

*Case report*

## Upgrading of a wastewater treatment plant with a hybrid moving bed biofilm reactor (MBBR)

Luigi Falletti <sup>1,\*</sup>, Lino Conte <sup>1</sup>, and Andrea Maestri <sup>2</sup>

<sup>1</sup> Department of Industrial Engineering, University of Padova, via Marzolo 9–35127 Padova, Italy

<sup>2</sup> Polesine Acque SpA, via B. Tisi da Garofolo 11–45100 Rovigo, Italy

\* **Correspondence:** Email: luigi.falletti@unipd.it, Tel: +39-049-8275531;  
Fax: +39-049-8275555.

**Abstract:** The wastewater treatment plant of Porto Tolle (RO, Italy) was originally projected for 2200 person equivalent (p.e.) and it was made of a pumping station, an activated sludge oxidation tank (395 m<sup>3</sup>), a settler (315 m<sup>3</sup>), and two sludge drying beds. Other units were not yet in use in 2008: a fine screen, a sand and grit removal unit, a new settler (570 m<sup>3</sup>), a disinfection tank and a sludge thickener. Effective hydraulic load was 245% higher, organic load was 46% lower and nitrogen load was 39% higher than project values. Moreover, higher pollutant loads and more strict emission limits for nitrogen were expected. So the plant was upgraded: the old settler was divided into a sector of 180 m<sup>3</sup> that was converted into a predenitrification tank, and a sector of 100 m<sup>3</sup> that was converted into a hybrid MBBR tank filled with 50% AnoxKaldnes<sup>TM</sup> K3 carriers; the new settler was connected to the hybrid MBBR, and the other units were started. Biofilm growth was observed two months after plant restarting, its concentration reached 1.1 g<sub>TS</sub>/m<sup>2</sup> (0.26 kg<sub>TS</sub>/m<sup>3</sup>), while activated sludge concentration was 2.0–2.8 kg<sub>TSS</sub>/m<sup>3</sup> in all the period of study. The upgraded plant treats 1587 m<sup>3</sup>/d wastewater with 57 kg<sub>COD</sub>/d, 23 kg<sub>BOD</sub>/d and 13.3 kg<sub>N</sub>/d, and has a significant residual capacity; the effluent respects all emission limits.

**Keywords:** hybrid moving bed; nitrogen; biofilm; activated sludge; wastewater treatment; upgrading

---

### 1. Introduction

In moving bed biofilm reactors (MBBR) the biomass grows as a biofilm on small plastic carriers that move freely into the wastewater; mixing biofilm reactors the biomass grows only on carriers, while in hybrid reactors there are both biofilm and suspended activated sludge in the same tank. Several processes with different kinds of floating carriers have been developed [1], with porous

