Experimental comparison between MBBR and activated sludge system for the treatment of municipal wastewater

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Abstract The aim of the described experimentation was the comparison of a low cost MBBR and an activated sludge system (AS). The MBBR applied system consists of the FLOCOR-RMP® plastic media with a specific surface area of about 160 m^2/rn^3 (internal surface only). The comparison with activated sludge (AS) was performed by two parallel treatment lines. Organic substance removal and nitrification were investigated over a 1 -year period. Comparing the results obtained with the two lines, it can be observed AS totCOD removal efficiencies were higher than MBBR ones; the average efficiencies for totCOD removal were 76 % for MBRR and 84 % for AS. On the contrary, the solCOD removals resulted alike (71 % for both systems).
In spite of the remarkable variations of wastewater temperature, mainly in winter (range of 5-21 ºC), the average ammonium removal efficiency resulted 92 % for MBBR and 98 % for AS. With an ammonium loads up to 1.0 g m^{-2} d^{-1} (up to 0.12 kg rn^{-3} d^{-1}), nitrification efficiencies in MBBR were more than 98 %. At higher loads decrease in the MBBR efficiency was registered; that is related to the increase in the applied COD load.
Keywords Wastewater; nitrification; fixed biomass; MBBR

Introduction

A fixed biomass system which has recently aroused interest in the field of wastewater treatment is the MBBR technology (Moving Bed Biofilm Reactor). Its principle is the growing of a fixed biofilm on plastic elements which move freely in the biological reactor The plastic elements have a diameter around 1-2 cm and a density very close to that one of water. Only 50-70 % of the tank is filled by elements. Compared to other fixed biomass systems (trickling filters and submerged biofilters), these systems show no clogging problems and lower head loss. Compared to activated sludge systems, MBBR have no bulking problem and can operate with more reactors in series at higher F/M ratios and with a more selected biomass for each treatment step. Moreover no sludge recycling is needed and management is easier(Rusten *et al.* 1997).

The aim of the described experimentation was the comparison of a low cost MBBR (FLOCOR-RMp® plastic media) and an activated sludge system (AS). Usually in MBBR systems the higher the cost of the element (that is the specific surface), the higher the efficiency. Using a low cost (low specific surface) element, the Authors wanted to investigate the lower limit of MBBR profitability. The specific surface of the used MBBR plastic media is 160 m^2/m^3.

The comparison with activated sludge (AS) was performed by two parallel treatment lines. Organic substance removal and nitrification were studied. The monitoring of the experimentation lasted from September 1997 to July 1998.

Materials and methods

The pilot plant was built according (o the scheme in Figure 1: each treatment line consisted in two 337 L oxidation reactors and a final settler (two additional reactors for denitrification studies were not used so far). Sludge recycling was applied only in the AS system. A fine bubble aeration was adopted for oxygen supply and mixing.

The pilot plant was built at the MWWTP of Trento (Italy), where wastewater is previously treated with ferric chloride, followed by primary sedimentation in order to decrease the organic load (to help nitrification and to reduce oxygen demand). The wastewater feeding the pilot plant was taken downstream these pre-treatments.

The MBBR plastic media characteristics are summarized in Table 1. 70 % of the tank volume was occupied by elements. As a consequence, the specific MBBR surface (referred to the reactor volume) was 112 m^2/m^3.

The continuously monitored parameters were: dissolved oxygen, temperature, pH, air flow rate. Three automatic samplers allowed to analyze daily average samples. The chosen parameters were: Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS) referring to the fixed biomass in the MBBR, total COD (totCOD), soluble flocculated COD (solCOD), readily biodegradable COD (RBCOD), TKN, $N\text{-}NH_4$, $N\text{-}NO_2$, $N\text{-}NO_3$ and phosphorus. All the lab analyses were obtained through the Standard Methods (APHA, 1995) whereas soluble flocculated COD was analyzed according to Mamais et *al.* (1992). Readily biodegradable COD (RBCOD) was assessed as the difference between solCODin and solCODout. The reason is the following: when the sludge retention time is high enough to allow nitrification, the solCODout is not biodegradable, according to the model of Ekama *et al.* (1986). Ah the analyses were carried out on daily average samples.

The assessment of the TSS on the fixed biomass elements was performed as follows: the biofilm was removed from ten plastic elements and diluted in a known amount of demineralized water; after filtration (0.45 μm) the sample was dewatered at 105 °C and weighed; because of the variability of plastic elements dimension, the obtained value was referred to the total measured surface of the ten elements; total suspended solids concentration was assessed through the total surface in a cubic meter of reactor.

Results and discussion

During the experimentation (lasted about 1 year), the influent to the two pilot plant lines and the effluent wastewater from MBBR and AS systems respectively were monitored.

