Comparison of the Efficiency of Moving- and Fixed-bed Bioreactors for Treatment of High-strength Synthetic Wastewater

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A lab-scale Plexiglas cubic container as a pre-aeration reactor with total volume of 10 L, and two integrated bioreactors including a moving-bed bioreactor (MBBR) and a fixed-bed bioreactor with total volume of 30 L separately were used for experimental study. The main purpose was to compare the performance of moving-bed and fixed-bed reactors for degradation of high organic loading in synthetic wastewater. Varying organic loadings of 0.5 to 9 kg COD m^3 d^{-1} were applied. Generally, the total microbial mass in terms of attached biofim and VSS was higher in the MBBR. The microbial mass in the MBBR increased from 4120 to 4640 mg L^{-1} and in the fixed-bed bioreactor from 4124 to 4564 mg L^{-1}. The COD removal efficiency in sequencing runs of operation in moving-bed and fixed-bed bioreactors varied from 96.27 % to 81.27 %, and from 95.2 % to 74.82 % respectively. The data obtained from this study indicate that MBBR, with the applied media in this study, was more efficient than the fixed-bed bioreactor for biodegradation of organic matter under identical operating conditions.

Key words:
Moving-bed reactor, fixed-bed reactor, biofilm, organic matter, biodegradation

Introduction

Application of integrated bioreactors in the forms of moving- or fixed-bed has been widely investigated and practiced.[1–3] Many investigations[4–7] have proven their advantages, which include high concentration of biomass, potential use of low cost beds, ability to treat higher flow rates or higher removal efficiency in the same flow rate compared to suspended growth reactors, effective treatment of low concentration wastewaters, ability to treat organic compound with low degradation rate, resistance to hydraulic and organic shock, lower energy and space requirements, lower yield and thus lower sludge production, and better quality of secondary effluent. The questions and challenges faced in this field are selecting suitable cost-effective support media, using material supporting fast and persistent microorganism attachment on carriers, the filling grade of aeration tank by carriers, the position of beds in aeration tank, and using fixed or moving beds in bioreactors.[8–11]

Factors such as porosity of the biofilm and carrier, substrate concentration in the bulk liquid, mass transfer at the biofilm–liquid interface and reaction rate in the biofilm, mainly affect the penetration depth of substrates within biofilms.[12–15] Considering the above factors, type of bed, i.e. fixed or moving bed, could greatly affect the performance of integrated bioreactors. It is believed that, due to the uniform access of substrate and oxygen to the biofilm, as well as the hydraulic regime and full submergence and movement of all carrier sides, the moving-bed bioreactors result in a thinner biofilm, which in turn enhances transformation and diffusion of substrate and dissolved oxygen within the biofilm. These factors generally enhance the performance of moving-bed bioreactors. On the other hand, easy washout of the biofilm attached to the carriers due to hydraulic shears could be considered as a concern point which could result in disturbed performance of bioreactor.[16–19] Many studies have been conducted to evaluate moving-bed bioreactors for treatment of different types of wastewaters. Wang *et al.* (2006) used a MBBR for treatment of municipal wastewater. The total nitrogen and COD removal was about 89.9 and 79 % in DO concentrations of 4 mg L^{-1} and HRT of 6 h.[20] In another study, Yen *et al.* (2008) studied the kinetics of nitrogen and carbon removal in a moving-bed bioreactor. The removal efficiencies of NH_4-N, NO_3-N and COD were about 75 %, 92 % and 70 %, respectively.[21]

Fixed-bed bioreactors are also investigated widely. Borghei et al. (2008) studied the kinetics of organic removal in fixed-bed aerobic bioreactor