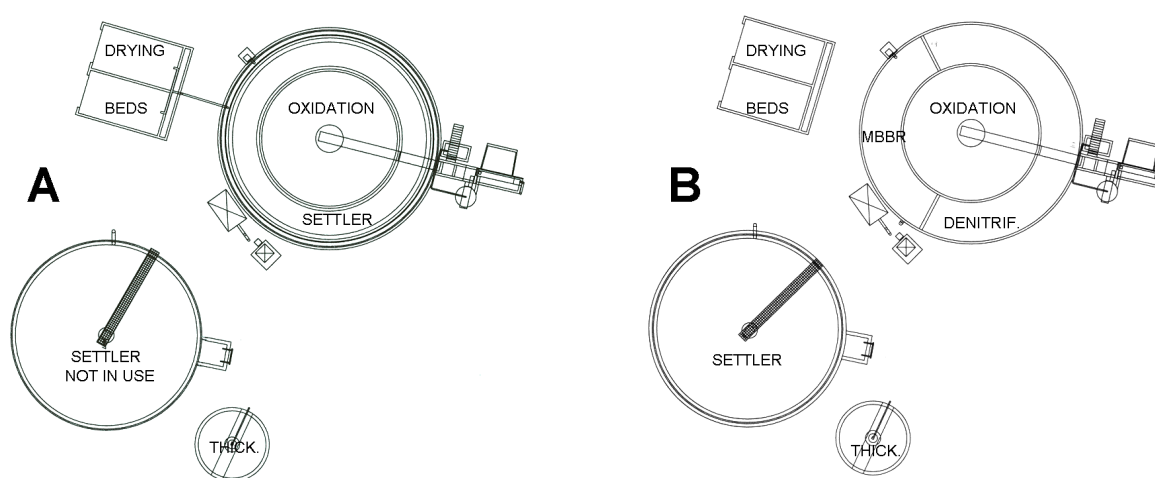
materials such as polyurethane and with nonporous material such as polyethylene. The process with the largest number of applications is the AnoxKaldnes™ MBBR with more than 400 plants in the world; it was developed in Norway, initially as a pure biofilm process, in a cooperation between the research institute SINTEF of Trondheim and the company AnoxKaldnes™ [2,3], and patented in 1991–1994. This technology is versatile and is applied for organic substance removal, nitrification and denitrification with several plant configurations; with sequencing-batch MBBR, biological phosphorus removal can be achieved [4]. Reactors for organic substance removal are usually dimensioned with surface loads as  $6 \text{ kg}_{\text{BOD}}/\text{m}^2\text{d}$  when 90% removal is requested; but for first-stage treatment of concentrated industrial wastewater, surface loads reach  $30\text{--}100 \text{ kg}_{\text{COD}}/\text{m}^2\text{d}$  [5]. Organic substance has a negative effect on nitrification, which is almost inhibited when surface load is higher than  $5 \text{ g}_{\text{BOD}}/\text{m}^2\text{d}$  [6]. Nitrification rate depends strongly on oxygen concentration (which is the limiting substrate when the ratio  $\text{O}_2/\text{N} < 2$ ); effect of temperature decrease is negative on nitrification rate but positive effect on oxygen solubility in water [7,8]. Literature reports values of  $0.8\text{--}1.0 \text{ g}_{\text{N}}/\text{m}^2\text{d}$  at  $15 \text{ }^\circ\text{C}$  and  $5 \text{ mg/L O}_2$  with a secondary effluent [9],  $0.5\text{--}0.7 \text{ g}_{\text{N}}/\text{m}^2\text{d}$  at  $7\text{--}15 \text{ }^\circ\text{C}$  and  $3.5\text{--}13.3 \text{ mg/L O}_2$  in a plant with 8 serial MBBR, 5 of which were aerated [10],  $0.5 \text{ g}_{\text{N}}/\text{m}^2\text{d}$  at  $6.4 \text{ }^\circ\text{C}$  and  $6.5 \text{ mg/L O}_2$  in a plant with 9 serial MBBR, 4 of which were aerated [11]. With a pure oxygen tertiary MBBR, nitrification rates of  $1.2\text{--}4.3 \text{ g}_{\text{N}}/\text{m}^2\text{d}$  were achieved at  $16\text{--}20 \text{ }^\circ\text{C}$  and oxygen concentrations until  $20 \text{ mg/L}$  [12]. Denitrification can be achieved with pre- or post-denitrification scheme; literature reports surface pre-denitrification rates of  $0.4\text{--}0.7 \text{ g}_{\text{N}}/\text{m}^2\text{d}$  at  $15 \text{ }^\circ\text{C}$  with raw wastewater (ratio  $\text{COD}/\text{N} > 3$ ), specific post-denitrification rates of  $1.2 \text{ g}_{\text{N}}/\text{m}^2\text{d}$  at  $15 \text{ }^\circ\text{C}$  with sodium acetate as carbon source [7,10]. Some case studies of hybrid plants with AnoxKaldnes™ carriers are also reported in literature, mainly as pilot scale researches [13,14,15] and upgrading of existing activated sludge plants on basis of results of previous pilot scale experiments: Klippan in Sweden [16], Broomfield in U.S.A. [17,18], Maserà in Italy [19], Gavà-Viladecans in Spain [20]. Studies report that nitrification is significantly improved with hybrid MBBR, according to Christensson and Welander [16] ca. 85% of nitrification is due to biofilm; organic substance oxidation and sludge settleability is also improved.

This paper deals with the wastewater treatment plant of Porto Tolle (Italy), which was upgraded by dividing an existing tank into an activated sludge denitrification tank, an activated sludge oxidation tank and a hybrid MBBR oxidation tank.

