Original Article

Upgrading of Kish Island Mirmohana Wastewater Treatment Plant using Moving Bed Biofilm Reactor Alternative

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Abstract

Background and purpose: The performance of full-scale moving bed biofilm reactor (MBBR) was evaluated as an alternative for upgrading of Kish Island Mirmohana wastewater treatment plant. In this study activated sludge process upgrade to MBBR process and different operating parameters were compared.

Materials and Methods: Effect of upgrading on different parameters such as organic loading rate (OLR), mixed liquor suspended solid (MLSS), mixed liquor volatile suspended solid, sludge retention time (SRT), sludge volume index (SVI), hydraulic loading rate (HLR), also removal efficiency of chemical oxygen demand, biochemical oxygen demand and total suspended solid were investigated.

Results: The study results show that with increasing the average flow influent (625.97 ± 38.6-1335.3 ± 102.06 m^3/d) and reducing of aeration tank volume (300-150 m^3), OLR (0.29 ± 0.1-1.82 ± 0.15), MLSS (1291.14 ± 463.43 mg/L-7382.85 ± 272.42 mg/L), SRT (12.5 ± 4.2 d-28.79 ± 3.84 d), SVI (54.94 ± 15.82-51.2 ± 9.31), HLR (13.85 ± 0.85-29.45 ± 2.25 m/d), and hydraulic retention time (4.61 ± 0.27-2.17 ± 0.17 h) were changed. Effluent concentrations under this operation condition were below the guidelines for irrigation water.

Conclusion: Hence, MBBR process is a good alternative for upgrading wastewater plants especially when they have inadequacy space or need modification that will require a large investment.

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Key words: Upgrading, Moving Bed Biofilm Reactor, Activated Sludge Process, Wastewater Treatment Plant

1. Introduction

The moving bed biofilm reactor (MBBR) process was developed in Norway and firstly set up about 30 years ago (1). The MBBR shows all the advantages of a standard biofilm reactor while at the same time treatment high particle loads (2). MBBRs have a number of advantages over conventional activated sludge (AS) technology, including fewer complexes to operate compared with AS systems, small footprint and reactor volume requirements, higher plant capacity due to higher biomass concentration, high resistance to hydraulic and organic load shock, increase in solids retention time and high removal performance under extreme loading conditions in plant upgrading. Higher solids retention time prevents the wash-out of slow-growing microorganisms, including nitrifying bacteria from the system. A key element of the MBBR is the use of small plastic biofilm support media to allow a high concentration of protected biofilm growth in a well-mixed reactor vessel (3, 4). Above all the main proof MBBR, is its ability to accumulate suspended and biofilm biomass in the same reactor simultaneously, which produce higher density of biomass in the system. When concentrations, loading and pH values of influent in a system fluctuate significantly, MBBRs have been shown to be more efficient and stable for toxic compounds and nutrient removal (3, 5). Moreover, stable nitrification under low temperatures, fast adaptation of biomass activity to toxic compounds, biochemical oxygen demand (BOD) removal and nitrification or under anoxic conditions for denitrification can be achieved.

All in all, the MBBR process has been chosen for many different applications both pilot- and full-scale installations. Esoy et al. were investigated upgrading of treatment plants for enhanced nitrification using biofilm carriers, oxygen addition and pre-treatment in the sewer network (6). Weiss et al. used MBBR process for enhancing nitrogen removal in a stabilization pond treatment plant. According to their report, the MBBR achieved an average nitrogen removal rate of 0.15 kg N/m^3.d (9.4 lb N/1000 ft^3.d). This rate was greater than the rate observed at many conventional AS systems that have implemented nitrogen removal. The solid yield from the pilot scale MBBR, 0.26 kg of waste biosolids/kg of chemical oxygen demand (COD) removed was lower than that observed at this full-scale plant (7). In China, a practical application of joint hydrolysis/acidification, MBBR and oxidation ditch as a combined biological wastewater treatment technique were used for upgrading and retrofitting a centralized wastewater treatment plant of pharmaceutical industrial park. MBBR and oxidation ditch represent 35.4% and 60.7% of NH_4^+ - N removal, 30.2% and 61.5% of COD removal, separately. Furthermore, their results demonstrated that the combined biological treatment system is a feasible and stable technique for upgrading wastewater treatment plant (8). Upgrading overloaded conventional AC treatment plants is a promising solution, particularly when they have space limitations or need modifications that will require a large investment (9).