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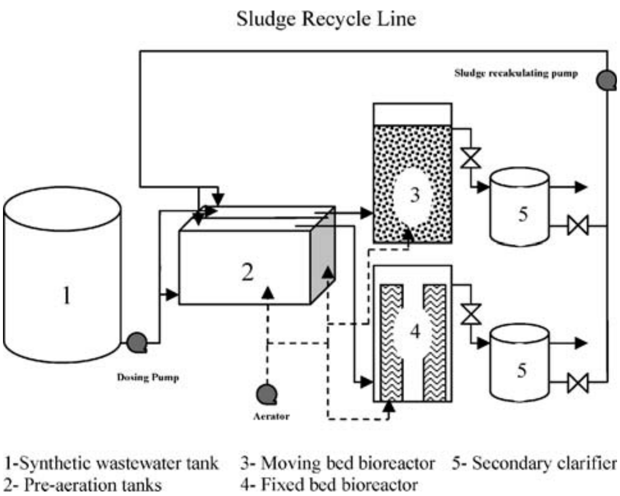
with pumice as fixed carrier for treatment of sugar production wastewater.[22]

According to literature and previous experiments of authors, this study was designed to compare the performance of moving- and fixed-bed integrated bioreactors for treatment of moderately high strength synthetic wastewater under identical operating conditions.

Materials and methods

Lab-scale bioreactors

A cubic Plexiglas reactor of 10-L total volume was used as pre-aeration tank before the integrated bioreactors. This tank was divided into two separate 5-L sections with a vertical sealed wall. The synthetic wastewater was passed through the pre-aeration tank and then fed into the integrated bioreactors. Two cylindrical Plexiglas reactors with total effective volume of 30 L were used as moving- and fixed-bed bioreactors for biological reactions. The reactors were followed by two separate clarifying tanks, with total volume of 6 L for each bioreactor. Forty percent of bioreactors were filled by packing. The MBBR was filled with a special media named 2H-BCN 014 KLL. Also a special type of fixed media by the name of Biofix was placed in the fixed-bed bioreactor. The characteristics of carriers are shown in Table 1. The bioreactors (both fixed and moving) were aerated with an aerator pump at injection capacity of up to 60 L_{air} min^{-1}. The contents of bioreactors were mixed with diffused air. Synthetic influent wastewater was fed by a dosing pump at capacity of 40 L h^{-1}, and also the settled activated sludge was returned to the pre-aeration tank from the clarifying tanks. The pilot was operated at room temperature (20–25 °C). A schematic diagram of lab-scale integrated bioreactor is shown in Fig. 1.



F i g . 1 – *Schematic of lab-scale integrated bioreactors*

T a b l e 1 – *Carrier characteristics*

Parameter	Characteristics	
	2H-BCN 014 KLL	Bio-fix
Material	HDPE	HDPE
Specific surface area	767 m^2 m^{-3}	480 m^2 m^{-3}
Mass of 1 m^3	151 kg	184 kg
Color	Black	Black

Inoculums

For use as inoculums, sludge was taken from the return sludge line of a full-scale municipal wastewater treatment plant in Tehran city. The sludge was thoroughly aerated for three days and chemical oxygen demand (COD), volatile suspended solids (VSS), and pH of the mixed liquor were measured at room temperature.

Synthetic wastewater

For startup, the reactor was fed with synthetic wastewater composed of glucose as carbon source and mineral medium including NH_4Cl, KH_2PO_4 (as nitrogen and phosphorus sources), $NaHCO_3$ (for pH adjustment) and trace elements. Synthetic wastewater composition is presented in Table 2. The amounts of constituents of synthetic wastewater were adjusted according to C:N:P ratio of 100:5:1 for optimum bacterial growth and metabolism.[23,24]

T a b l e 2 – *Composition of synthetic wastewater at the beginning of experiments*

Constituent	Amount
$C_6H_{12}O_6$[c] (mg L^{-1})	890
NH_4Cl (mg L^{-1})	28
KH_2PO_4 (mg L^{-1})	5.6
$MgSO_4$ (mg L^{-1})	69.6
$CaCl_2 \cdot 2H_2O$ (mg L^{-1})	22.5
$CuSO_4 \cdot H_2O$ (mg L^{-1})	0.08
$Na_2MoO_4 \cdot 2H_2O$ (mg L^{-1})	0.15
$MnSO_4 \cdot H_2O$ (mg L^{-1})	0.13
$ZnCl_2$ (mg L^{-1})	0.23
$CoCl_2 \cdot 6H_2O$ (mg L^{-1})	0.42
$FeCl_2 \cdot 4H_2O$ (mg L^{-1})	17.25

