

Upgrading of Kish Island Markazi wastewater treatment plant by MBBR

Mehdi Ahmadi, Hassan Izanloo, Aliakbar Mehr alian, Hoda Amiri and Mohammad Noori Sepehr

ABSTRACT

The potential of a moving bed biofilm reactor (MBBR) in full scale has been investigated as an alternative for upgrading of the Kish Island Markazi wastewater treatment plant. In this regard, the activated sludge process (ASP) upgraded to an MBBR process and different operating parameters results in this change compared with ASP. Results show that with increasing the average flow influent from $1,049 \pm 88$ to $1,944 \pm 275 \text{ m}^3 \text{ d}^{-1}$ and reducing the aeration tank volume from 300 to 150 m^3 , organic loading rate (OLR), mixed liquor suspended solids (MLSS), sludge retention time (SRT), sludge volume index (SVI), hydraulic loading rate (HLR) and hydraulic retention time (HRT) were changed to 0.32 ± 0.04 – $1.8 \pm 0.36 \text{ kg COD/m}^3 \text{ d}$, $2,641.19 \pm 284.99$ – $7,354.2 \pm 778.35 \text{ mg L}^{-1}$, 5.28 ± 0.64 – $22.1 \pm 1.53 \text{ d}$, 135 ± 37.3 – 29.2 ± 3.81 , 23.14 ± 1.94 – $43.37 \pm 5.04 \text{ m d}^{-1}$ and 2.76 ± 0.22 – $1.48 \pm 0.18 \text{ h}$, respectively. Effluent concentrations under this operation condition were well below the discharge limits for irrigation water. Therefore, the MBBR process is a good alternative for upgrading wastewater plants especially when there is inadequate space or modifications are needed that will require large investment.

Key words | activated sludge process, MBBR, upgrading, wastewater treatment plant

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INTRODUCTION

Kish is a 91.5-square-kilometre resort island in the Persian Gulf. It is part of the Hormozgan province south of Iran. Due 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 one million tourists annually. Kish Island was established in 1998 with a nominal capacity of $900 \text{ m}^3 \text{ d}^{-1}$ but in recent years the influent has increased to $2,300 \text{ m}^3 \text{ d}^{-1}$. Hence, there is a major need for upgrading and retrofitting of the wastewater treatment plant to prevent environmental challenges due to the discharge of wastewater to the sea. An MBBR has been widely applied as a stand-alone process or it can be used to specifically enhance or upgrade the treatment potential of wastewater treatment

plants. It is a biofilm treatment system capable of degrading polluting organic compounds and nutrients (N and P) in wastewater effluents. The 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. The reactors can be operated under aerobic conditions for biochemical oxygen demand (BOD) removal and nitrification or under anoxic conditions for denitrification. Compared to other fixed biomass systems (trickling filters and submerged biofilters), it shows no clogging problems and lower head loss. MBBR has many advantages over conventional wastewater treatment processes (i.e. activated sludge). The main advantages of such systems using biofilm processes are: fewer complexes to operate

compared with activated sludge systems and small footprint and reactor volume requirements, their ability to increase biological reaction rates through accumulation of high concentration of active biomass and the high resistance to hydraulic and organic load shock (Lazarova & Manem 1994, 2000). High effluent quality in terms of nutrient removal, good disinfection capability, higher volumetric loading, shock-load protection and less sludge production (Metcalf & Eddy 2003; Melin *et al.* 2006) are the main advantages of MBBR. As a consequence of such advantages the MBBR process has been chosen for many different applications, both pilot- and full-scale installations. Esoy *et al.* (1998) investigated the upgrading of treatment plants for enhanced nitrification using biofilm carriers, oxygen addition and pre-treatment in the sewer network. Simulation analyses have been performed to compare the performance of conventional activated sludge process (ASP) and MBBR for plant upgrading by Hvala *et al.* (2002), pilot plant and simulation experiments have shown better performance of MBBR than conventional ASP. MBBR gives better performance in term of nitrogen removal at low temperatures. This technology was therefore chosen for plant upgrading (Hvala *et al.* 2002). Weiss *et al.* (2005) used the MBBR process for enhancing nitrogen removal in a stabilization pond treatment plant. According to their report, the MBBR achieved an average total nitrogen removal rate of $0.15 \text{ kg NH}_3/\text{m}^3 \text{ d}$ ($9.4 \text{ lb NH}_3/1,000 \text{ ft}^3/\text{day}$) which was greater than the rate observed at many conventional activated sludge systems that have implemented nitrogen removal. The solid yield from the pilot scale MBBR, 0.26 kg of waste biosolids per kg of chemical