Flowrate was 48-100 L/h for each line. The theoretic hydraulic retention time (HRT) was the same for the two lines: 6.7-14.0 h for the oxidation process (3.3-7.0 h for each aerobic reactor); 2.5-5.0 h for the settling stage. According to hydrodynamic tests the aerobic reactors resulted nearly completely stirred. Thus real HRT and theoretical HRT could be assumed equal.

Organic substance removal

In Table 2 data on influent characteristics after pre-treatments are shown.

TotCOD and solCOD effluent concentrations are shown in Figures 2 and 3. Data on AS and MBBR lines are shown more in details in Table 3.

The average efficiencies for totCOD removal were 76 % for MBBR and 84% for AS. These values are related to an average inflow concentration of 231 mgCOD/L and average outflow concentrations of 56 and 37 mgCOD/L for MBBR and AS respectively. The maximun influent concentration resulted 570 mgCOD/L. The COD peaks in the effluent resulted 117 mgCOD/L (MBBR) and 50 mgCOD/L (AS). The average efficiencies for solCOD were 71 % for both systems. This value is related to an average inflow concentration of 87 mg solCOD/L (range 36-170 solCOD/L) and average outflow concentrations of 25 and 24 mg solCOD/L for MBBR and AS respectively.

In Figures 4 and 5 totCOD and solCOD removals are related to the volume of the two systems and to the biofilm surface of the MBBR. Axes related to the surface specific load [kg totCOD m^{-2} d^{-1}] refer only to MBBR. The bisector lines in Figures 4 and 5 mean 100 % removal efficiency.

Comparing the results obtained with the two lines, it can be observed AS totCOD removal efficiencies were higber than MBBR ones (for the same total COD load). On the contrary, the solCOD removals resulted alike.

The different efficiency in the two systems is related to the different biomass concentration. The biomass concentration ranged from 1.3 to 3.4 kgTSS/m^3 (average value: 2.1 kgTSS/m^3) in AS system and from 0.8 to 1.5 kgTSS/m^3 (average value: 1.0 kgTSS/m^3) in the MBBR system. In the first MBBR reactor biofilm growth was remarkably higher than observed in the second one: the average concentrations were 1.4 kgTSS/m^3 (range 1.2-1.6 kgTSS/m^3) in the first stage (with a higher applied load) and 0.3 kgTSS/m^3 (range 0.20.5 kgTSS/m^3) in the second stage (with a lower applied load). These values mean elements with an average biofilm equal to 12.5 gTSS/m^2 in the MBBR first stage and 2.7 gTSS/m^2 in the MBBR second stage (the surface which can be colonised is only the inner one).

The soluble COD is easily removed in both the systems, but the particulate COD is removed depending on the hydrolysis and bioflocculation ability of each system. The higher the biomass concentration, the higher the enzymatic hydrolysis and bioflocculation, the higher the particulate COD removal. Because of this reason the AS system showed higher efficiencies of total COD removal when compared to MBBR system.

The average totCOD load applied for TSS unit was 0.51 kgCOD $kgTSS^{-1}$ d^{-1} for the MBBR system and 0.42 kgCOD $kgTSS^{-1}$ d^{-1} for AS. The average totCOD removal loads, referred to the biomass unit, were 0.39 kgCOD $kgTSS^{-1}$ d^{-1} for MBBR and 0.33 kgCOD $kgTSS^{-1}$ d^{-1} for AS. Thus, if removal is referred to the biomass unit in the reactor, its value is comparable in the two systems: 76.5 % for MBBR and 78.5 % for AS. If removal is referred to the reactor volume its value is higher for AS. The reason is the low specific surface of the plastic elements used in this experimentation. Elements with higher specific surface to be colonised could allow an increase of the volumetric load removed.

Finally, TSS average concentrations in the effluent of the two lines were 23 mgTSS/L for MBBR (range 6-37 mgTSS/L) and 10 mgTSS/L for AS (range 5-22 mgTSS/L).

Ammonium removal

In spite of the remarkable variations of wastewater temperature, mainly in winter (range of 5-21 ºC), the average ammonium removal efficiency resulted 92 % for MBBR and 98 % for AS. The average concentrations resulted 32.4 mg/L in the influent, 3.2 mg $N\text{-}NH_4^+$/L in the MBBR effluent and 0.5 mg $N\text{-}NH_4^+$/L in the AS effluent (see Table 3). In Figure 6 the dynamics of the influent and effluent concentrations of the two lines for three applied flowrates (100 L/h, 42 L/b e 67L/h).

The volumetric and superficial loads of applied and removed are shown in Figure 7 (superficial loads refer only to MBBR).

Comparing the nitrification results of the two systems, the MBBR line shows a behaviour depending on the applied load. Two zones can be pointed out in the graph: a first one where nitrification efficiency is the highest possible (> 98 %: data on the bisector line); a second one where the increasing load causes a different performances among treatment systems. At higher loads AS system reaches the maximum efficiency. On the contrary MBBR system shows lower efficiencies at higher loads. Experimental data refer to a wide range of temperature (5-21 ºC); however, no significant correlation between the decrease in the MBBR nitrification efficiency and temperature values was found. This decrease can be related to the lower biomass concentration in MBBR system and to the increasing organic carbon load.