[a]Amounts for total COD of 500 mg L^{-1}
[c]Purity of $C_6H_{12}O_6$ = 60 %

Bioreactor startup and biomass attachment

The reactor was first operated in batch mode for approximately 9 weeks and DO was adjusted to 4–5 mg L^{-1}. The COD at the beginning of the experiments was adjusted to 500 mg L^{-1}. After 24 hrs of aeration, the aerators were switched off and the sludge was allowed to settle. Then 1.5 L of the supernatant was withdrawn and replaced with new synthetic wastewater. The biofilm attachment and growth on carriers was monitored visually. The COD, DO, VSS, MLSS and pH were monitored daily.

Experimental procedure

After obtaining desired results in terms of COD removal and biofilm growth in batch-mode operation, the flow was made continuous. Organic load was increased in two sequencing stages, first through HRT depletion by introducing more flow rate in a constant volume of bioreactor and then in the second stage, by increasing the glucose concentration in constant HRT of 8 h.

Steady-state condition in this study was defined as conditions in which effluent characteristics did not vary significantly over 7 to 10 days of continuous operation. All the experimental data taken under steady-state conditions are expressed in terms of arithmetic averages obtained from at least three replicates. Different operating conditions are summarized in Table 3.

Table 3 – *Operational conditions in different runs for continuous flow experiments*

Stage	Run	HRT (h)	COD (mg L^{-1})	OLR (kg COD m^3 d^{-1})
Stage 1	1	24	500	0/5
	2	16	500	0/75
	3	8	500	1/5
	4	4	500	3
Stage 2	5	8	500	1/5
	6	8	1000	3
	7	8	1500	4/5
	8	8	2000	6
	9	8	2500	7/5
	10	8	3000	9

Loading in constant glucose concentration and varying HRT

In the first stage, the reactor was operated at four hydraulic retention times of 24, 16, 8 and 4 h, and constant influent COD of 500 mg L^{-1}. The effluent COD, NH_4-H, PO_4-P, DO, VSS, MLSS, attached biofilm and pH were monitored until steady-state conditions were achieved. Achieving steady-state conditions in each run took approximately 2 to 3 weeks.

Loading in varying glucose concentrations and constant HRT

In the second stage, the reactor was operated at constant HRT of 8 h and COD concentrations of 500, 1000, 1500, 2000, 2500 and 3000 mg L^{-1}. The aforementioned parameters were also monitored until steady-state conditions at this stage were observed.

Analytical methods

The COD, DO, and suspended VSS were measured according to standard methods.[25] The pH value was monitored frequently with a Hach Company pH-meter and was adjusted with sodium bicarbonate when necessary. The attached biomass was determined by gravimetric method. The biofilm mass was determined using 100 media elements that were sampled randomly from the fixed-bed bioreactor. The media elements were separated from the wastewater and dried until constant mass in an oven at 103 °C. The dried samples were weighed in order to determine the total mass (*M* total) composed of media element mass (*M* media) and the attached biomass. The biomass was then washed off, the clean media elements were weighed, and the amount of biofilm solids attached to the 100 media elements was calculated using eq. (1). The amount of biomass in the reactor could then be determined since the total number of carrier elements in the reactor with filing grade of 40 % was known.[26]

This procedure was followed for both fixed- and moving-bed bioreactors.

$$BS_{100} = M \text{ total} - M \text{ media} \quad (1)$$

Statistical analysis

Mean and standard deviation were used to describe obtained data. Data were also analyzed by using Wilcoxon Signed Ranks Test. Operational parameters such as VSS, total biomass, biofilm and COD in moving-bed and fixed-bed bioreactors were analyzed according to mean difference and Wilcoxon test.