Dvorak et al. using full-scale MBBR for treatment of a high content of cyanides and aniline, very high salinity, diphenyl guanidine and phenyl urea residues, and considerable fluctuations in concentrations as well as temperature during the year. According to the results, the system was capable of treating such hardly biodegradable industrial wastewater with high removal efficiency, with mean cyanide removal efficiency ranging from 75% to 99%, respectively. Aniline removal efficiency also reached more than 85%, whereas diphenyl guanidine, phenyl urea and N,N-diphenyl urea removal was almost quantitative (4).

Kish is a 91.5 km^2 resort island in the Persian Gulf. It is part of the Hormozgan province south of Iran. Owing to its free trade zone status it is touted as a consumer's paradise, with numerous malls, shopping centers, tourist attractions, and resort hotels. It has an estimated population of 20,000 residents and about 1 million tourists annually. Mirmohana AS wastewater treatment plant in Kish Island was established in 1998 with a nominal capacity of 600 m^3/d that in recent years, the influent increased to 1480 m^3/d. Hence, there is a major need for upgrading and retrofitting of the wastewater treatment plant to prevent environmental challenges due to discharge of wastewater to sea body. The aim of this work was to evaluate of MBBR for upgrading of Mirmohana wastewater treatment plant in Kish Island.

2. Materials and Methods

This study was conducted in 2 time periods, April-December 2011 (before upgrading) and April-December 2012 (after upgrading). Effect of upgrading on different parameters such as organic loading rate (OLR), mixed liquor suspended solid (MLSS), mixed liquor volatile suspended solid (MLVSS), sludge retention time (SRT), sludge volume index (SVI), hydraulic loading rate (HLR), also removal efficiency of COD, BOD_5 and total suspended solid (TSS) were investigated during these periods. Table 1 shows different characteristics of Mirmohana wastewater treatment plant before and after upgrading. Also, table 2 shows characteristics of the plastic media used in MBBR for retrofitting purpose. A flow scheme of the system before and after upgrading is shown in figure 1.

2.1. Analytical methods

Analysis of COD, pH, TSS, BOD_5, MLSS, MLVSS and SVI were done according to Standard Methods (10).

3. Results

3.1. Effect of influent flow rate on performance of activated sludge process (ASP) and MBBR

A comparison of ASP and MBBR at different operating conditions has shown a similar efficiency of both processes with regard to COD removal. It is evident from figure 2, in spite of changing the average flow influent from 625.97 ± 38.6 to 1335.3 ± 102.06 m^3/d and reducing of two aeration tank to one, MBBR process perform approximately the same with ASP, and effluent quality of both systems slowly deteriorating with increasing the influent flow. Also, concentration of Mirmohana wastewater treatment plant before and after upgrading is mentioned in table 3.

Table 1. Different characteristics of Mirmohana wastewater treatment plant

Units	Characteristics	Before upgrading	After upgrading
-	Process	AS	MBBR
	Influent flow (m^3/d)	625.97 ± 38.6	1335.3 ± 102.06
Aeration tank	Number	2	1
	Volume (m^3)	300	150
	HRT (h)	23.05 ± 1.4	5.62 ± 0.60
	OLR (kg COD/m^3/d)	0.29 ± 0.1	1.82 ± 0.15
	F/M (Kg BOD/Kg MLSS/d)	0.13	0.09
Final clarification	Number	2	2
	Volume (m^3)	120	120
	HRT (h)	4.61 ± 0.27	2.17 ± 0.17
	HLR (m/d)	13.85 ± 0.85	29.45 ± 2.25

MBBR: Moving bed biofilm reactor, HRT: Hydraulic retention time, OLR: Organic loading rate, COD: Chemical oxygen demand, MLSS: Mixed liquor suspended solid, AS: Activated sludge

Table 2. Characteristics of the media used in MBBR

Characteristic	Value
Material	HDPE
Shape	Corrugated cylinder
Density (g cm^{-3})	≤0.1
Dimensions (mm)	8 × 8
Specific surface (m^2 m^{-3})	≥700

MBBR: Moving bed biofilm reactor, HDPE: High-density polyethylene

3.2. Effect of upgrading to MBBR on aeration tank hydraulic retention time (HRT)

Figure 3 shows the Effect of upgrading to MBBR on aeration tank HRT.As shown in this figure 3, average HRT was reduced from 23.05 ± 1.4 h to 5.62 ± 0.15 h as a result of increasing inflow rate and conversed two aeration basins to one basin after upgrading.