## 2. Plant description

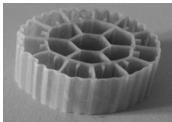
The wastewater treatment plant of Porto Tolle (RO, Italy) was originally projected for 2200 p.e.; expected loads were  $550 \text{ m}^3/\text{d}$ ,  $264 \text{ kg}_{\text{COD}}/\text{d}$ ,  $132 \text{ kg}_{\text{BOD}}/\text{d}$  and  $26 \text{ kg}_{\text{N}}/\text{d}$ . Emission limits were stated by the Regional Plan for Water Resanation and were:  $\text{TSS} \leq 35 \text{ mg/L}$ ,  $\text{COD} \leq 125 \text{ mg/L}$ ,  $\text{BOD} \leq 25 \text{ mg/L}$ ,  $\text{NH}_4^+ \leq 20 \text{ mg/L}$ ,  $\text{NO}_2\text{-N} \leq 1 \text{ mg/L}$ ,  $\text{NO}_3\text{-N} \leq 30 \text{ mg/L}$ ,  $\text{P} \leq 10 \text{ mg/L}$ . The plant was originally made of a pumping station, a circular activated sludge oxidation tank ( $395 \text{ m}^3$ ) aerated by a  $1480 \text{ Nm}^3/\text{h}$  blower and fine bubble diffusers, a sedimentation unit in the external circular crown ( $315 \text{ m}^3$ ), and two drying beds for sludge (Figure 1A). Other units were built but not yet in use in 2008: a fine screen, a sand and grit removal unit, a circular sedimentation tank ( $570 \text{ m}^3$ ), a disinfection tank with peracetic acid and a sludge thickener. According to average data of 2007, the plant treated  $1898 \text{ m}^3/\text{d}$  with  $35 \text{ mg/L TSS}$ ,  $75 \text{ mg/L COD}$ ,  $37 \text{ mg/L BOD}$ ,  $19.1 \text{ mg/L TKN}$ ; hydraulic load was 245% higher, organic load was 46% lower and nitrogen load was 39% higher than project values. Wastewater was (and is) very dilute because of infiltrations of rain waters and clean water from the river Po. Even if the plant respected

emission limits, the regional environmental law was near to be modified with more strict emission limits for nitrogen and the plant had no denitrification; moreover, higher pollutant incoming loads were expected for following years. So it was decided to modify the plant and to start units that were still not in use; the choice to convert part of existing volume into a hybrid MBBR was justified with the possibility of reducing activated sludge concentration in the plant. So the circular crown was divided into two sections (Figure 1B): a sector of 180 m<sup>3</sup> was converted into a predenitrification tank, a sector of 100 m<sup>3</sup> was converted into a hybrid MBBR oxidation tank. This reactor was filled with 50% AnoxKaldnes<sup>TM</sup> K3 carriers (Table 1) and aerated by a new 1000 Nm<sup>3</sup>/h blower and medium bubbles air diffusers. The plant was modified in July 2013 and restarted with all units in August; carriers were introduced in the MBBR tank in two phases (75% in August and 25% in September).



**Figure 1. (A) Plant of Porto Tolle in first configuration and (B) after upgrading.**

**Table 1. Characteristics of AnoxKaldnes<sup>TM</sup> K3 carriers.**

Shape	
Length (mm)	12
Diameter (mm)	25
Density (g/cm <sup>3</sup> )	0.95
Nr. carriers pr. m <sup>3</sup>	144000
Maximum filling degree	66%
Effective specific surface (m <sup>2</sup> /m <sup>3</sup> carriers)	500

### 3. Material and methods

The upgraded plant was studied in the period 12 August–22 November 2013; hydraulic load was measured daily and samples were taken every week from raw wastewater and final effluent. These samples were analyzed to determine concentration of TSS, COD, BOD, TKN, NH<sub>4</sub>-N, NO<sub>2</sub>-N, NO<sub>3</sub>-N

and total nitrogen (Tot-N); analysis were conducted according to Italian standard methods published by IRSA-CNR. Since 15 September, samples of carriers were taken from the hybrid MBBR every two weeks to determine biofilm concentration, oxidizing activity and nitrifying activity with laboratory batch tests. Biofilm concentration was determined as difference of dry weight between 100 carriers with biofilm and the same carriers after cleaning with sodium hypochlorite solution. Oxidizing activity of biofilm was determined as follows: 100 carriers with biofilm were put in contact with 1 L raw wastewater under constant aeration; at the beginning of the test and after 1 hour samples were taken, filtered and analyzed to determine COD concentration; the difference between these values was divided by biofilm concentration to calculate oxidizing activity ( $\text{mg}_{\text{COD}}/\text{g}_{\text{TS}}\text{h}$ ). Nitrifying activity was determined in a similar way, but a standard solution of ammonium chloride (ca. 50 mg/L) and sodium hydrogen carbonate (ca. 200 mg/L) was used instead of raw wastewater, and nitrifying activity ( $\text{mg}_{\text{N}}/\text{g}_{\text{TS}}\text{h}$ ) was calculated from the difference in ammonium concentration divided by biofilm concentration.