Results and discussion

Performance of pre-aeration unit

As mentioned in the previous section, a pre-aeration tank with short HRT of 0.45 h was used before the bioreactors. The COD and VSS variations are shown in Table 4. Because of the

Table 4 – *Experimental data obtained under steady-state conditions for pre-aeration reactor*

OLR (kg COD m^3 d^{-1})[a]	HRT (h)	VSS (mg L^{-1})		COD_{in} (mg L^{-1})		COD_{out} (mg L^{-1})		COD removal (%)	
		Ave	± Std	Ave	± Std	Ave	± Std	Ave	± Std
16	0.45	1985	± 41	500	–	395	± 3	21	± 6
16	0.45	1993	± 26	500	–	390	± 5	22	± 4
16	0.45	2089	± 33	500	–	395	± 7	21	± 3
16	0.45	2127	± 27	500	–	400	± 6	20	± 5
16	0.45	2150	± 38	500	–	390	± 6	22	± 8
32	0.45	2179	± 20	1000	–	850	± 8	15	± 9
48	0.45	2186	± 43	1500	–	1320	± 7	12	± 6
64	0.45	2198	± 35	2000	–	1780	± 5	11	± 4
80	0.45	2214	± 21	2500	–	2250	± 4	10	± 9
96	0.45	2242	± 31	3000	–	2820	± 8	6	± 7

[a]The OLR was calculated for whole volume

short retention time of 0.45 h and low volume of pre-aeration unit (5 L), high organic loadings of 16 to 96 kg COD m^3 d^{-1} were applied to the pre-aeration reactor. Along with OLR increase, the COD removal efficiency decreased from 22% to 6%. The highest COD removal efficiency of 22 % was observed in OLR of 16 kg COD m^3 d^{-1} and the lowest of 6 % in OLR of 96 kg COD m^3 d^{-1}. The abundance of soluble carbon and sufficient DO supports bacterial metabolism and growth, and a bacterial mass with excellent abilities for biodegradation increases. But low HRT hinders this ability and metabolism is continued in the following bioreactors with higher rates. Therefore, supplying a highly aerated biomass with acceptable degradative capabilities to the attached growth bioreactors is obtained. The results showed that removal efficiency was low in organic loadings higher than 16 kg COD m^3 d^{-1}. It seems that because of continuous aeration at concentrations higher than 2 mg L^{-1}, the microorganisms fed into the bioreactors are highly ready for biodegradation of organic matter. Therefore, the main effect of the pre-aeration reactor is the acceleration of biodegradation in the following integrated bioreactors.

Performance of moving-bed bioreactor

A summary of operational results obtained for the moving-bed bioreactor is presented in Table 5. The VSS and biofilm concentrations increased from 3114 to 3290 mg L^{-1} and from 980 to 1190 mg L^{-1} respectively, along with OLR increase. The biofilm value in another study by Plattes *et al.* (2006) was 2600 to 2800 mg L^{-1} for OLR of 1.386 kg m^3 d^{-1}. They used MBBR for treatment of domestic wastewater. The filling grade of the reactor, type of media, and operating conditions such as HRT and OLR may be the most important reasons for the difference. The highest COD removal efficiency of 96.27 % was obtained at OLR 0.295 kg COD m^3 d^{-1} (COD concentration of 295 mg L^{-1} and HRT of 24 h) and the lowest efficiency of 81.27 % at OLR 8.460 kg COD m^3 d^{-1} (COD concentration of 2820 mg L^{-1} and HRT of 8 h), compared to the 66 % COD removal efficiency obtained by Plattes *et al.* (2006) for OLR 1.386 kg COD m^3 d^{-1},[26] which is much lower than the data obtained in this study, and also total COD removal efficiency of 91 % at OLR 4.08 kg COD m^3 d^{-1} which is in agreement with the results of this study.

The results indicate that removal efficiency was generally lowered as the OLR increased, but the mass of organic matter removed was increased. For compression, 2292 mg COD was removed in OLR 8460 g COD m^3 d^{-1} with 81.27 % removal efficiency, while 284 mg COD was removed in OLR 0.295 kg COD m^3 d^{-1} with COD removal efficiency of 96.27 %. The increase in concentrations of VSS and biofilm along with OLR confirm this matter. The lower COD removal efficiency of 88 % in run 4 compared with runs 6, 7, 8 and 9 (COD removal efficiency above 90 %) indicate that HRT is more effective on reactor performance than organic matter concentration.