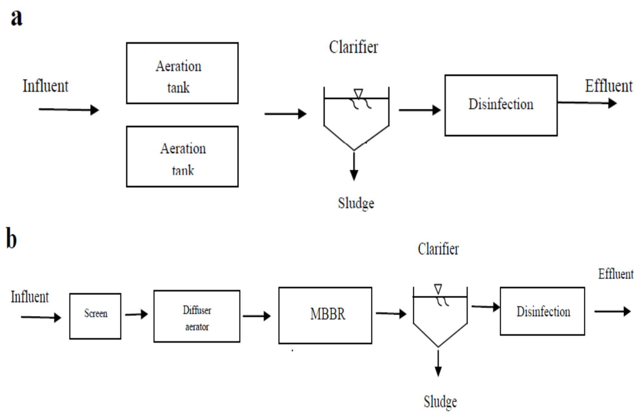

Figure 1. Flow diagram of Mirmohana wastewater treatment plant before (a) and after (b) upgrading

3.3. Effect of upgrading to MBBR on OLR

The results in figure 4 show that increasing the average OLR from 0.29 ± 0.1 before upgrading to 1.82 ± 0.15 kg COD/m^3/d.

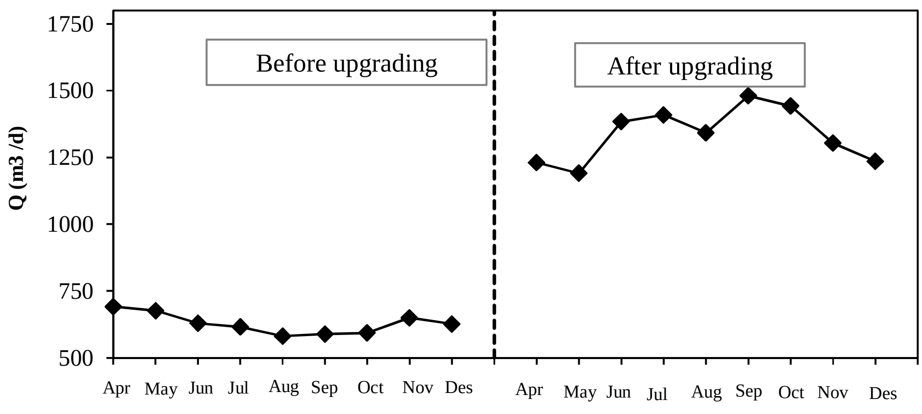

Figure 2. Flow rate variation before and after wastewater plant upgrading

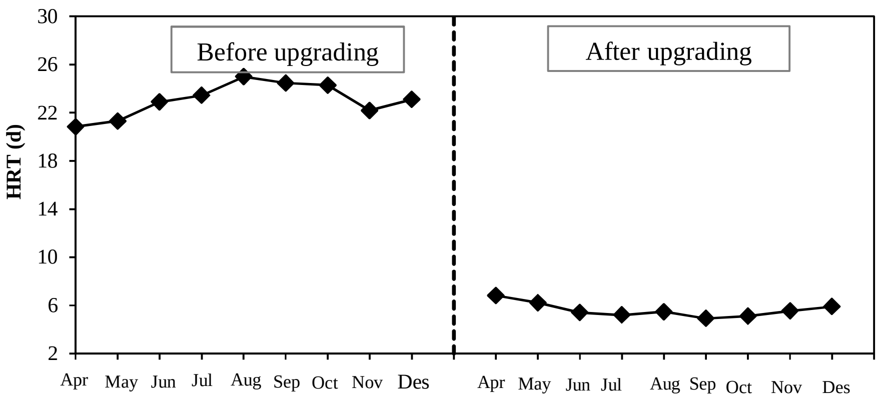

Figure 3. Hydraulic retention time variation before and after wastewater plant upgrading

3.4. Effect of upgrading to MBBR on MLSS and MLVSS

MLSS and MLVSS of both the systems were regularly determined at different SRT. According to figure 5, average MLSS of conventional ASP (before upgrading) in suspended form was 1291.14 ± 463.43 mg/L and average MLSS of MBBR process (after upgrading) in attached form in steady-state was 7382.85 ± 272.42 mg/L. Whereas, average MLVSS of conventional ASP in suspended form and MBBR process in attached form in steady-state was 903.79 ± 324.40 and 5168 ± 190.69 mg/L, respectively (Figure 6).

