Research Paper

Sewage treatment efficacy and heavy metal removal in moving bed biofilm based treatment plants of northern India

Khalid Muzamil Gani, Muntjeer Ali, Ankur Rajpal, Hitesh Jaiswal and Absar Ahmad Kazmi

ABSTRACT

Moving bed biofilm reactor based sewage treatment plants (STPs) have been installed in northern India over the last decade. As such, there are no performance evaluation studies of this technology in the region. Evaluation of four such STPs was carried out in terms of removal efficiencies of physico-chemical parameters, microbiological parameters and heavy metals. Results showed that the average chemical oxygen demand, biological oxygen demand, total suspended solids, total nitrogen and total phosphorus removal of all STPs ranged from 74 to 91%, 81 to 95%, 79 to 93%, 44 to 80% and 58 to 85%, respectively. Total and thermotolerant (faecal) coliform in the influent and effluent of STPs ranged from $1.5 \times 10^4$ to $9.3 \times 10^7$ most probable number (MPN)/100 mL and 0 MPN/mL to 2,400 MPN/mL, respectively. Heavy metal concentration (nickel, zinc, cadmium, iron, lead, chromium, and copper) in effluent samples of all the STPs was below Indian discharge limits except lead. Integrated efficiency (IE) of the STPs was also evaluated and the results showed that the actual IE of all STPs was 0–10% larger than standard IE, indicating the suitability of the technology in the region.

Key words | evaluation, heavy metal, India, MBBR, performance, wastewater treatment

INTRODUCTION

Moving bed biofilm reactor (MBBR) technology (a combination of suspended as well as attached growth process) was developed in Scandinavia in the late 1980s and has been successfully used in municipal and industrial wastewater treatment (Odegaard et al. 1994; Gani et al. 2014, 2015). This technology has been employed in many regions of India especially in northern states like Jammu and Kashmir, Uttar-akhand and Uttar Pradesh. In Srinagar city of Jammu and Kashmir, which lies in the extreme north of India and where the famous Dal Lake is located, three sewage treatment plants (STPs) out of a total of six wastewater treatment plants, around the lake periphery are based on MBBR technology. In Uttarakhand state, approximately 20% of installed sewage treatment capacity in class I towns is treated by this technology (Central Pollution Control Board, CPCB 2015). Similarly, in Uttar Pradesh, which is one of the largest states in northern India, a 42,000 m$^2$/d STP based on the MBBR technology at Daulatganj, Lucknow was constructed during the first phase of the Gomti Action Plan to reduce the pollution load of the River Gomti. Performance evaluation of a treatment plant inspects its present status as the treatment process depends on existing geographical and environmental factors. Moreover, available opportunities for better wastewater treatment are discovered by evaluation. However, these STPs in northern India are lacking such evaluation. The aim of this study was to evaluate wastewater treatment performance, heavy metal removal and sludge characteristics of four MBBR based STPs located in northern India.
Integrated efficiency (IE) of the treatment plants was also evaluated to explain overall performance of this technology in the region.

MATERIALS AND METHODS

The following MBBR plants were chosen for the study and their description is given in the supplementary information (available in the online version of this paper).

1. 400 m$^3$/d Delhi, Land and Finance (DLF) Emporio, Vasant Kunj, New Delhi
2. 3,200 m$^3$/d Habak, Srinagar, Jammu and Kashmir
3. 3,500 m$^3$/d Srinagar (Garhwal), Uttarakhand
4. 56,000 m$^3$/d Daulatganj, Lucknow Uttar Pradesh

RESULTS AND DISCUSSION

Influent and effluent characteristics

The average influent and effluent physico-chemical characteristics of all four STPs is shown in Table 1. The percentage removal efficiencies are shown in Figure 1(a). The wastewater treatment performance of the 400 m$^3$/d DLF Emporio, Vasant Kunj, New Delhi plant was consistent in terms of biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS) and total phosphorus (TP) removal with average removal efficiencies as 88.1 ± 1.9%, 95.1 ± 1%, 93 ± 1.09%, and 82 ± 4.66%, respectively. The microbiological parameters were also reduced significantly in the STP. Total coliforms and thermotolerant (faecal) coliforms in the influent of the STP were 2.4 × 10$^8$ MPN/100 mL and 1.7 × 10$^4$ MPN/100 mL, respectively, which reduced to 2,400 MPN/100 mL and zero in the effluent. The reason for the high effluent quality was the series of tertiary treatment that is provided in the STP. The tertiary treatment systems at the treatment plant are multi grade filtration, adsorption with activated carbon filter and softening.