Table 5 – *Experimental data obtained under steady-state conditions for moving-bed bioreactor*

Run of operation	OLR (kg COD m^3 d^{-1})[a]	Parameter												
		Day of operation	HRT	VSS (mg L^{-1})		Biofilm (mg L^{-1})		COD_{in} (mg L^{-1})		COD_{out} (mg L^{-1})		COD removal (%)	
				Ave	± Std	Ave	± Std	Ave	± Std	Ave	± Std	Ave	± Std
1	0.295	0–31	24	3144	± 14	980	± 10	295	–	11	± 6	96.27	± 6
2	0.435	32–57	16	3150	± 21	1102	± 9	290	–	12	± 4	95.86	± 4
3	0/885	58–87	8	3152	± 22	1110	± 12	295	–	18	± 3	93.89	± 3
4	1.8	88–112	4	3160	± 36	1120	± 14	300	–	36	± 5	88	± 5
5	0.870	113–130	8	3150	± 18	1115	± 21	290	–	17	± 8	94.13	± 8
6	2.130	131–153	8	3232	± 27	1135	± 16	710	–	47	± 9	93.38	± 9
7	3.555	154–180	8	3240	± 19	1190	± 11	1185	–	99	± 6	91.64	± 6
8	5.040	181–205	8	3285	± 26	1280	± 15	1680	–	147	± 4	91.25	± 4
9	6.675	206–228	8	3290	± 28	1285	± 18	2225	–	218	± 9	90.2	± 9
10	8.460	229–253	8	3286	± 20	1278	± 7	2820	–	528	± 7	81.27	± 7

[a]The OLR was calculated for whole volume

Performance of fixed-bed bioreactor

A summary of operational results obtained for the fixed-bed bioreactor is presented in Table 6. The VSS and biofilm concentrations were increased along with OLR from 0.295 to 8.460 kg COD m^3 d^{-1}. The VSS and biofilm concentrations were increased gradually from 3360 and 760 mg L^{-1} to 3790 and 850 mg L^{-1} respectively. Similar to moving-bed bioreactor, the highest COD removal efficiency of 95.2 % was obtained at OLR 0.295 kg COD m^3 d^{-1} (COD concentration of 295 mg L^{-1} and HRT of 24 h) and the lowest efficiency of 74.82 % at OLR 8.460 kg COD m^3 d^{-1} (COD concentration of 2820 mg L^{-1} and HRT of 8 h). Compared to this work, Farzadkia *et al.* (2010) studied a fixed-bed bioreactor for treatment of synthetic wastewater containing glucose and propylene glycol as carbon source.[27] The COD removal efficiency for OLR from 1.25 to 10 kg COD m^3 d^{-1} ranged from 35 to 96 % with COD removal efficiencies of more than 90 % for OLR less than 4 kg COD m^3 d^{-1}. Also, the

Table 6 – *Experimental data obtained under steady-state conditions for fixed-bed bioreactor*

Run of operation	OLR (kg COD m^3 d^{-1})[a]	Parameter												
		Day of operation	HRT	VSS (mg L^{-1})		Biofilm (mg L^{-1})		COD_{in} (mg L^{-1})		COD_{out} (mg L^{-1})		COD removal (%)	
				Ave	± Std	Ave	± Std	Ave	± Std	Ave	± Std	Ave	± Std
1	0.295	0–30	24	3360	± 27	760	± 9	295	–	14	± 7	95.2	± 7
2	0.435	31–55	16	3412	± 30	810	± 11	290	–	22	± 9	92.41	± 9
3	0/885	56–87	8	3578	± 25	826	± 16	295	–	25	± 5	91.52	± 5
4	1.8	88–115	4	3594	± 31	828	± 7	300	–	50	± 2	83.33	± 2
5	0.870	116–138	8	3580	± 21	820	± 10	290	–	26	± 4	91.03	± 4
6	2.130	139–163	8	3610	± 26	827	± 12	710	–	68	± 3	90.42	± 3
7	3.555	164–187	8	3745	± 18	830	± 17	1185	–	175	± 8	85.23	± 8
8	5.040	188–215	8	3750	± 22	840	± 14	1680	–	287	± 6	82.91	± 6
9	6.675	216–238	8	3786	± 23	845	± 12	2225	–	410	± 5	81.57	± 5
10	8.460	239–259	8	3790	± 15	850	± 18	2820	–	710	± 4	74.82	± 4