#### 4. Results and discussion

Results of analysis during restarting phase of the upgraded plant are listed in Table 2; influent pollutant concentrations were very low, mainly because of significant infiltrations of rain waters and clean water from the river Po; this dilution explains reasonably pollutant removal efficiencies which were not as high as expected. The plant respected always emission limits. Average pollutant loads were  $90.5 \text{ kg}_{\text{COD}}/\text{d}$ ,  $36.5 \text{ kg}_{\text{BOD}}/\text{d}$  and  $21.1 \text{ kg}_{\text{N}}/\text{d}$ ; since the plant was upgraded to treat up to  $180 \text{ kg}_{\text{COD}}/\text{d}$ ,  $90 \text{ kg}_{\text{BOD}}/\text{d}$  and  $60 \text{ kg}_{\text{N}}/\text{d}$ , it has still significant residual capacity.

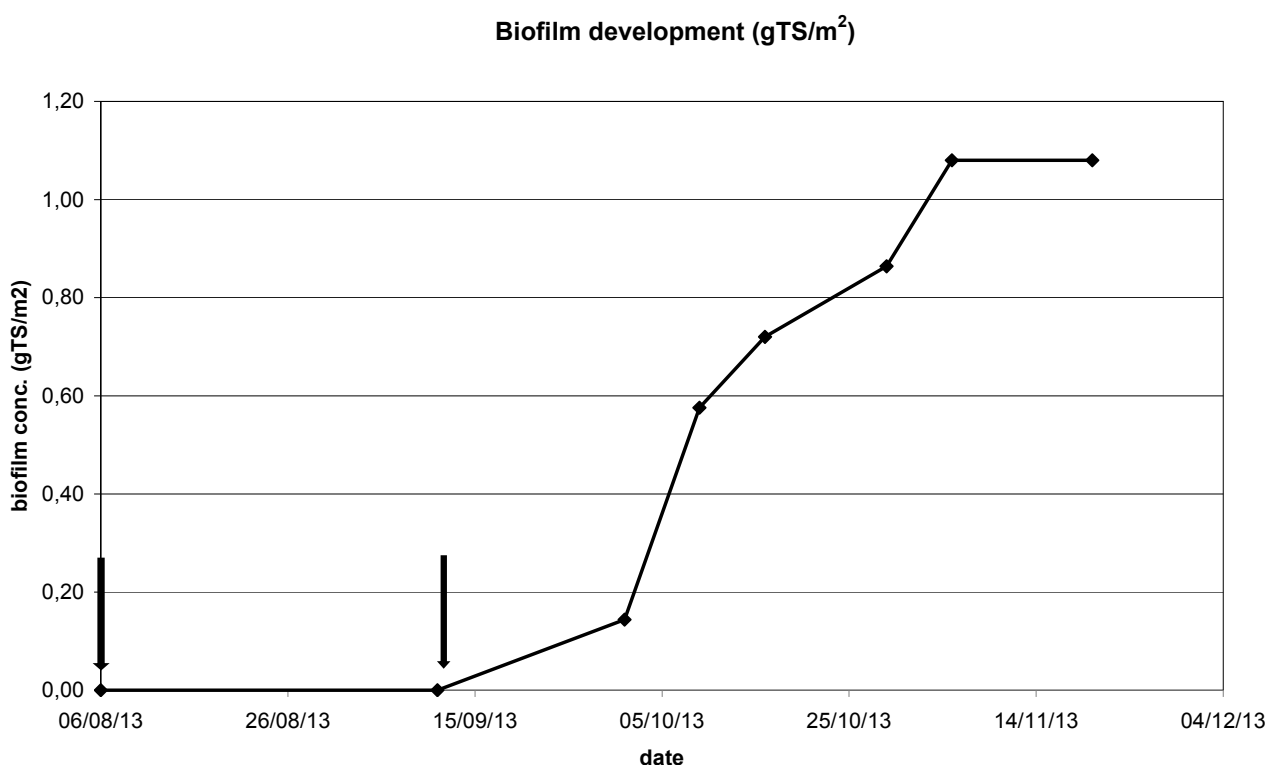
**Table 2. Hydraulic load and pollutant concentrations at the plant of Porto Tolle.**