The influent and effluent sewage characteristics of the 3,200 m$^3$/d MBBR STP at Habak, Srinagar J&K are shown in Table 1. Since this plant is located in a cold place the nitrification is affected by the lower temperatures especially in winter when the temperature is below 0 °C. The removal efficiencies of COD, BOD, TSS, total nitrogen (TN) and TP were 73.1 ± 9.43%, 81 ± 7.49%, 79 ± 5.41%, 42 ± 9.47% and 70 ± 4.85%, respectively. These removal efficiencies were lowest (Figure 1(a)) because of the low temperature. Frequent power cuts are also a problem during winters which results in low performance of the plant. Polyaluminium chloride is added to the aeration tank effluent for better settling and phosphorus removal. With the help of a chlorine dose of 2.5 ppm the total and thermotolerant coliform count decrease to 120 and 0 MPN/100 mL in the final effluent, respectively. The STP is expected to have enhanced nutrient removal (>90% TN removal) to control eutrophication in Dal Lake. However that nutrient removal is not achieved. The average ammonia percentage removal was only 52% and TN removal efficiency was 44% only. Apart from low temperature, the process configuration of the plant is not any specific biological nutrient removal process and is thus lacking proper nutrient removal.

The wastewater treatment performance of the 3,500 m$^3$/d MBBR STP at Garhwal, Uttarakhand was also stable in terms of BOD, COD, TSS, TN and TP removal. The average percentage removal of COD and BOD, TSS, TN and TP was 90.8 ± 1.8%, 93.7 ± 1.4%, 83 ± 1.3%, 90.3 ± 5.8% and 85.1 ± 3%, respectively. Effluent parameters were well below the discharge limits prescribed by the National River Conservatory Directorate (NRCD). Ammonia removal was maximum (91%) among the evaluated MBBRs. The reason for this may be due to the hydraulic retention time of the MBBR (4 hours) favouring simultaneous carbon oxidation and nitrification in the aeration tank (Andreottola et al. 2000).

The performance of the 56,000 m$^3$/d MBBR STP at Daulatganj, Lucknow in terms of COD, BOD, TSS, TN and TP removal efficiencies was 82.2 ± 2.8%, 81.2 ± 1.9%, 82 ± 5.6%, 86.2 ± 8.2% and 58 ± 9%, respectively (Table 1). Although BOD and COD removal was not as large as the other MBBRs (Figure 1(a)), the effluent quality satisfied discharge regulations of NRCD.

Heavy metal removal

Table 2 shows the concentration of heavy metals (nickel, zinc, cadmium, iron, lead, chromium and copper) in the
Table 1 | Characteristics of influent and effluent wastewater treated at different MBBRs based STPs

