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COMPARISON OF OVERALL PERFORMANCE BETWEEN MOVING-BED AND CONVENTIONAL SEQUENCING BATCH REACTOR

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ABSTRACT

The main objective of present work was to compare the overall performances of "moving-bed" and "conventional" sequencing batch reactor. For this purpose, different experimental parameters including COD and dye concentration, turbidity, MLSS concentration, MLVSS/MLSS ratio, sludge volume index (SVI) and Oxidation-Reduction Potential (ORP) were calculated. One conventional sequencing batch reactor and three moving-bed sequencing batch reactors (MB-SBR) were operated in this study. Each MB-SBR was equipped with a type of moving biofilm carrier. The results of dye, COD and turbidity analysis showed that there were no significant differences between the moving-bed and conventional sequencing batch reactors in the matters of effluent quality. A higher fluctuation of MLSS concentration and also higher SVI were observed in moving-bed compared to that of the conventional sequencing batch reactor. Higher ORP values which mean higher oxidation potential were measured in the reactors equipped with the moving carriers in comparison with those measured in the conventional sequencing batch reactor.

Key words: Overall Performance; Biological treatment; Moving-bed sequencing batch reactor (MB-SBR); Biofilm carrier

INTRODUCTION

In spite of the reasonable efficiency of physicochemical wastewater treatment techniques such as adsorption, coagulation/flocculation, electrocoagulation and fenton (Mollah *et al*., 2004; Hasani Zonoozi *et al*., 2009; Azizi *et al*., 2010; Elmorsi *et al*., 2010), these methods have shown to face some drawbacks including cost and energy consumption (Pandey *et al*., 2007), generation of large amounts of sludge which require safe disposal (Supaka *et al*., 2004) and interference with other wastewater constituents (Van der Zee and Villaverde, 2005). Therefore, biological processes as the environmentally friendly and cost-competitive alternatives to the physicochemical treatment of wastewaters have excessively been applied within the last decades (Sirianuntapiboon *et al*., 2005; Garcia *et al*., 2008; Yang *et al*., 2009). Nevertheless, the operational difficulties experienced with the conventional suspended-growth systems as well as high production of different types of industrial wastewaters containing more biologically recalcitrant compounds motivated considerable efforts for the development of attached-growth (biofilm) processes (Dulkadiroglu *et al*., 2005).

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Previous experiences of applying different types of fixed bed biofilm processes such as Rotating Biological Contactors (RBCs), trickling filters, fixed media submerged biofilters, fluidized bed reactors have proved the suitable features of these systems including high biomass retention time, no need for sludge recycling and ability to withstand organic shocks (Hamoda, 1989). The attached-growth processes also have shown to be more drastic than suspended-growth systems for the removal of difficult to degrade compounds (Jiang and Bishop, 1994).

In recent years, due to some difficulties associated with the operation of fixed bed biofilm systems such as clogging and necessity of backwash, there has been a growing interest in the application of moving-bed biofilm reactors (MBBR) in which the biofilm is grown on the surfaces of moving carriers instead of the fixed ones. The MBBR was first introduced in Norway in 1994 (Ødegaard *et al.*, 1994) and now are successfully operated in more than 400 large-scale wastewater treatment plants in 22 different countries (Rusten *et al.*, 2006; Kermani *et al.*, 2008; Zafarzadeh *et al.*, 2010). The feasibility and efficiency of these reactors for the treatment of many industrial effluents including chemical industry, refinery and slaughter house, pulp and paper industry and also wastewaters containing recalcitrant compounds such as aniline and phenol have been sufficiently demonstrated by different researchers (Rusten *et al.*, 1994; Borghei and Hosseini, 2004; Delnavaz *et al.*, 2008; Bassin *et al.*, 2011). In spite of some studies have been recently done to investigate the effects of moving biofilm carriers and their movement on some characteristics of MBBR such as effluent TSS, biofilm morphology and secretion of extracellular polymeric substances (EPS) (Pei-shi *et al.*, 2009), there is still a need to work on performance of moving-bed biofilm systems.