3.5. Effect of upgrading to MBBR on SRT

The concentration of biomass is expressed as gVSS L^{-1} media to be able to calculate the SRT. SRT of the ASP and MBBR was calculated according to the following equation

$$SRT = \left(\frac{VX}{Qw.Xw + Q.Xe} \right)$$

Where: V, reactor volume; X, average biomass concentration of the reactor (mg VSS L^{-1}); Q_w, excess sludge (L d^{-1}); X_w, concentration of the excess sludge (mg VSS L^{-1}); Q wastewater flow rate (L d^{-1}); X_e effluent concentration (mg VSS L^{-1}) and according to Tawfik et al., X_e = $COD_{suspended}$/1.4 (11). As shows in figure 7, average SRT of ASP (before upgrading) was 12.5 ± 4.2 d whereas average SRT of MBBR process (after upgrading) in steady-state was 28.79 ± 3.84 d.

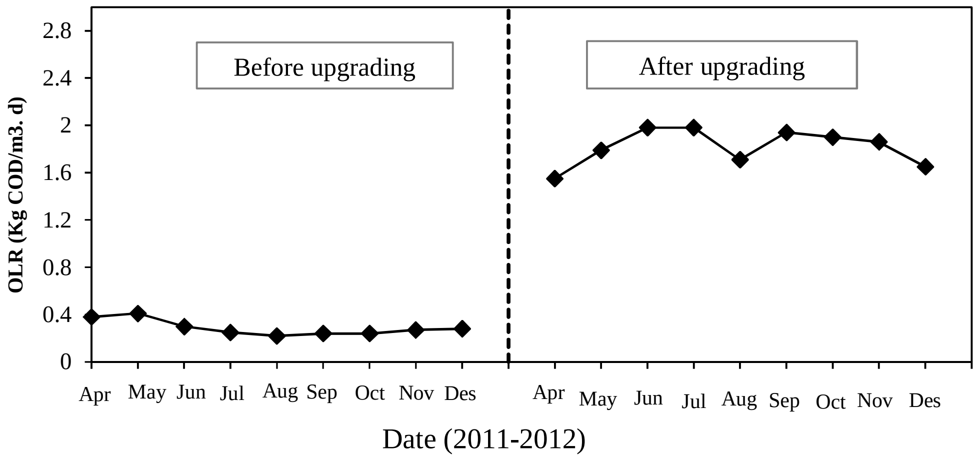

Figure 4. Organic loading rate variation before and after wastewater plant upgrading

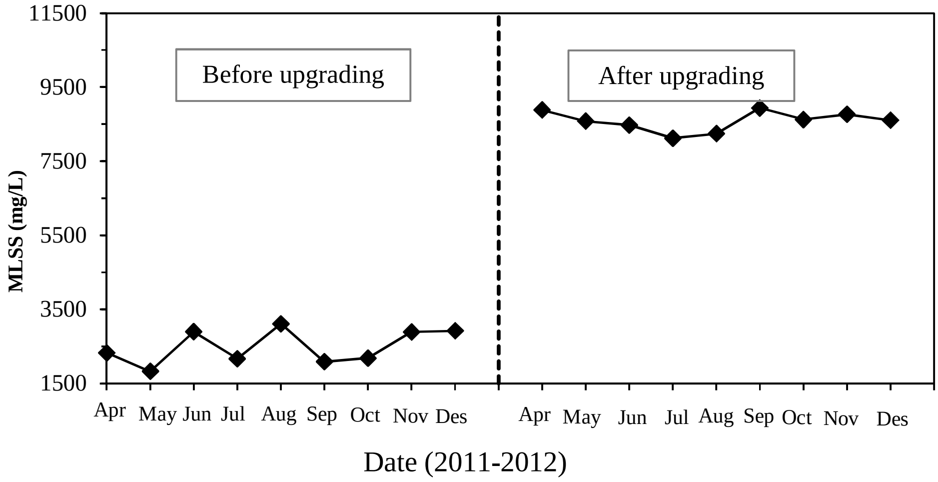

Figure 5. Mixed liquor suspended solid variation before and after wastewater plant upgrading

3.6. Effect of upgrading to MBBR on SVI

According to results average SVI of ASP was 54.94 ± 15.82 and in MBBR process was 51.2 ± 9.31 (Figure 8). Also, the variation of SVI after upgrading is lower than before upgrading.