oxygen demand (COD) removed, was lower than that observed at this full-scale plant (Weiss *et al.* 2005). 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 in a pharmaceutical industrial park. The MBBR and oxidation ditch represent 35.4 and 60.7% of $\text{NH}_4^+\text{-N}$ removal, 30.2 and 61.5% of COD removal, separately. Also, their results demonstrated that the combined biological treatment system is a feasible and stable technique for upgrading a wastewater treatment plant (Lei *et al.* 2010). Upgrading overloaded conventional activated sludge treatment plants is a promising solution, particularly when they have space limitations or need modifications that will require large investment (Tizghadam *et al.* 2008). The aim of this work was to evaluate the potential of MBBR for upgrading the Markazi wastewater treatment plant in Kish Island.

METHODS

This study was conducted over two time periods, April to December 2008 (before upgrading) and April to December 2009 (after upgrading) and the effect of upgrading on different parameters such as OLR, MLSS, mixed liquor volatile suspended solid (MLVSS), SRT, SVI, HLR, also the removal efficiency of COD, BOD_5 and total suspended solid (TSS), were investigated during these periods. Table 1 shows the different characteristics of Markazi wastewater treatment plant before and after upgrading. Table 2 represents influent

Table 1 | Different characteristics of Markazi wastewater treatment plant

Units	Characteristics	Before upgrading	After upgrading
–	Process	Activated sludge (AS)	MBBR
	Influent flow ($\text{m}^3 \text{ d}^{-1}$)	$1,049 \pm 88$	$1,944 \pm 275$
Aeration tank	No.	2	1
	Volume (m^3)	300	150
	HRT (h)	20.6 ± 1.6	5.8 ± 1.2
	OLR ($\text{kg COD}/\text{m}^3 \text{ d}$)	0.32 ± 0.04	1.8 ± 0.36
Final clarification	No.	3	3
	Volume (m^3)	120	120
	HRT (h)	2.76 ± 0.22	1.48 ± 0.18
	HLR (m d^{-1})	23.14 ± 1.94	43.37 ± 5.04

Table 2 | Influent wastewater characteristics during the experimental period

Parameter	Sampling interval	Value
BOD ₅ (mg L ⁻¹)	Weekly	130–173.5
COD (mg L ⁻¹)	Daily	280–438
pH	Daily	6.83–7.92
TSS (mg L ⁻¹)	Daily	93.56–195.17
Temperature (°C)	Daily	24.5–33.32
Flow rate; before upgrading (m ³ d ⁻¹)	Daily	971–1,207
Flow rate; after upgrading (m ³ d ⁻¹)	Daily	1,379–2,306

wastewater characteristics during the whole experimental period according to *Standard Methods* (APHA *et al.* 2005), and Table 3 shows characteristics of the plastic media used in MBBR for retrofitting purpose.

Analytical methods

Analysis of COD, pH, TSS, BOD₅, MLSS, MLVSS and SVI were carried according to *Standard Methods* (APHA *et al.* 2005).

RESULTS AND DISCUSSION

Effect of influent flow rate on performance of 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 1(a) that in spite of changing the average flow influent from $1,049 \pm 88$ to $1,944 \pm 275$ m³ d⁻¹ and reducing the two aeration tanks

to one, the MBBR process performs approximately the same with ASP, and the effluent quality of both systems slowly deteriorates with the increasing influent flow. According to the literature, an important advantage of MBBR is that less volume is required for treating the wastewater. In a simulation analysis, Hvala *et al.* (2002) reported that 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 3,000 m³ d⁻¹ (the normal operating point was 1,143 m³ d⁻¹). As shown in Table 4, the MBBR process performance in terms of COD removal efficiency was higher than ASP; moreover, according to this table TSS removal efficiency before upgrading is higher than after upgrading, although the 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⁻¹). Similarly, Ødegaard *et al.* (2000) reported that only 10% of the effluent SS from a moving bed biofilm process could be removed via settling when the COD loading rate was higher than 30 g COD/m² d while more than 60% of the suspended solids (SS) could be removed when the loading rate was less than 10 g COD/m² d. Ong *et al.* (2004) reported that the 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 solids settling in the treated effluent. As evident from the data in Table 4, the efficiency of BOD₅ in the MBBR process was similar to ASP. Average removal efficiency before upgrading was achieved ($73.64 \pm 2.23\%$) and after upgrading this was $76.01 \pm 2.22\%$. The periods of high elevated BOD₅ were associated with high influent BOD₅ concentrations and poor settling in the final clarifiers.

