate in the MBBR system. The kinetic parameters in *Ks* and *k* values in this phase of the study have been found to be 110.7 mg COD/L and 0.35 mg COD/mg VSS. d, respectively. The high k-value thereby indicates the metabolic activeness of microorganisms in utilizing glucose effectively and efficiently. Additionally, the μ_{max} value of 0.20 suggests that the microbial population has a moderate growth rate. A similar study was made using immersed membrane bioreactor by Al-Malack and Muhammad H (2006) the reported *Ks* and *Y* values were 11-181 mg COD/L and 0.52-0.6 mg VSS/mg COD. d respectively[11].

Phase-II: Day 28-55 (Feed with 75% glucose and 25% leachate)

In this phase, the glucose concentration in the feed was reduced from 100 to 75% with a leachate concentration of 25%Despite the change in feed concentration the total COD of the influent remained 1000 ± 20 mg/L with OLR 0.95 kg COD/m^3/day with HRT of 21 h. However, when the reactor was

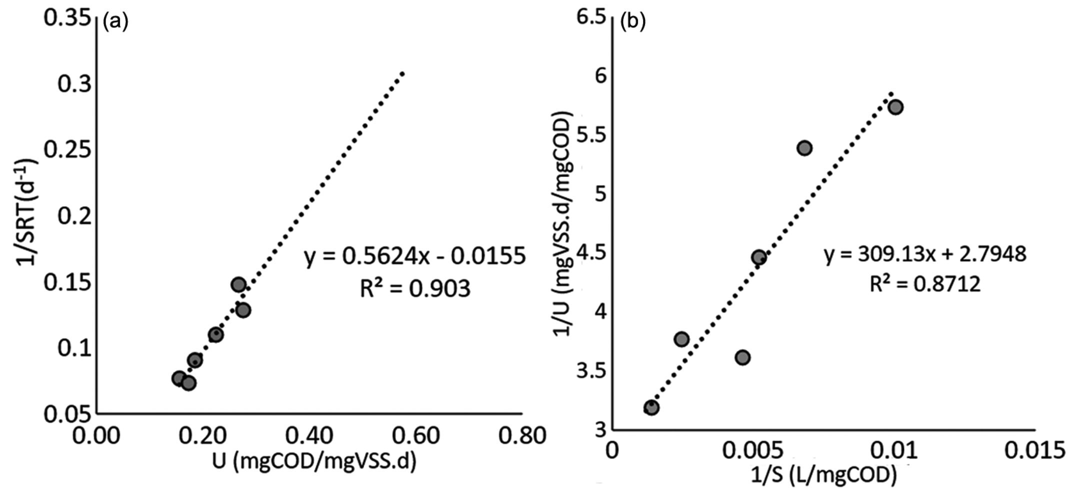

Fig. 3 — (a-b) Biokinetic coefficients determination in Phase-I with 100% glucose (a) Y and Kd, & (b) Ks and k.

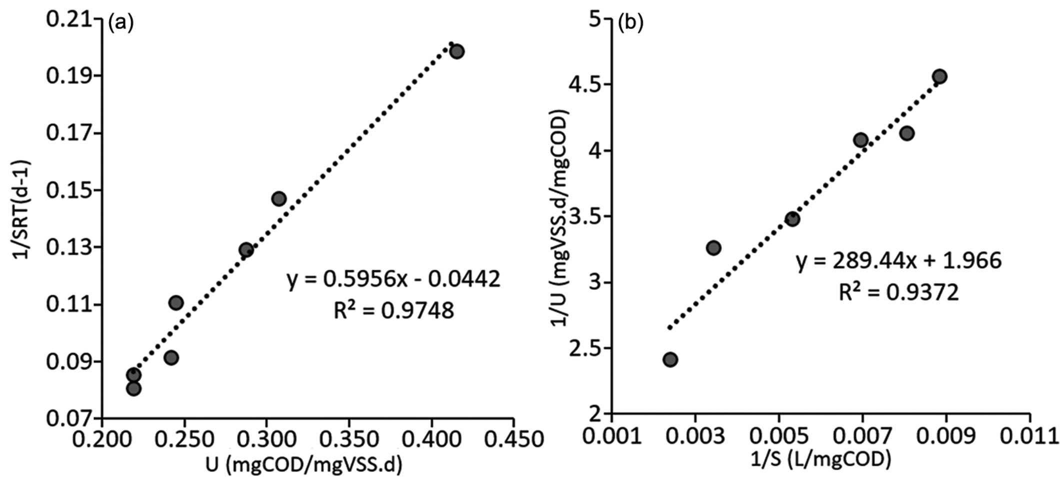

Fig. 4 — (a-b) Biokinetic coefficients determination in Phase-II with 75% glucose and 25 % leachate (a) Y and Kd, & (b) Ks and k.