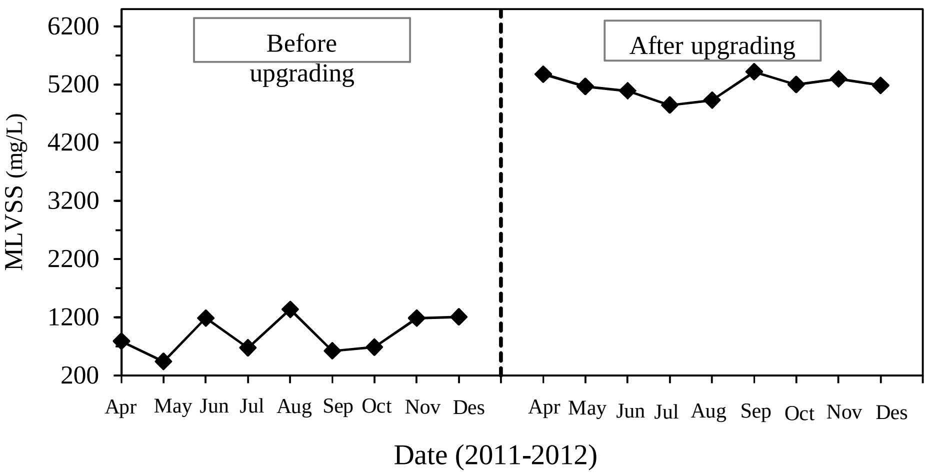

Figure 6. Mixed liquor volatile suspended solid variation before and after wastewater plant upgrading

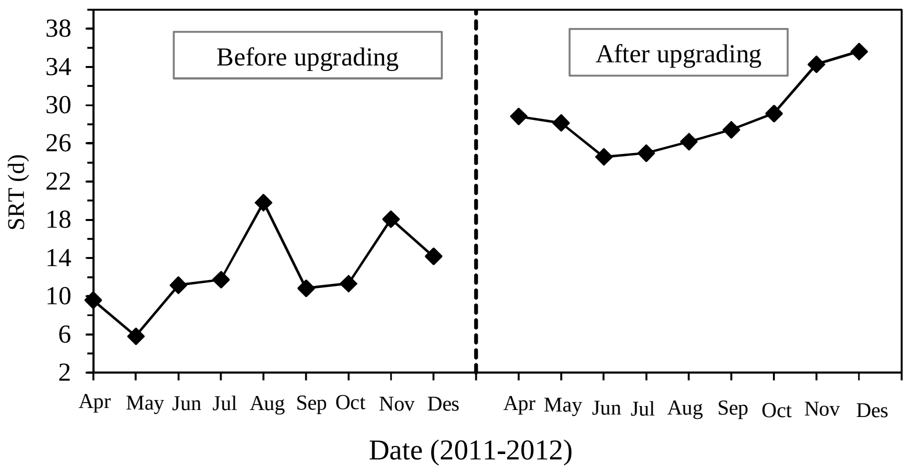

Figure 7. Sludge retention time variation before and after wastewater plant upgrading

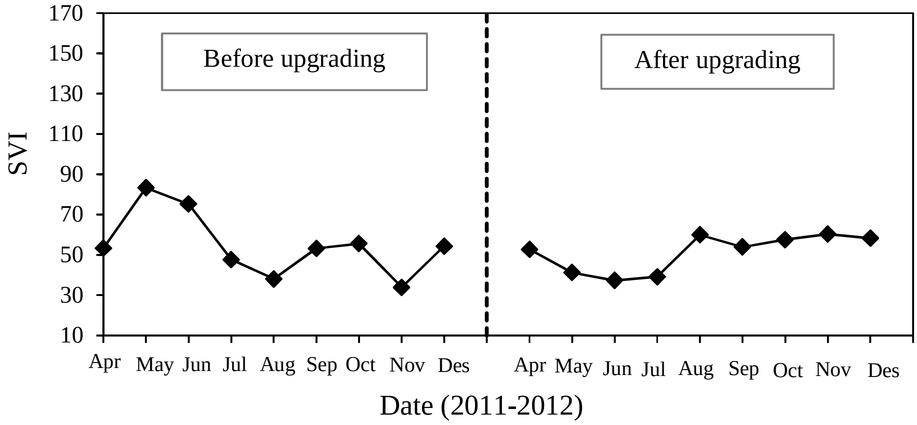

Figure 8. Sludge volume index variation before and after wastewater plant upgrading