Effect of upgrading to MBBR on aeration tank HRT

Figure 1(b) shows the effect of upgrading to MBBR on aeration tank HRT. As shown in this figure, the average HRT was reduced from 20.6 ± 1.6 to 5.8 ± 1.2 h as a result of increasing inflow rate and the decrease of aeration basins to one basin after upgrading. The reduction in HRT led to a corresponding increase in COD effluent after upgrading (73.62 ± 7.67 to 82.4 ± 13.07 mg L⁻¹). Despite this increase,

Table 3 | Characteristics of the media used in MBBR

Characteristic	Value
Material	High-density polyethylene (HDPE)
Shape	Corrugated cylinder
Density (g cm ⁻³)	≤ 0.1
Dimensions (mm)	8×8
Specific surface (m ² m ⁻³)	≥ 700

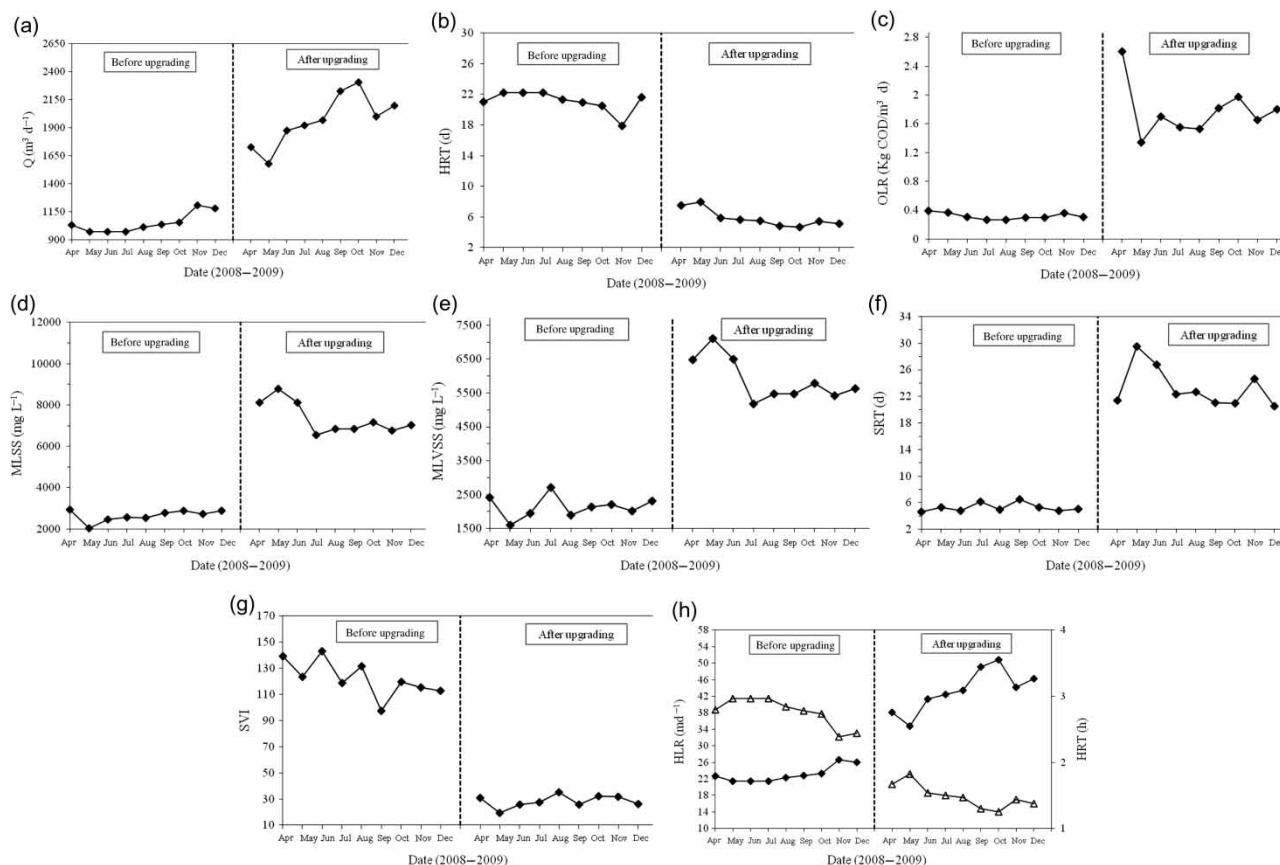


Figure 1 | (a) Flow rate variation before and after wastewater plant upgrading. (b) HRT variation before and after wastewater plant upgrading. (c) OLR variation before and after wastewater plant upgrading. (d) MLSS variation before and after wastewater plant upgrading. (e) MLVSS variation before and after wastewater plant upgrading. (f) SRT variation before and after wastewater plant upgrading. (g) SVI variation before and after wastewater plant upgrading. (h) HLR \blacktriangle and HRT \triangle variation before and after wastewater plant upgrading.

the COD concentration in the effluent was below the regulation value for irrigation water during the entire period of operation ($\geq 200 \text{ mg L}^{-1}$); this is because of the increase in average MLSS from $2,642 \pm 284$ to $7,354 \pm 778 \text{ mg L}^{-1}$

Table 4 | Removal efficiencies of Markazi waste water treatment plant before and after upgrading

	Before upgrading	After upgrading
Process	Activated sludge	MBBR
Influent flow ($\text{m}^3 \text{d}^{-1}$)	$1,049 \pm 88$	$1,944 \pm 275$
COD_{in} (mg L^{-1})	325.99 ± 46.19	387.1 ± 29.63
COD_{eff} (mg L^{-1})	73.62 ± 7.67	82.4 ± 13.07
BOD_{in} (mg L^{-1})	152.56 ± 10.71	164.1 ± 8.21
BOD_{eff} (mg L^{-1})	42.56 ± 6.21	39.8 ± 5.88
TSS_{in} (mg L^{-1})	124.46 ± 18.73	152 ± 33.08
TSS_{eff} (mg L^{-1})	20.53 ± 3.9	29.6 ± 9.69

after upgrading. In this situation ($\text{HRT} = 5.8 \pm 1.2 \text{ h}$), the efficiency of the MBBR system for COD removal achieved was over $80 \pm 2.1\%$. Wang *et al.* (2006) reported a lower removal efficiency of COD (71.3–77.1%) in an MBBR treating domestic wastewater at HRT 6 h. This indicates that the MBBR process in the Markazi plant has a good operating conditions with increased removal efficiency of COD.