[a]The OLR was calculated for whole volume

VSS varied from 1896 to 2289 mg L^{-1} [27] which were less than 3360 to 3790 mg L^{-1} in this study. This could be due to the lower volume of the fixed packing in their study (22 %) which supports suspended growth. The biofilm varied from 2.089 to 5.15 mg L^{-1} in experimented OLR, compared to 760 to 850 mg L^{-1} in this study. Perhaps the differences between the two media and their specific surface area, operating conditions, and the presence of propylene glycol in the study of Farzadkia *et al.* (2010) are the most important reasons for this matter.

Comparison of moving-bed and fixed-bed bioreactors

The statistical analysis results are presented in Table 7. All compared parameters in both bioreactors were significant with p value < 0.05.

The results generally indicate more biofilm mass attached to the media in the moving-bed bioreactor than in the fixed-bed bioreactor. For example, in run 5 under same operating conditions for both reactors, the biofilm mass in fixed-bed reactor was 820 mg L^{-1} compared to 1115 mg L^{-1} in moving-bed reactor. This trend was observed in all runs of operation. Possible reasons for this include better oxygen and substrate diffusion in the biofilm attached to the media of moving-bed reactor, thus the bacterial mass having uniform access to it, the media is well-circulated through the entire volume of the reactor, formation of a thin, active and effective biofilm in moving-bed bioreactor compared to fixed-bed packing containing several points with thick and dead anaerobic biofilm, as well as no clogging in the packing of the moving-bed reactor which enhances biofilm efficiency. Statistical analysis with paired sample t-test indicated that the differences in biofilm data are insignificant until run 6 (p value < 0.05), and statistically significant for runs 7 to 10 (p value > 0.05). A pictorial view of media containing biofilm for both fixed and moving media are presented in Figs. 3 (a) and (b). The VSS concentrations in fixed-bed reactor were generally higher than moving-bed reactor. For example, in

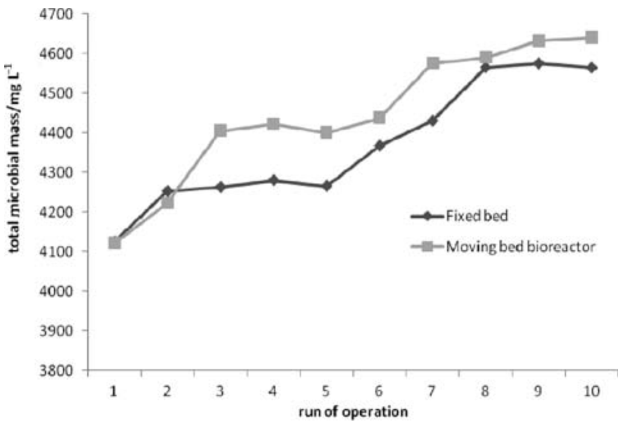


Fig. 2 – *Comparison of total microbial mass concentrations in moving- and fixed-bed bioreactors*