3.7. Effect of upgrading to MBBR on final clarifier hydraulic load rate and retention time

As shows in figure 9 final clarifier HLR increased form 13.85 ± 0.85 to 29.45 ± 2.25 m/d and HRT decrease from 4.61 ± 0.27 to 2.17 ± 0.17 h; as a result of increasing the flow rate from 625.97 ± 38.6 to 1335.3 ± 102.06 m3/d after upgrading, effluent quality remained in the standard range.

4. Discussion

The MBBR process has successfully operated for upgrading overloaded AS wastewater treatment plant (average flow influent from 625.97 ± 38.60 to 1335.3 ± 102.06 m^3/d). This process is effective for upgrading the wastewater treatment plant for domestic wastewater with COD <500 mg/L at short (HRT ≈ 6 h) and allowing high solid retention times (SRT ≈ 29 d). According to the literature, an important advantage of MBBR is less volume required for treating the wastewater. Hvala et al. in a simulation analysis reported both ASP and MBBR have the same efficiency of both technologies in relation to organic matter removal, where the influent flow was gradually changed from 500 to 3000 m^3/d (normal operating point was 1143 m^3/d) (12) which is adapted to figure 2. As shown in table 3, the MBBR process performance in terms of COD removal efficiency was higher than ASP, moreover TSS removal efficiency before upgrading is higher than after upgrading; although amount of TSS in the effluent after upgrading was below the regulation value for irrigation water during the entire period of operation (≥100 mg/L). Similarly, Qdegaard et al. reported that only 10% of the effluent SS from a moving bed biofilm process could be removed via settling when COD loading rate was higher than 30 g COD/m^2 d. while, more than 60% of the SS could be removed when the loading rate was less than 10 g COD/m^2.d (13). Also, Ong et al. reported that difference between the effluents settled and filtered COD increased with decreasing HRT. Their observation suggested that a shorter HRT would lead to more dispersed growth and therefore poor suspended solid settling in the treated effluent (14). As evident by the data in table 3, the efficiency of BOD_5 in the MBBR process was higher than ASP. Average removal efficiency before upgrading was achieved 77.61 ± 3.5 (%) and after upgrading was 79.41 ± 4.97 (%). The periods of high elevated of BOD_5 were associated with high influent BOD_5 concentrations and poor settling in the final clarifiers.

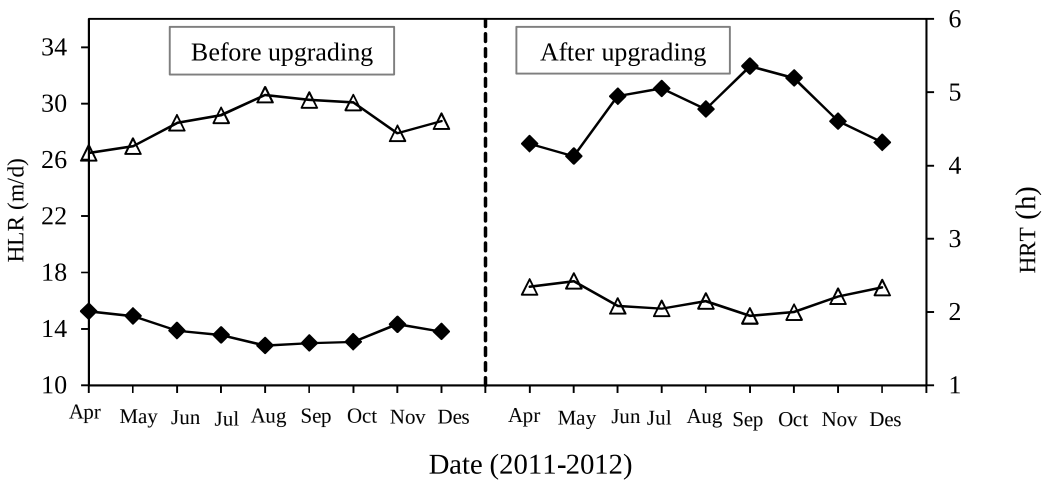

Figure 9. Hydraulic loading rate —◆— and hydraulic retention time —△— variation before and after wastewater plant upgrading