Effect of upgrading to MBBR on OLR

The results in Figure 1(c) show that increasing the average OLR from 0.32 ± 0.04 before upgrading to $1.8 \pm 0.36 \text{ kg COD/m}^3 \text{d}$. Upgrading caused an increase of the COD in the final effluent but it remained below the regulation value for irrigation water. This good efficiency is due to the high specific surface area of the plastic media ($\geq 700 \text{ m}^2 \text{m}^{-3}$) and the 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 instance, Vendramel *et al.* (2011) reported that with influent COD 500 mg L^{-1} , OLR $0.5 \text{ kg, BOD}_5/\text{m}^3 \text{ d}$ and HRT 24 h , the removal efficiency of COD and total organic carbon (TOC) achieved 80 ± 6 and $56 \pm 7\%$, respectively. Thus, MBBR is an efficient and cost effective alternative for upgrading a wastewater treatment plant. Although MBBR provides a long biomass retention time and holds high loading rates without any problems of clogging (Wang *et al.* 2006), based on results it can be concluded that with an increase in OLR ammonia concentration in the final effluent (Rusten *et al.* 1998; Tawfik *et al.* 2010) the COD will increase.

Effect of upgrading to MBBR on MLSS and MLVSS

The MLSS and MLVSS of both systems were determined regularly at different SRT. According to Figure 1(d), the average MLSS of conventional ASP (before upgrading) in suspended form was $2,641.19 \pm 284.99 \text{ mg L}^{-1}$ and the average MLSS of the MBBR process (after upgrading) in attached form in steady-state was $7,354.2 \pm 778.35 \text{ mg L}^{-1}$, whereas the average MLVSS of conventional ASP in suspended form and MBBR process in attached form in steady-state was $2,140.26 \pm 324.48$ and $5,893.8 \pm 612.65 \text{ mg L}^{-1}$, respectively (Figure 1(e)). The average MLSS concentration in conventional ASP was generally $2,641.19 \pm 284.99 \text{ mg L}^{-1}$ 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 = $152 \pm 33.08 \text{ mg L}^{-1}$). This is probably because of a high concentration of biomass attached to plastic media ($6,709.79 \pm 199.63 \text{ mg/m}^2/\text{pack}$). The amount of MLSS for MBBR design was suggested at $6,000\text{--}8,500 \text{ mg L}^{-1}$, and the MLSS in the aeration tank of the Markazi wastewater treatment plant was in the range of previous work (Metcalf & Eddy 2003).