The main objective of present work was to investigate the overall performance of moving-bed sequencing batch reactor (MB-SBR) including effluent quality (COD concentration, dye concentration and turbidity), MLSS concentration, MLVSS/MLSS ratio, sludge volume index (SVI) as well as Oxidation-Reduction Potential (ORP) and compare with those of conventional sequencing batch reactor (SBR). It should be noted that in order to understand if the thickness of the attached-growth biofilm was as enough as the azo bond reduction needs, the azo dye Acid Red 18 (AR18) (which is decolorized just in the anaerobic condition) was added to the reactors feed solution.

MATERIALS AND METHODS

Synthetic wastewater composition

Chemical composition of synthetic wastewater used in this study was as follows: Azo dye AR18 (40 mg/L), powdered milk (1 g/L) as the main carbon source, urea (152 mg/L) as the nitrogen source, KH_2PO_4 (32 mg/L) and K_2HPO_4 (40 mg/L) as the phosphorus source. Influent COD concentration was about 1000 mg/L. An azo dye (C.I. Acid Red 18 (AR18)), which is commonly used in textile industries in Iran was obtained from Alvan Sabet Company (Iran). Chemical structure of AR18 is presented in Fig. 1.

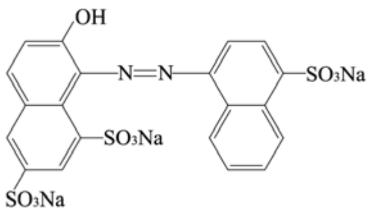


Fig. 1: Chemical structure of C.I. Acid Red 18

Reactors configuration

The experimental setup consisted of one conventional SBR and three MB-SBRs. All reactors were made of plexiglas with the inner diameter of 14 cm, height of 50 cm and total volume of 9.8 liters which 5 liters were working volume. Schematic of the MB-SBRs and conventional SBR is shown in Fig. 2.

Three types of plastic media, M1, M2 and M3 were used as biofilm carrier in MB-SBR1; MB-SBR2 and MB-SBR3, respectively. Physical properties of these carriers are listed in Table 1. About 50 percent of the working volume of MB-SBRs was filled with biofilm carriers and a coarse bubble aeration system made them thoroughly immersed.

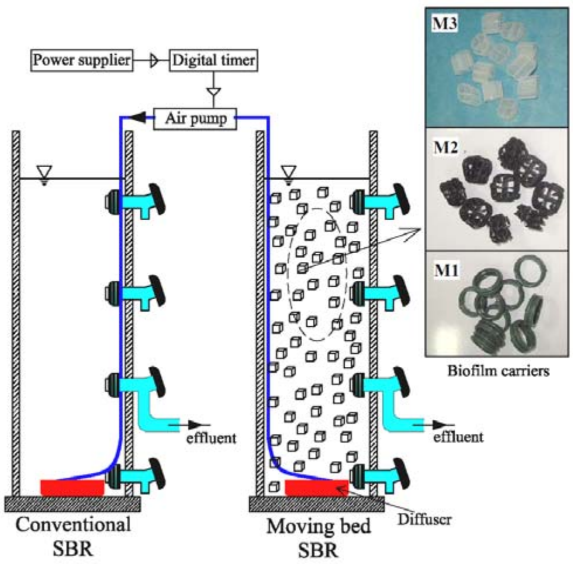


Fig. 2. Schematic of the moving-bed and conventional SBR used in this study

Startup and operation of the reactors

Bio-sludge was collected from Zargandeh municipal wastewater treatment plant, Tehran (Iran) as the inoculums of the aerobic SBR and MB-SBRs. To acclimatize the microorganisms, all reactors were initially operated with dye-free synthetic wastewater, low COD loading and about 2500 mg/L MLSS. Then during one week the influent COD and dye concentration were increased and finally reached the constant values of about 1000 mg/L and 40 mg/L, respectively. An SBR treatment cycle consists of a timed sequence which typically includes the following steps: Fill, React, Settle, Decant and Idle (Mahvi, 2008). In present study, operation cycle for all reactors was 24 hours including 15 min filling, 22 hours aeration, 1 hour settling, 15 min discharge and 30 min idle time. In the filling phase, 2 liters of the synthetic wastewater was supplied to MB-SBRs as well as the conventional SBR. In the reaction phase an electromagnetic air pump (RESUN; ACO-006, China) was used for supplying air and keeping the dissolved oxygen concentration above 3 mg/L. To keep the bio-sludge concentration stable, 350 mL of mixed liquor of all reactors was wasted during the reaction phase. Hydraulic retention time (HRT) was kept 2 days. Reactors operation was done at room temperature (20-22°C).