Parameter		Raw influent			Final effluent			Removal
		min	average	max	min	average	max	
Hydraulic load	$\text{m}^3/\text{d}$	306	1587	2208	306	1587	2208	
TSS	mg/L	< 10	15	28	< 10	11	32	63%
COD	mg/L	< 25	57	214	< 25	25	49	56%
BOD	mg/L	< 5	23	111	< 5	6	15	74%
TKN	mg/L	6.0	13.3	41.3	< 4	< 4	< 4	85%
NH <sub>4</sub> -N	mg/L				< 0.5	< 0.5	< 0.5	
NO <sub>2</sub> -N	mg/L				< 0.1	< 0.1	< 0.1	
NO <sub>3</sub> -N	mg/L				7.3	10.7	12.4	
Tot-N	mg/L	6.0	13.3	41.3	7.3	10.7	12.4	20%

Note: when values were lower than detection limits, for calculations of average values and removal efficiencies they were considered as half of detection limits.

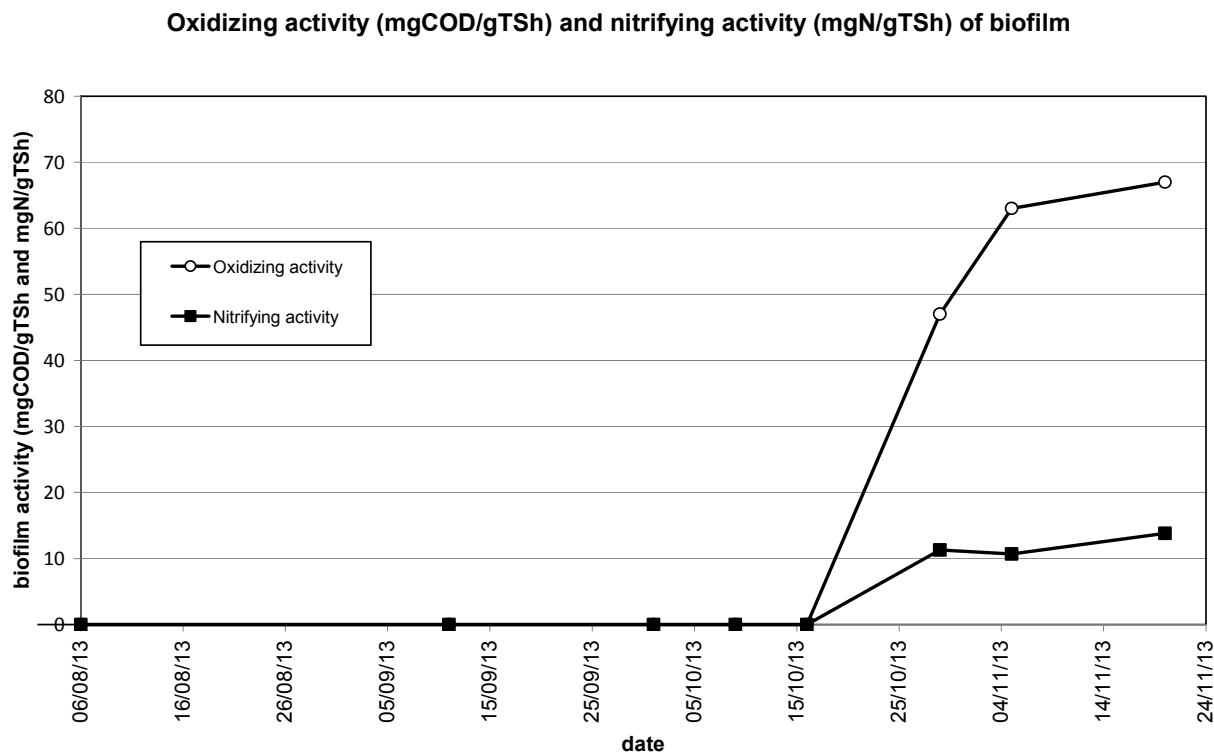
Figure 2 shows biofilm growth in the hybrid MBBR tank, the two arrows indicate carriers introduction. There was no significant biofilm growth for almost two months after first carriers introduction (75% of total carriers amount); then biofilm concentration reached  $1.1 \text{ g}_{\text{TS}}/\text{m}^2$  ( $0.27 \text{ kg}_{\text{TS}}/\text{m}^3$  tank) in one month; in the same period activated sludge concentration was  $2.0\text{--}2.8 \text{ g}_{\text{TSS}}/\text{m}^3$ . The start-up period of this plant was longer than the ones encountered by other two