Effect of upgrading to MBBR on SRT

The concentration of biomass is expressed as g VSS L^{-1} media to be able to calculate the SRT. SRT of the ASP and

MBBR was calculated according to the following equation:

$$\text{SRT} = \left(\frac{VX}{Q_w X_w + QX_e} \right)$$

where V is the reactor volume; X is the average biomass concentration of the reactor (mg VSS L^{-1}); Q_w is the excess sludge (L d^{-1}); X_w is the concentration of the excess sludge (mg VSS L^{-1}); Q is the wastewater flow rate (L d^{-1}); X_e is the effluent concentration (mg VSS L^{-1}) and, according to Tawfik *et al.* (2010), $X_e = \text{COD}_{\text{suspended}}/1.4$. As shown in Figure 1(f), the average SRT of ASP (before upgrading) was $5.28 \pm 0.64 \text{ d}$ whereas the average SRT of the MBBR process (after upgrading) in steady-state was $22.1 \pm 1.53 \text{ d}$. In spite of the higher flow rate, OLR, HLR and shorter HRT in the MBBR process compared to ASP, the Markazi wastewater treatment plant showed good efficiency of effluent. This is because of the greater biomass involved and also the longer overall sludge retention time in the MBBR process than ASP. The larger mass of organisms in the bioreactor facilitate a very stable biological process, particularly at high flows and loads with 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, which allows 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 (Stantec team 2008).

Effect of upgrading to MBBR on SVI

The conventional way of monitoring for sludge settleability is by determining the SVI. In a conventional activated sludge plant (with $\text{MLSS} < 3,500 \text{ mg L}^{-1}$) the normal range of SVI is $50\text{--}150 \text{ mL g}^{-1}$. A high SVI (150 mL g^{-1}) indicates bulking conditions, whereas an SVI below 70 mL g^{-1} indicates the predominance of pin-point (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 (Bitton 2005). SVI variation before and after upgrading was investigated (Figure 1(g)). According to the results,

the average SVI of ASP was $135 \pm 37.3 \text{ mL g}^{-1}$ and in the MBBR process was $29.2 \pm 3.81 \text{ mL g}^{-1}$. Although sludge settleability after upgrading is lower than before upgrading, this caused no disagreeable effect on effluent and it was still remained below the regulation value for irrigation water. The biofilm system, like the activated sludge process, also needs the sedimentation process to separate treated effluent from the microbial flocs. It is well known that the settling characteristics of microbial floc in a biological treatment system are important because they affect both treatment efficiency and the surface of the settling tank (Bailey *et al.* 1994). Further, it has been reported that the settling characteristics of the MBBR sludge were poorer than the activated sludge (Leiknes & Ødegaard 2001).

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

As shown in Figure 1(h), the final clarifier HLR increased from 23.14 ± 1.94 to $43.37 \pm 5.04 \text{ m d}^{-1}$ and the HRT decreased from 2.76 ± 0.22 to $1.48 \pm 0.18 \text{ h}$; as a result of increasing the flow rate from $1,049 \pm 88$ to $1,944 \pm 275 \text{ m}^3 \text{ d}^{-1}$ after upgrading, the effluent quality remained in the standard range. The amount of HLR for MBBR design was suggested as $12\text{--}19.2 \text{ m d}^{-1}$; the HLR of the Markazi wastewater treatment plant is in accordance with this (Metcalf & Eddy 2003).

CONCLUSION

The MBBR process has successfully operated for upgrading an overloaded activated sludge wastewater treatment plant (average flow influent from $1,049 \pm 88$ to $1,944 \pm 275 \text{ m}^3 \text{ d}^{-1}$). This process is effective for upgrading the wastewater treatment plant for domestic wastewater with $\text{COD} < 500 \text{ mg L}^{-1}$ at short hydraulic retention times ($\text{HRT} \approx 6 \text{ h}$) and allowing high solid retention times ($\text{SRT} \approx 23 \text{ d}$). 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 inadequate space or need modification that will require large investment. Effluent concentrations under this operation condition were well below the discharge limits for irrigation water.

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