Dye concentration measurement

Decolorization efficiency was determined by monitoring the decrease in absorbance at 507 nm, the maximum absorbent wavelength of AR18 with a background of distilled water using UV-Vis spectrophotometer (DR 4000, HACH, USA). Dye concentrations were determined from the developed absorbance-concentration calibration curve (Fig. 3). The samples were diluted with distilled water if necessary. Before the analysis, the samples withdrawn from the treatment systems were centrifuged at 6000 rpm for 10 min. All experiments were conducted at room temperature (20-22°C).

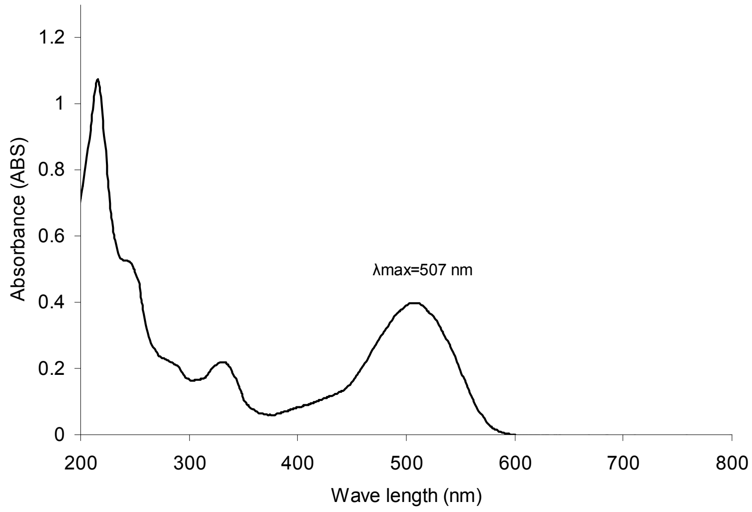
Table 1: Physical characteristics of the biofilm carriers

	Type of media used in MB-SBR1, 2, 3		
	M1	M2	M3
Shape	Cylindrial	Cubic	Cubic
Density (g/cm^3)	0.93	0.95	0.89
Specific surface area (m^2/m^3)	190	415	517
Weight of each carrier (g)	0.17	0.43	0.21
Filling ratio (%)	50	50	50

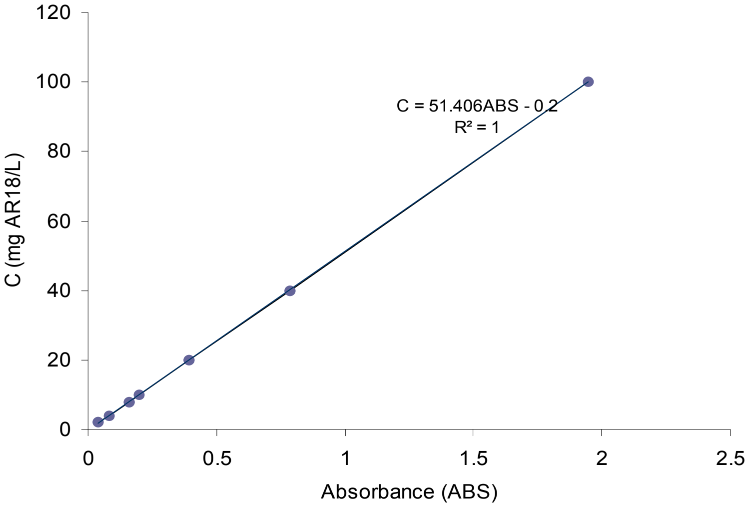
Other chemical analysis
The chemical oxygen demand (COD), dye absorbance ratio, mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), turbidity, dissolved oxygen (DO), pH and sludge volume index (SVI) were determined by using standard methods for the examination of water and wastewater (APHA *et al*., 1998).