authors for similar hybrid MBBR plants fed with municipal wastewater; Di Trapani et al. [13] report that their pilot plant reached good working conditions one month after starting-up; Christennson and Welander [16] report a start-up period of 49 days for their pilot plant; Santamaria et al. [20] report a start-up period of one month. The slower biofilm growth in the hybrid MBBR of Porto Tolle can be explained with the significant dilution of raw wastewater; the plant studied by Di Trapani et al. treated an influent with 257–632 mg/L COD and 23–54 mg/L  $\text{NH}_4\text{-N}$ , and the plant studied by Christennson and Welander treated an influent with 186–256 mg/L COD and 31–37 mg/L  $\text{NH}_4\text{-N}$ . The plant studied by Santamaria et al. treated an influent with 289–481 mg/L BOD. The first biofilm growth in the full-scale hybrid MBBR plant of Maserà [19] required one month; that plant treated an influent with 210–680 mg/L COD and 40–96 mg/L TKN, and biofilm concentration reached  $1.7 \text{ g}_{\text{TS}}/\text{m}^2$  in less than 3 months after carriers introduction.



**Figure 2. Biofilm development in the hybrid MBBR tank.**

Figure 3 shows oxidizing activity and nitrifying activity of biofilm; significant activity ( $67 \text{ mg}_{\text{COD}}/\text{g}_{\text{TS}}\text{h}$  and  $13.8 \text{ mg}_{\text{N}}/\text{g}_{\text{TS}}\text{h}$ ) was evidenced since the end of October. Since biofilm concentration was ca.  $1.1 \text{ g}_{\text{TS}}/\text{m}^2$  in that period, these values can be converted into superficial removal rates, i.e. respectively  $1.77 \text{ g}_{\text{COD}}/\text{m}^2\text{d}$  and  $0.36 \text{ g}_{\text{N}}/\text{m}^2\text{d}$ . Christennson and Welander [16] report higher superficial nitrification rates ( $0.86\text{--}1.18 \text{ g}_{\text{N}}/\text{m}^2\text{d}$ ); also this significant difference can be explained considering the dilution of influent wastewater of Porto Tolle.



**Figure 3. Oxidizing and nitrifying activity of biofilm in the hybrid MBBR tank.**

## 5. Conclusion

These results confirm that hybrid MBBR is a suitable technology to upgrade existing activated sludge wastewater treatment plants in limited space without building new tanks. The plant of Porto Tolle was overloaded hydraulically and for nitrogen, and had no denitrification in its original scheme. So the old settler was converted into a predenitrification tank and a hybrid MBBR tank, and another settler (already built but not yet in use in 2008) was connected to the biological section. The plant was so upgraded to treat up to 180 kg<sub>COD</sub>/d, 90 kg<sub>BOD</sub>/d and 60 kg<sub>N</sub>/d; the same biological section without carriers could treat up to 120 kg<sub>COD</sub>/d, 60 kg<sub>BOD</sub> and 40 kg<sub>N</sub>/d with current emission limits.

During the start-up phase the plant received very diluted wastewater with 57 mg/L COD, 23 mg/L BOD and 13.3 mg/L TKN on average basis. Thus pollutant removal efficiencies were apparently low even if the plant respected emission limits. First biofilm growth was observed ca. two months after first carriers introduction, and its concentration reached 1.1 g<sub>TS</sub>/m<sup>2</sup> in the following month. Start-up time was longer and biofilm concentration was lower than respective values reported by other authors for similar hybrid MBBR plants, reasonably because of very low BOD and TKN concentration in incoming wastewater. Laboratory batch tests on biofilm evidenced an oxidizing activity of 67 mg<sub>COD</sub>/g<sub>TSh</sub> (1.77 g<sub>COD</sub>/m<sup>2</sup>d) and a nitrifying activity of 13.8 mg<sub>N</sub>/g<sub>TSh</sub> (0.36 g<sub>N</sub>/m<sup>2</sup>d).

The plant has a significant residual capacity (both for organic substance oxidation and for total nitrogen removal) that will be useful for future pollutant load increases or if emission limits become stricter than current ones.