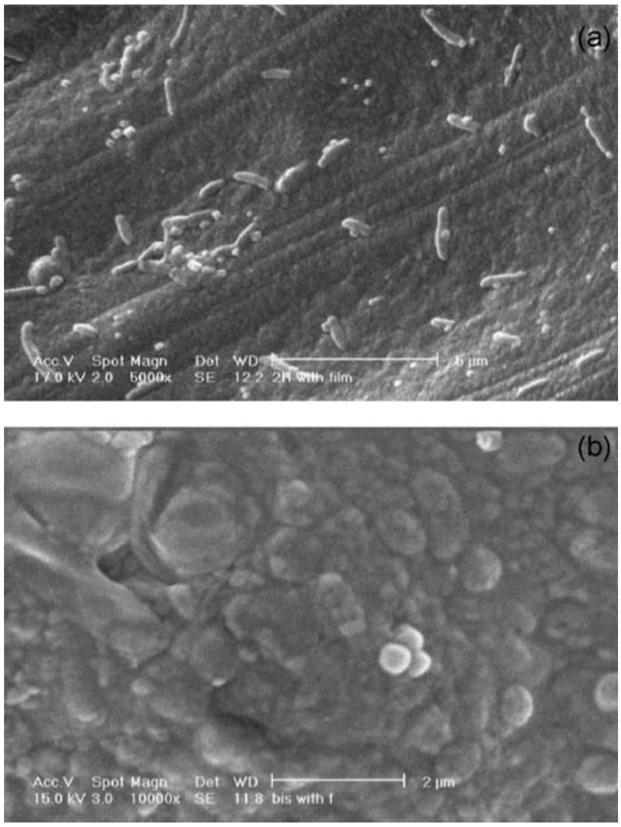


Fig. 3 – *Electronic-microscope images of biofilm attached to (a) fixed-bed media and (b) moving-bed biofilm*

Table 7 – *Statistical Analysis Data*[28]

Variable / Statistic	Fixed yield – MBBR yield	Fixed biofilm – MBBR biofilm	VSS of fixed-bed reactor – VSS of MBBR	Total fixed biomass – Total moving biomass	COD out of fixed – COD out of MBBR
Z	–2.803(a)	–2.807(a)	–2.803(b)	–2.397(a)	–2.803(b)
Asymp. Sig. (2-tailed)	.005	.005	.005	.017	.005

[a]Based on positive ranks.

[b]Based on negative ranks.

[c]Wilcoxon Signed Ranks Test

run 6 with the same operating conditions for both bioreactors, the VSS concentration in fixed-bed reactor was 3610 mg L^{-1} compared with 3232 mg L^{-1} in moving-bed reactor. This trend was observed in all runs of operation.

The sloughing of the dead, anaerobic and thick biofilm in fixed-bed reactor, which was measured as VSS, is probably the main reason for higher VSS in fixed-bed reactor. Since the active and inactive VSS were not distinguished in these experiments, the value of VSS was higher in fixed-bed rector with no enhancement in COD removal efficiency, as the performance of moving-bed reactor was better generally. This claim was proved statistically by a paired *t*-test with *p* value of 0.05. The results of the statistical analysis indicates that the removal efficiency in fixed- and moving-bed reactors were statistically significant (p value > 0.05) for all runs of operation. Statistical analysis with paired sample *t*-test indicated that the differences of VSS concentrations were significant statistically in all runs of operation (p value > 0.05). The results of total microbial mass including attached and suspended mass are compared in Fig. 2. With the exception of runs 1 and 2, the total microbial mass in moving-bed reactor was higher than in fixed-bed reactor.

The COD removal efficiency of moving-bed reactor for runs of operation 1 to 10 with OLR 0/295 to 8/460 kg COD m^3 d^{-1} were 1.07 %, 3.45 %, 2.37 %, 4.6 %, 3.1 %, 2.96 %, 6.41 %, 8.34 %, 8.63 % and 6.45 % higher than fixed-bed reactor, respectively. According to Figs. 4(a) and (b), the COD removal efficiency decreased gradually along with OLR increase in both bioreactors with a rather weak correlation coefficient of 0.75 for moving-bed bioreactor and 0.54 for fixed-bed bioreactor. The usage of a random media with higher specific surface area of 767 m^2 m^{-3} in contrast to fixed media with specific surface area of 480 m^2 m^{-3} was the most important reason for better efficiency of moving-bed bioreactor. Furthermore, clogging of packing, canalization of flow, formation of thick and dead biofilm, low efficiency of DO and substrate diffusion in the depth of biofilm in positions with poor hydraulic regime of flow and lack of uniform biofilm formation in total surface of media in fixed-bed reactor are the potential reasons for lower COD removal efficiency in fixed-bed bioreactor.