RESULTS

Comparison of effluent quality in MB-SBRs and conventional SBR
Table 2 summarized the main experimental results obtained in this study. As presented in Table 2, the average effluent COD concentration in MB-SBR1-3 and the conventional SBR were 43.4 mg/L, 24.8 mg/L, 26.8 mg/L and 26.9 mg/L, respectively. Therefore, there was



(a)



(b)

Fig. 3: UV-Vis spectral analysis of AR18: a) UV-Vis spectrum; b) Calibration curve

Table 2: The main experimental results obtained during the reactors operation period

Reactors	SBR	MB-SBR1	MB-SBR2	MB-SBR 3
Effluent COD (mg/L)	43.4 ± 13.4	24.8 ± 17.3	26.8 ± 16.8	26.9 ± 15.0
COD removal (%)	96.1 ± 1.2	97.7 ± 1.6	97.5 ± 1.5	97.6 ± 1.4
Effluent turbidity (NTU)	1.9 ± 0.3	3.1 ± 1.7	3.5 ± 1.9	3.3±2.2
MLSS (mg/L)	2535 ± 245	3135 ± 761	3245 ± 729	2938 ± 636
MLVSS (mg/L)	1931 ± 157	2624 ± 724	2739 ± 587	2459 ± 445
MLVSS/MLSS (%)	76 ± 5.1	82 ± 3.7	82 ± 2.1	82 ± 4.8
SV_{30} (mg/L)	100 ± 100	511 ± 290	473 ± 342	353 ± 314
SVI (mL/g of MLSS)	40 ± 43.3	160 ± 98.1	144 ± 119	120 ± 111

no considerable difference between the MB-SBRs and conventional SBR in the matter of effluent COD. The variation of COD removal efficiency within 45 days of reactors operation period is illustrated in Fig. 4. The results also revealed that the dye removal efficiency as well as the effluent turbidity of MB-SBRs and conventional SBR was almost the same. The lack of AR18 decolorization as well as the visual observation of biofilm carriers surfaces proved that the thickness of the attached-growth biofilm was not as enough as the azo bond reduction needs.