---

## Conflict of Interest

All authors declare no conflicts of interest in this paper.

## References

1. Pastorelli G, Processi a biomassa adesa a letto mobile. Sviluppi nelle tecniche di depurazione delle acque reflue (Moving bed biofilm processes, in “Development in wastewater treatment techniques”); 2000. 52<sup>nd</sup> Sanitary-Environmental Engineering Course proceedings, Milan.
2. Ødegaard H, Rusten B, Siljudalen JG (1999) The development of the moving bed biofilm process—from idea to commercial product. *Eur Water Manage* 2: 6-43.
3. Helness H, Ødegaard H (2001) Biological phosphorus and nitrogen removal in a sequencing batch moving bed biofilm reactor. *Water Sci Technol* 43: 233-240.
4. Ødegaard H, Rusten B, Westrum T (1994) A new moving bed biofilm reactor—Application and results. *Water Sci Technol* 28: 157-165.
5. Ødegaard H, Gisvold B, Strickland J (2000) The influence of carrier size and shape in the moving bed biofilm process. *Water Sci Technol* 41: 383-391.
6. Rusten B, Hem L, Ødegaard H (1995) Nitrification of municipal wastewater in moving-bed biofilm reactors. *Water Environ Res* 67: 75-86
7. Ødegaard H, Rusten B (1993) Norwegian experiences with nitrogen removal in a moving bed biofilm reactor. *Documentation of 9*: 205-221.
8. Salvetti R, Azzelino A, Canziani R, et al. Effects of temperature on tertiary nitrification in moving-bed biofilm reactors. *Water Res* 40: 2981-2993.
9. Hem LJ, Rusten B, Ødegaard H (1994) Nitrification in a moving bed biofilm reactor. *Water Res* 28: 1425-1433.
10. Rusten B, Hem LJ, Ødegaard H (1995) Nitrogen removal from dilute wastewater in cold climate using moving-bed biofilm reactors. *Water Environ Res* 67: 65-74.
11. Rusten B, Siljudalen JG, Bungun S (1995) Moving bed biofilm reactors for nitrogen removal: from initial pilot testing to start-up of the Lillehammer WWTP. *WEFTEC Proceedings* 95: 21-25.
12. Bonomo L, Pastorelli G, Quinto E, et al. (2000) Tertiary nitrification in pure oxygen moving bed biofilm reactors. *Water Sci Technol* 41: 361-378.
13. Di Trapani D, Mannina G, Torregrossa M, et al. (2008) Hybrid moving bed biofilm reactors: a pilot plant experiment. *Water Sci Technol* 57: 1539-1545.
14. Di Trapani D, Mannina G, Torregrossa M, et al. (2010) Comparison between hybrid moving bed biofilm reactor and activated sludge system: a pilot plant experiment. *Water Sci Technol* 61: 891-902.
15. Di Trapani D, Christensson M, Ødegaard H (2011) Hybrid activated sludge/biofilm process for the treatment of municipal wastewater in a cold climate region: a case study. *Water Sci Technol* 63: 1121-1129.
16. Christensson M, Welander T (2004) Treatment of municipal wastewater in a hybrid process using a new suspended carrier with large surface area. *Water Sci Technol* 49: 207-214.
17. Josslin B, Johnson CH, Haegh M. Increasing BNR capacity in activated sludge systems by use of the HYBAS<sup>TM</sup> process—Example from a full scale installation at Broomfield BWRf in Colorado; 2006. WEFTEC Annual Conference & Exposition, Dallas, USA.

- 
18. Rutt K, Seda J, Johnson CH (2006) Two year case study of integrated fixed film activated sludge (IFAS) at Broomfield, CO WWTP. *Proceedings of the water environment federation* 13: 225-239.
  19. Falletti L, Conte L (2007) Upgrading of activated sludge wastewater treatment plants with hybrid moving-bed biofilm reactors. *Ind Eng Chem Res* 46: 6656-6660.
  20. Santamaria A, Zalakain G, Hernández M, et al. (2011) Remodelación del tratamiento biológico de la EDAR Gavà-Viladecans mediante el proceso híbrido Hybas (Modification of biological treatment of EDAR Gavà-Viladecans with hybrid process Hybas, in Spanish language). *Agua* 327: 58-65.

© 2014, Luigi Falletti, et al., licensee AIMS Press. This is an open access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>)