If nitrification efficiency is calculated as ammonium load removed vs. biomass weight, the average values are 0.080 kg $kgTSS^{-1}$ d^{-1} for MBBR and 0.047 kg $kgTSS^{-1}$ d^{-1} for AS system. That is the biomass of the MBBR system showed a better specific ability to nitrify, but the available surface of MBBR elements was not high enough to surpass AS system in performances. Moreover in AS nitrification develops in the whole available volume (the two reactors in series). On the contrary in MBBR nitrification fully develops only in the second reactor (low loaded).

With an ammonium load up to 1.0 g m^{-2} d^{-1} (up to 0.12 kg m^{-3} d^{-1}), nitrification efficiencies were more than 98 %. At higher loads decrease in the MBBR efficiency was registered (see Figure 7). That is related to the increase in the applied COD load (see Figure 8). The correlation between totCOD load and nitrite concentration in the effluent is showed in Figure9.

It can be observed from Figures 8 and 9 that at an applied load of 0.6 kg totCOD m^{-3} d^{-1} (5.4 g totCOD m^{-2} d^{-1}) nitrification efficiency decreases remarkably and nitrite concentration increases rapidly over 0.6 mg/L (discharge Italian limit).

In Table 3 Nitrite data are shown: Nitrite concentrations in the AS effluent are very low (range 0.01-0.32 mg NO_2-N/L). On the contrary, MBBR shows higher values (range 0.01-2.96 mg NO_2-N/L). Nitrite is an intermediate product of nitrification; its generation depends on a partial convertion of Ammonium. In particular, for COD loads lower than 0.6 kgCOD m^{-3} d^{-1} or 5.4 gCOD m^{-2} d^{-1} Nitrite concentration results lower than 0.5 mgN-NO_2/L. Higher loads cause a remarkable increase in Nitrite concentration.

MBBR was set in two stages, thus the first one basically aims to the organic substance removal, whilst the second one is specialised in nitrification. The average concentration in the influent was 5.9 mgN-NO_3/L. The effluent of the first stage resulted 6.3 mgN-NO_3/L, whilst the effluent of the second one resulted 24.2 mgN-NO_3/L. In the case of the AS line, the same influent gave an average effluent concentration equal to 26.9 mgN-NO_3/L.

Nitrification rates, obtained with AUR lab tests (Kristensen, 1992), showed values comparable with the pilot plants ones (Table 4). For AS tests only one sample was used; for MBBR plastic elements were taken from both the stages. Tests were developed thanks to the addition of Ammonium chloride. The nitrification rate at a controlled temperature (20 ºC) was assessed by the analyses of samples taken at prearranged intervals. In Table 4 the nitrification rate data are summarized.

Considering the removal rates referred to the biomass concentration, the following values can be obtained: 0.27 mg $gTSS^{-1}$ h^{-1} in the MBBR first stage, 3.16 $mggTSS^{-1}$ h^{-1} in the MBBR second stage, to be compared to 2.51 $mggTSS^{-1}$ h^{-1} in the AS system.

These values obtained by AUR lab tests match with the removed load assessed for the plant; in fact, the pilot plant allowed an average removal equal to 0.047 kg $kgTSS^{-1}$ d^{-1} whilst the AUR test gave a value of 0.050 kg $kgTSS^{-1}$ d^{-1}. The difference can be explained with the different temperature: data of the pilot plant resulted from an operation with temperature ranging between 5 and 21 .5 ºC; the average value was 14.3 ºC, lower than the lab temperature (20 ºC).

Concerning MBBR the average removed load in the pilot plant second stage resulted 0,080 kg $kgTSS^{-1}$ d^{-1} that is very close to that one assessed by the AUR test, 0.076kg $kgTSS^{-1}$ d^{-1}.

Conclusions

MBBR and AS pilot plants showed nearly comparable performances in totCOD and sfCOD removal. However, the specific surface (160 m^2/m^3) of the MBBR plastic media used in the described experimentation was not enough to overcome AS in performance. The limit of the MBBR was not the specific biomass activity but the biomass concentration.

From the obtained results a minimum value for MBBR specific surface can be proposed, in order to be competitive with a traditional activated sludge system. The specific surface of the plastic media should be higher than 200-250 m^2/m^3 assuming a filling rate of 70 %; with a filling rate lower than 70 % the overall surface decreases; thus the plastic element must have a higher specific surface.

Apart from the specific surface matter, MSBR shows a few advantages when compared to AS:

1. biomass retention time and hydraulic retention time are independent thanks to the presence of the fixed biofilm;
2. specialized biomass for C and N removal can be selected in multi-reactor configuration;
3. the treatment process is easier thanks to the absence of sludge recycling;
4. settling shows no bulking problem.

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