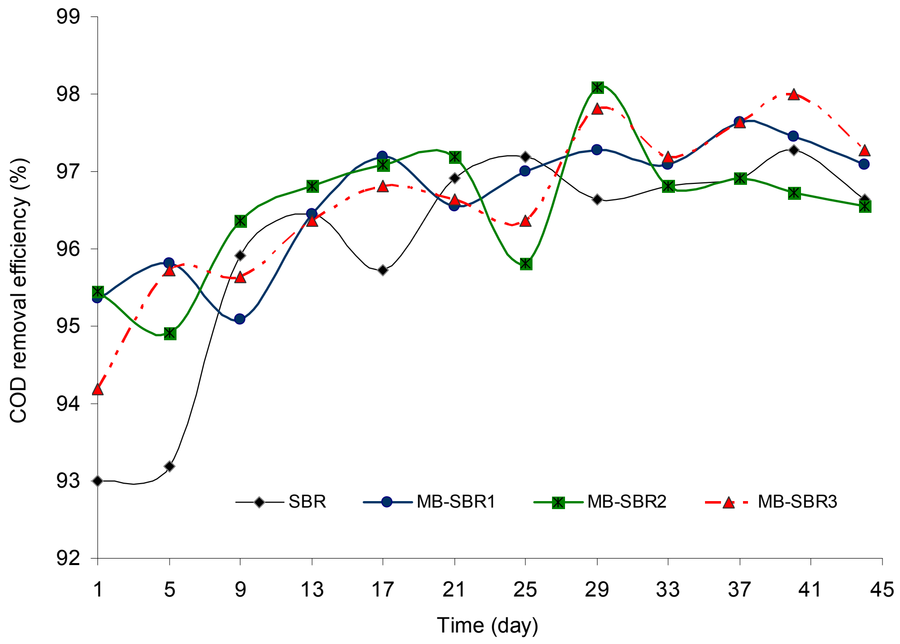


Fig. 4: The variation of reactors COD removal efficiency during operation period

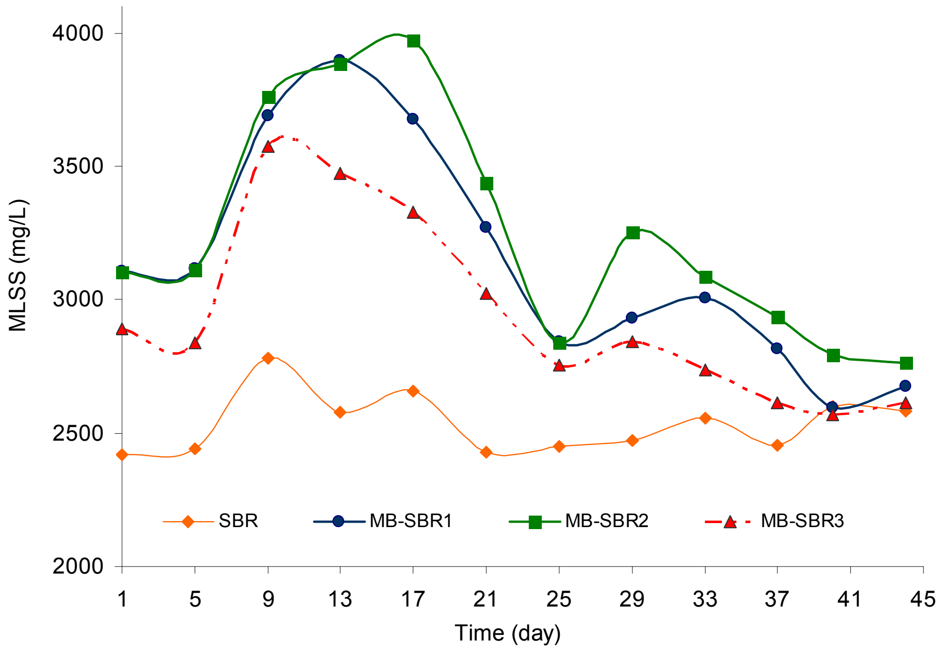


Fig. 5: The variation of MLSS concentration in MB-SBRs and conventional SBR

Comparison of MLSS and MLVSS in MB-SBRs and conventional SBR

Although during the operation days, all conditions such as temperature, organic loading rate, aeration rate were same for all reactors, some significant differences in bio-sludge characteristics (MLSS and MLVSS) in the MB-SBRs and conventional SBR were observed. In order to compare the variation of biomass concentration in the MB-SBRs and conventional SBR, the change in MLSS concentration in the all applied reactors is shown in Fig. 5.

According to Fig. 5 and also the values of standard deviation for MLSS concentration in Table 2 (245, 761, 729 and 636 mg-MLSS/L for conventional SBR and MB-SBR1-3, respectively), a high fluctuation of MLSS concentration occurred in MB-SBRs in comparison with the almost stable MLSS concentration in the conventional SBR. By measuring the MLVSS concentration, it was understood that, the average MLVSS/MLSS ratio in conventional SBR was 76%, while in MB-SBRs, it was calculated more than 82%.

Comparison of SVI in MB-SBRs and conventional SBR

In order to determine sludge settleability in biological processes, sludge volume index is considered as an appropriate and widely used parameter (Qian *et al.*, 2009). According to Standard Methods, SVI is the volume of 1g of dried bio-sludge after 30 min sedimentation (APHA *et al.*, 1998). As presented in Table 2, the average SVI of the conventional SBR was 40 mL/g, while it was obtained about 160 mL/g, 144 mL/g and 120 mL/g for MB-SBR1, 2 and 3, respectively. The variation of SVI in the MB-SBRs and conventional SBR during 45 days of operation period is compared in Fig. 6.