switched to feed containing 25% of leachate, an MLSS reduction from 4323 to 2425 mg/L was observed. Also, Table 3 shows that the overall COD removal efficiency varied from 26% to 93% with TSS removal increased from 32% to 89% in the entire phase of the study. The biokinetic coefficients of phase-II has also been determined and is shown through Fig. 4(a-b). The *Y* and K_d values in this phase were found to be 0.59 mg VSS/mg COD. d and 0.044 d^{-1} respectively. The relatively low Y value is thus an indication of inefficient utilization of substrate by microorganisms thereby leading towards a lower conversion rate of glucose into biomass. Similarly, *Ks* and *k* were assessed to be 152 mg COD/L and 0.52 mg COD/mg VSS. d, respectively, thus confirming the fair affinity of microorganisms for the substrate in overall conversion in an MBBR system. Also, the μ_{max} value of 0.31 indicates the growth rate of microorganisms in the system while metabolizing the substrate. Further work is in progress with respect to 100% leachate treatment using MBBR with a COD value of 1000 ± 20 mg/L at 21 h. Kinetic coefficient values of Y 0.59 mg VSS/mg COD. d and 0.044 d^{-1}assessed in the present study can be well compared with the values reported in the literature with *Y*value of 0.3-0.6 mg VSS/mg COD. d and K_d value of 0.06-0.15 d^{-1}[12]. Hussain et al., (2022) in their study of textile dye treatment using Aerobic MBBR reported the *Ks* to be 53-168 mg COD/L and *k* in the range of 0.024-0.128mgCOD/mgVSS.d[13].

4 Conclusion

Present study findings confirm that glucose is a readily degradable co-substrate that can be effectively used for the startup of aerobic MBBR for high-strength wastewater treatment. Further, aerobic MBBR systems can treat landfill leachate effectively and efficiently with a maximum COD removal efficiency of 92% at a COD concentration of 1000 ± 20 mg/L with 21 h HRT. The kinetic coefficients in terms of Y and K_d of 0.55 mg VSS/mg COD. d and $0.044d^{-1}$, thereby demonstrating better yield of microorganismsgrowth and effective metabolic activeness of microorganisms in the utilization of 75% glucose and 25% leachate as substrate. The present findings indicate that real-scale aerobic MBBR systems are found to be quite effective in dealing with landfill leachate that contains high concentrations of organic matter and other toxicants which are difficult to degrade under normal conditions. The evaluated kinetic coefficients further indicate the lower sludge production rate with a high degree of treatment using under the COD concentration of 1000 ± 20 mg/L at 21 h.

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References

1 Teng C, Zhou K, Peng *C, Water Research,* 117525 (2021) 410.

2 Luo H, Zeng Y, Cheng Y, He D*, Pan X, Science of The Total Environment,* 135468 (2020)703.

3 Ram C, Kumar A, Rani P, *Bio Resources,* (2021)4275.

4 CPCB Delhi *"Annual Report on Solid Waste Management", 11th Edn, ISBN: 47447/2022/UPC-II-HO,*(2021)118. https://cpcb.nic.in/uploads/MSW/MSWAnnualReport_2020 21.pdf.

5 Barwal A & Chaudhary R*, Reviews in Environmental Science and Biotechnology,* 13(2014)285.

6 Wang K, Li L, Tan F, *Archaea,* (2018)

7 Gu Q, Sun T, Wu G, Li M, and Qiu, *Bioresour Technol*, 166(2014)72.

8 Biase A, Devlin T R, and Oleszkiewicz J A*, Journal of Environmental Engineering,* 142(2016).

9 Javid A H, Hassani A H, Ghanbari B, & Yaghmaeian, *Int J Environ Res,* 7(2013)963.

10 Hussain A, Dubey S. K, and Kumar, *Water ResourInd*, 11(2015)81.

11 Al-Malack M, *J Memb Sci,* 271(2006)47.

12 Metcalf & Eddy Inc, Tchobanoglous G, Burton FL, & Stensel H D*, Water Reuse, Wastewater Engineering Treatmentand Reuse*, 4th Edn, ISBN:978-0070495395 (2017).

13 Madan R, Madan S, &Hussain A*, Appl Biochem Biotechnol,* (2022)