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Vasant Kunj, Delhi</th>
<th>Habak, Srinagar, (J&amp;K)</th>
<th>Srinagar, Uttarakhand</th>
<th>Lucknow, UP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inlet</td>
<td>Outlet</td>
<td>Inlet</td>
<td>Outlet</td>
</tr>
<tr>
<td>Temperature</td>
<td>C</td>
<td>15 ± 6.2</td>
<td>17.3 ± 4.1</td>
<td>11.5 ± 3.1</td>
<td>12.8 ± 3.7</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>7.2 ± 0.4</td>
<td>7.9 ± 0.4</td>
<td>6.9 ± 1</td>
<td>7.1 ± 1.2</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>mg/L CaCO₃</td>
<td>514.2 ± 68</td>
<td>326.4 ± 62.6</td>
<td>375 ± 30</td>
<td>250 ± 22.5</td>
</tr>
<tr>
<td>Total COD</td>
<td>mg/L</td>
<td>727 ± 138</td>
<td>85.4 ± 18.3</td>
<td>339.6 ± 66</td>
<td>84.6 ± 17.3</td>
</tr>
<tr>
<td>Soluble COD</td>
<td>mg/L</td>
<td>246.5 ± 89.3</td>
<td>56. ± 14.4</td>
<td>138 ± 17.4</td>
<td>48 ± 21.1</td>
</tr>
<tr>
<td>Total BOD</td>
<td>mg/L</td>
<td>415 ± 87.9</td>
<td>19 ± 4.1</td>
<td>155 ± 22.2</td>
<td>27 ± 7.2</td>
</tr>
<tr>
<td>Soluble BOD</td>
<td>mg/L</td>
<td>77.4 ± 28.6</td>
<td>9.4 ± 2.4</td>
<td>64.9 ± 12.5</td>
<td>14.1 ± 2.9</td>
</tr>
<tr>
<td>TSS</td>
<td>mg/L</td>
<td>566.2 ± 84.6</td>
<td>38.8 ± 4.3</td>
<td>338 ± 89</td>
<td>66.2 ± 12.3</td>
</tr>
<tr>
<td>VSS*</td>
<td>mg/L</td>
<td>360.4 ± 77.4</td>
<td>17.8 ± 3.6</td>
<td>154 ± 39.3</td>
<td>25.8 ± 2.9</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>mg/L</td>
<td>38.1 ± 17.7</td>
<td>14.6 ± 13.6</td>
<td>27.2 ± 14.4</td>
<td>13.1 ± 6.4</td>
</tr>
<tr>
<td>TKN**</td>
<td>mg/L</td>
<td>54.8 ± 23</td>
<td>20.1 ± 16.6</td>
<td>43.3 ± 23.5</td>
<td>24 ± 14.2</td>
</tr>
<tr>
<td>TN</td>
<td>mg/L</td>
<td>60 ± 25</td>
<td>22.6 ± 16.8</td>
<td>46.3 ± 24.3</td>
<td>25.9 ± 14.7</td>
</tr>
<tr>
<td>Ortho-Phosphorus</td>
<td>mg/L</td>
<td>4.4 ± 2.6</td>
<td>0.7 ± 0.6</td>
<td>1.8 ± 0.6</td>
<td>0.3 ± 0.1</td>
</tr>
<tr>
<td>TP</td>
<td>mg/L</td>
<td>15.4 ± 5.2</td>
<td>2.5 ± 0.6</td>
<td>4.1 ± 1.2</td>
<td>1.1 ± 0.3</td>
</tr>
<tr>
<td>Total Coliform</td>
<td>MPN/100mL</td>
<td>2.40 × 10⁸</td>
<td>2,400</td>
<td>1.20 × 10⁷</td>
<td>120</td>
</tr>
<tr>
<td>Thermotolerant Coliform</td>
<td>MPN/100mL</td>
<td>1.70 × 10⁴</td>
<td>Nil</td>
<td>8.50 × 10²</td>
<td>Nil</td>
</tr>
</tbody>
</table>

*Volatile suspended solid; **Total kjeldahl nitrogen.
influent and effluent wastewater of these STPs. Chromium, lead, nickel and cadmium were not present in the influent of the STP at Vasant Kunj Delhi, which may be due to the source of wastewater being nearby shopping malls where there is no industrial activity. The concentrations of heavy metals at the other three STPs were in the range of 0.15–3.2, 0.15–2.3 and 0.09–2.85 mg/L and lead was present in minimum concentration at each STP (Table 2). The concentrations found in this study were comparable to that reported by De la Varga et al. (2013) for municipal wastewaters.