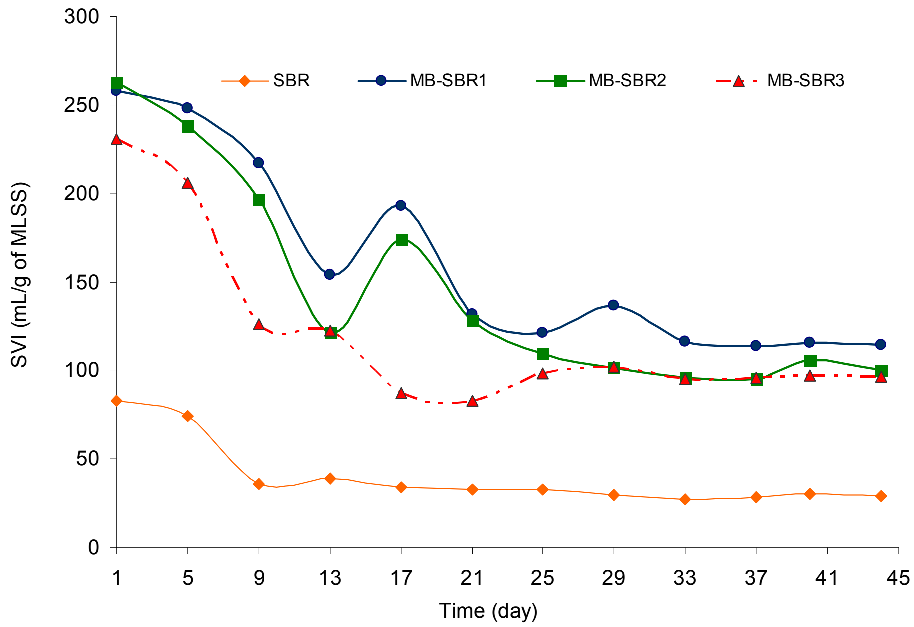


Fig. 6: Comparison of SVI variation between the MB-SBRs and conventional SBR

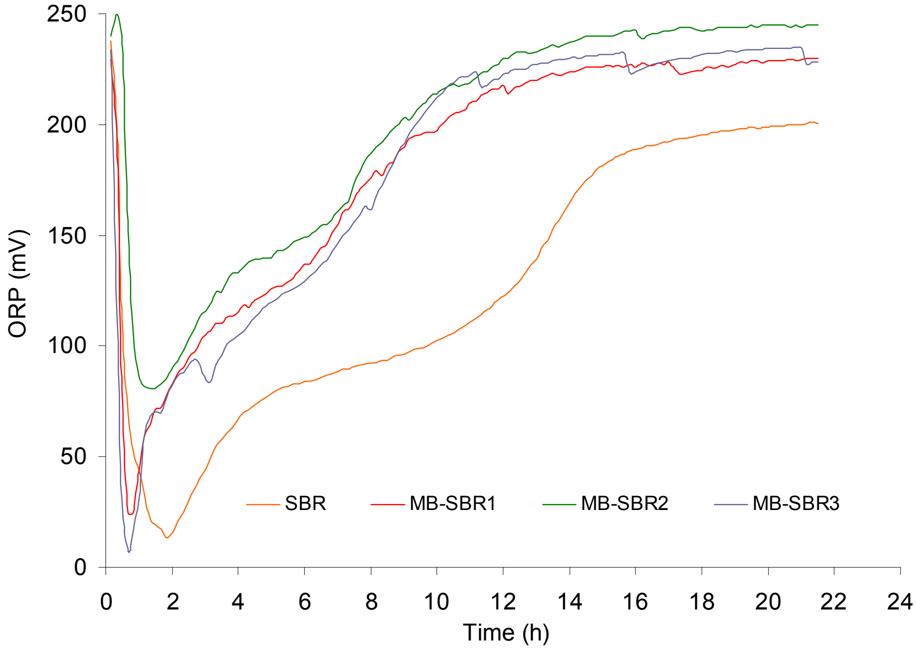


Fig. 7: Comparison of ORP variation between the MB-SBRs and conventional SBR during reaction phase

As seen in Fig. 6, after nine days, the SVI in the conventional SBR became stable, while in MB-SBRs after about 25 days the reactors showed the steady value of SVI. Also a significant similarity was observed between SVI trends in all three MB-SBRs.