In figure 3, the reduction in HRT led to a corresponding increase in COD effluent after upgrading (77.04 ± 10.2-85.3 ± 8.94 mg/L). Despite this increase, the COD concentration in the effluent was below the regulation value for irrigation water during the entire period of operation (≥200 mg/L); it is because of increase in average MLSS from 1291.14 ± 463.43 to 7382.85 ± 272.42 mg/L after upgrading. In this condition (HRT = 5.62 ± 0.60), efficiency of MBBR system for COD removal was achieved over 80%. Wang et al. reported a lower removal efficiency of COD (71.3-77.1%) in a MBBR treating domestic wastewater at HRT 6 h (15). This indicates that MBBR process in Mirmohana plant has a good operation condition with increased the removal efficiency of COD.

According to figure 4, after upgrading caused an increase of the COD in the final effluent but it remained below the regulation value for irrigation water. This good efficient is due to high specific surface area of the plastic media (≥700 m^2 m^{-3}) and biomass function in MBBR system compared to ASP. These results are remarkable when compared to the submerged fixed-bed aerobic reactor to achieve similar removals. For instant Vendramel et al. reported that with influent COD 500 mg/L, OLR 0.5 kg BOD_5/m^3.d and HRT 24 h, the removal efficiency of COD and TOC was achieved 80 ± 6 and 56 ± 7 respectively (16). Although MBBR provides a long biomass retention time and hold high loading rates without any problems of clogging (15). However, on the basis of results, it can be concluded that with an increase in OLR ammonia concentration in the final effluent (11, 17) and COD will be an increase. As shown in figure 5, average MLSS concentration in conventional ASP generally was 1291.14 ± 463.43 mg/L for wastewater treatment, whereas in the MBBR process high removal efficiency was obtained even at a relatively low MLSS concentration (average MLSS in the water phase = 190.1 ± 29.80 mg/L). This is probably because of a high concentration of biomass is attached to plastic media (6949.34 ± 91.80 mg/m^2.pack). Amount of MLSS for MBBR design was suggested 6000-8500 mg/l that MLSS in aerated basin of Mirmohana wastewater treatment plant is accordance with it (18).

In spite of higher flow rate, OLR, HLR and shorter HRT in MBBR process compare to ASP, Mirmohana wastewater treatment plant has good efficiency of effluent (Figure 7). This is because of greater biomass involved and also the longer overall SRT in MBBR process than ASP. The larger mass of organisms in the bioreactor facilitate a very stable biological process particularly at high flows and loads less potential for the washout of nitrifying organisms. Also, the increased biomass effectively increases SRT or sludge age of the system by about 2.5 times that allow nitrification at low temperature. It should be noted that fixed film media support the growth and retention of nitrifying organisms due to the very long SRT of the biofilm. Therefore, If the SRT is too long, the MLSS concentration will be high, and there will be a tendency to develop nitrification (19).

The conventional way of monitoring for sludge settle ability is by determining the SVI. In a conventional AS plant (with MLSS <3500 mg/L) the normal range of SVI is 50-150 mL/g. A high SVI (>150 mL/g) indicates bulking conditions, whereas an SVI below 70 mL/g indicates the predominance of pin (small) flocs. In Pin-point flocs, filamentous bacteria are absent or occur in low numbers. This results in small flocs that do not settle well. The secondary effluent is turbid despite the low SVI (20). In figure 8, although sludge settle ability after and before upgrading is lower than 70 mL/g, this caused no unpleasant effect on effluent, and it was still remained below the regulation value for irrigation water. Biofilm system, like the ASP, also needs the sedimentation process to separate treated effluent from the microbial flocs. It has been well known that settling characteristics of microbial floc in a biological treatment system is so important because it affects both treatment efficiency and the surface of the settling tank (21). Further, it has been reported that settling characteristics of the MBBR sludge were poorer than the AS (22, 23).

The MBBR process has good contact between wastewater and microorganisms without clogging and channeling. Also, it is a good alternative for upgrading wastewater plants especially when they have inadequacy space or need modification that will require a large investment. Effluent concentrations under this operation condition were well below the discharge limits for irrigation water.

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