Nickel, zinc, cadmium, iron, lead, chromium and copper in effluent samples (Table 2) were in the range of 0–0.283 mg/L, 0.157–0.754 mg/L, 0–0.12 mg/L, 0.9–2.03 mg/L, 0–0.09 mg/L, 0–0.225 mg/L, 0–0.087 mg/L, respectively. In effluent the concentration was found to be less than the Indian discharge standards for inland surface water discharge (CPCB 2007) and safe for inland surface water discharge. Although the effluent concentrations of heavy metals of Habak, Srinagar STP were below discharge standards, this level of heavy metal concentration has an effect on the Dal Lake in which the effluent is discharged. Raja et al. (2013) reported an increasing trend of heavy metal pollution in the waters of Dal Lake for which they identified the effluent from the STP as the main source of heavy metal pollution. The heavy metal removal efficiencies of these evaluated MBBRs are shown in Table 2. The removal efficiencies followed the trend that copper was removed most efficiently (80–100%) in all STPs followed by chromium, iron and zinc (>60%). Lead, nickel and cadmium were poorly removed by these STPs (below 50%).

**Integrated efficiency evaluation**

Since individual evaluation parameters like BOD, TSS and TN represent efficiency of those particular processes by which these parameters are reduced without providing an integrated approach for performance comparison of STPs. BOD removal efficiency represents aerobic oxidation of organic matter by heterotrophic biomass. TSS removal efficiency represents settling effectiveness. TN removal represents the nitrification as well as denitrification. To have an integrated approach for the evaluation of these STPs, Jamwal et al. (2008) used an integrated approach for calculation of integrated efficiencies of STPs. The approach evaluates overall efficiencies based on average removal efficiencies of combined physico-chemical and microbiological parameters.

The effluent from these MBBRs was discharged into inland water bodies therefore effluent should meet standard limits as prescribed in the guidelines of the Central Public Health & Environmental Engineering Organisation (CPHEEO) (CPHEEO 2012). Also, MBBRs were mentioned as a wastewater treatment technology option for class I towns of India and the effluent quality parameters after tertiary treatment were recommended (Ganga River Basin: Environment Management Plan, GRB EMP 2010). BOD, TSS, TP and Thermotolerant Coliforms were recommended parameters. For this reason the actual, standard and recommended IE of these STPs were calculated based on these parameters by using Equation (1).

\[
I.E. = \frac{1}{4} \left[ E_{BOD} + E_{SS} + E_{TP} + E_{FC} \right]
\]
Where \( I.E. \) is the integrated efficiency, and \( E_{BOD}, E_{SS}, E_{TP} \) and \( E_{FC} \) are average percentage removal efficiencies of these parameters. When calculated with respect to actual, standard and recommended effluent values \( I.E. \) results in actual \( I.E. \), standard \( I.E. \) and recommended \( I.E. \), respectively. By this method, not only was a comparison between these MBBRs possible, but the present status of these STPs with respect to satisfying the discharge limits was also revealed and is shown in Figure 1(b).

The results showed that the \( I.E. \) of the MBBR at Vasant Kunj is highest (93%) whereas the MBBR at Habak Srinagar has the lowest \( I.E. \) of 87.6%. \( I.E. \) of all four MBBR based STPs was greater than the standard efficiency showing that the technology fulfills the criteria for discharging their effluent into inland water bodies. However, none of the evaluated MBBRs satisfied the criteria of recommended effluent quality for class I cities of India. The actual \( I.E. \) of MBBR Vasant Kunj Delhi was just 5% lower than the recommended \( I.E. \) as compared to 10% in case of the remaining three MBBRs. This shows the advantage of advance tertiary treatment and suggests use of such processes in MBBRs to meet the recommended criteria.

### CONCLUSIONS

This study evaluated the performance of four MBBR based STPs of north India. The organic removal efficiency of all STPs was satisfactory and effluents were complying with the Indian discharge regulations. The nutrient removal in all STPs was also efficient except for the 3,200 m³/d Habak, Srinagar, Jammu and Kashmir STP, due to the low temperature in the region. The effluent of the 400 m³/d DLF Emporio, Vasant Kunj, New Delhi STP satisfied the criteria of reuse also by advance tertiary treatment of chlorination and adsorption. Heavy metals in the effluents were below the discharge limits. \( I.E. \) evaluation of these STPs showed that MBBR based STPs are satisfactorily performing in northern India and with an advance tertiary treatment system their effluent may facilitate effluent reuse also.

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