Comparison of ORP in MB-SBRs and conventional SBR

Oxidation-Reduction Potential (ORP) is one of the widely used parameters to understand whether a solution has the potential of withdrawing electron or the potential of donating electron. Reduction (decolorization) of azo dyes is an oxidation-reduction reaction in which the dye acts as an electron acceptor and the biodegradable primary substrate acts as an electron donor (Van der Zee and Villaverde, 2005). In order to compare the oxidation-reduction ability of MB-SBRs and conventional SBR, the variation of ORP was monitored through a complete reaction cycle in all reactors (Fig. 7). As obvious in Fig. 7, in similar times after the start of the reaction phase, the value of ORP in MB-SBRs has been significantly higher than that in the conventional SBR.

DISCUSSION

According to the obtained results, the average COD removal efficiency in the conventional SBR and MB-SBR1-3 were 96.1%, 97.7%, 97.6% and 97.5%, respectively. Therefore, no significant influence on COD removal efficiency was observed by using biofilm carriers with different specific surface area. As illustrated in Fig. 4, the effluent COD concentrations in MB-SBRs were more stable than that in the conventional SBR. More stability of COD removal in moving-bed SBR in comparison with conventional SBR was also reported by other researchers (Sirianuntapiboon and Yommee, 2006).

As mentioned by other researchers, azo bond (N=N) cleavage occurs in anoxic or anaerobic condition (Van der Zee and Villaverde, 2005; Çınar *et al*., 2008). Biofilm studies have also shown that aerobic reactions occur in the shallow layer of the biofilm and oxidation-reduction reactions occur in the biofilm`s deeper zone (Buitrón *et al*., 2004). Therefore, no AR18 removal efficiency observed in MB-SBR reveals that the thickness of the attached-growth biofilm was not as enough as the azo bond reduction required.

A high fluctuation of MLSS concentration was observed in all MB-SBRs compared to that in the conventional SBR. As shown in Fig. 5, in MB-SBRs, the MLSS concentration increased within the first 13- 17 days and then decreased as far as reached in almost constant value in 33th days of operation. The average of MLVSS/MLSS ratio for the conventional SBR was 76%, while for all MB-SBRs it was higher than 82%. This shows that bio-sludge combination of MB-SBRs includes more volatile or organic compounds in comparison with the conventional SBR.

According to Fig. 6, the SVI in MB-SBRs initially raised at the beginning of the operation days and then decreased to the stable value within the about 33 days, while the SVI of the conventional SBR reached a constant value (about 35) within the nine first days. The main reason for higher SVI in MB-SBRs compared to that in the conventional SBR is the increase of shear stress due to the biofilm carriers movement which delay the formation of compressed and settleable bio-sludge flocs. This result is compatible with the report of Qian *et al*., 2009 describing that as the aeration induced shear stress raised, the sludge volume index initially increased and then decreased.

Comparison of ORP trend between MB-SBRs and the conventional SBR shows that at the same time of the reaction phase, the value of ORP in MB-SBRs was considerably higher than that in the conventional SBR. It means that the oxidation ability of the MB-SBRs was more than that of the conventional SBR.

This work was done with a main objective of comparison of overall performance between moving-bed and conventional SBR. The main conclusions of this study can be summarized as below:

The obtained results of COD and dye concentration as well as the turbidity of the reactors effluent showed that there were no significant differences between the MB-SBRs and conventional SBR in the matters of effluent quality. Investigation of biomass characteristics revealed a higher fluctuation of MLSS concentration and SVI in all three MB-SBRs in comparison with that in the conventional SBR. The SVI determined from MB-SBRs was also higher than that determined from the conventional SBR. The average of MLVSS/MLSS ratio for SBR was 76%, while for all MB-SBRs it is more than 82%. Evaluation of ORP changes during the reaction phase, disclosed the higher value of ORP measured in MB-SBRs compared to the values measured in the conventional SBR.

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