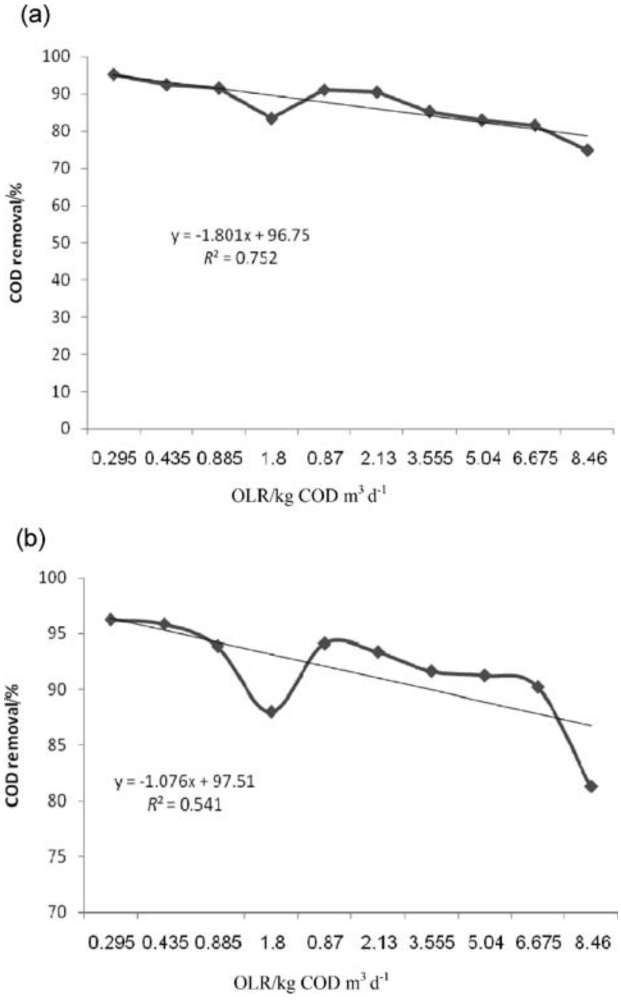


Fig. 4 – *Variations of COD removal along with organic loading (a) moving-bed bioreactor, (b) fixed-bed bioreactor*

Conclusion

The summaries of results obtained in this study are presented below. The pre-aeration tank decreased the influent organic matter in the range of 6 to 21 % for OLR_s of 16 to 96 kg COD m^3 d^{-1}. It is believed that the biomass entering the integrated bioreactors is highly suitable for rapid biodegradation of organic matter because of sufficient aeration, but otherwise lacks sufficient contact time in pre-aeration tank. The COD removal in moving-bed bioreactor decreased from 96.27 % to 81.27 % along with OLR increase from 0.295 to 8.460 kg COD m^3 d^{-1}. Similar to moving-bed reactor, the COD removal efficiency for fixed-bed reactor decreased from 95.2 % to 74.82 % under the same operating conditions. The data of COD removal between two reactors were statistically significant (p value > 0.05). It should be noted that the total microbial mass, including attached biofim and VSS in moving-bed reactor (4120 – 4640 mg L^{-1}) was higher than fixed-bed reactor (4124 – 4564 mg L^{-1}) in the same operating conditions. The data obtained from this study confirms that moving-bed bioreactor is more efficient than fixed-bed bioreactor for biodegradation of moderate to highly loaded systems treating wastewaters containing organic matter in identical operating conditions.

List of symbols and abbreviations

COD – Chemical Oxygen Demand, mg L^{-1}

DO – Dissolved Oxygen, mg L^{-1}

HRT – Hydraulic Retention Time, h

MLSS – Mixed Liquor Suspended Solids, mg L^{-1}

SVI – Sludge Volume Index, mL g^{-1}

VSS – Volatile Suspended Solids, mg L^{-1}

HDPE – High Density Polyethylene

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