Application of Membrane Bioreactor technology for urban wastewater treatment in Tunisia: Focus on treated water quality

This paper presents the physical-chemical and microbiological efficiencies of a submerged membrane bioreactor treating a domestic wastewater.

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Abstract

Water is a fundamental issue for the current and future development of Tunisia. In fact, effective water management is essential for socio-economic development and for maintaining healthy ecosystems. The balance between available water resources and the need for water supply is growing from one year to another, and the deficit in water resources is rapidly becoming larger. To fill in this gap, a strategy based on water conservation and the search of unconventional resources, such as reuse of treated wastewater, has been adopted in Tunisia. Membrane technology can make a significant contribution since membrane filtration enables the production of high quality water. The paper summarizes results of the EC-funded PURATREAT project (Contract No. 015449) and aims to assess the efficiency of submerged membrane bioreactor (SMBR) technology in domestic wastewater treatment with a view to reuse. A treated water of a high physico-chemical and microbiological quality was obtained after treatment, such that the water could be reused for unrestricted irrigation of ground crops for human consumption.

Introduction

Water is the most strategically important resource on Earth, which is essential for urban, industrial and agricultural needs. With the ever-increasing urban population and economic activities, water usage and demand are continuously increasing (Lu et al, 2010). There are many water shortage problems currently in the world, some of which are more serious than others. Rich and poor countries have quite different concerns over their water supply (Howell, 2004). The Mediterranean Region is an arid or semi-arid area, with typical rainfall ranging from 100 to 400 mm per year and 3000 h or more of sun per year (Bolzonella et al, 2010). In Africa, where large areas of the continent are already suffering water scarcity, there is a lack of simple access to drinking water at a nearby location and also a lack of any kind of sanitation for large segments of the population (Howell, 2004). To improve water availability, researchers have proposed the reclamation and reuse of municipal wastewater.

The activated sludge process is the most widely used biological treatment process for both domestic and industrial wastewaters in the world. This process

The PURATREAT project:

- Funded by the EC (Contract No. 015449), Duration 01/01/2006 - 30/06/2009.
- In total 10 partners, coordinated by ttz Bremerhaven
- More information: http://www.puratreat.com/

Key findings

- The removal efficiencies of soluble COD, Total COD, total nitrogen (TKN), and total suspended solids (TSS) reached respectively 89%, 73%, 88% and 100%.
- The treated water was free from both bacteria and viruses, hence pathogen free.
- The treated wastewater was found to be suitable for unrestricted irrigation in Tunisia, i.e. suitable for use in irrigating ground-based crops for human consumption.

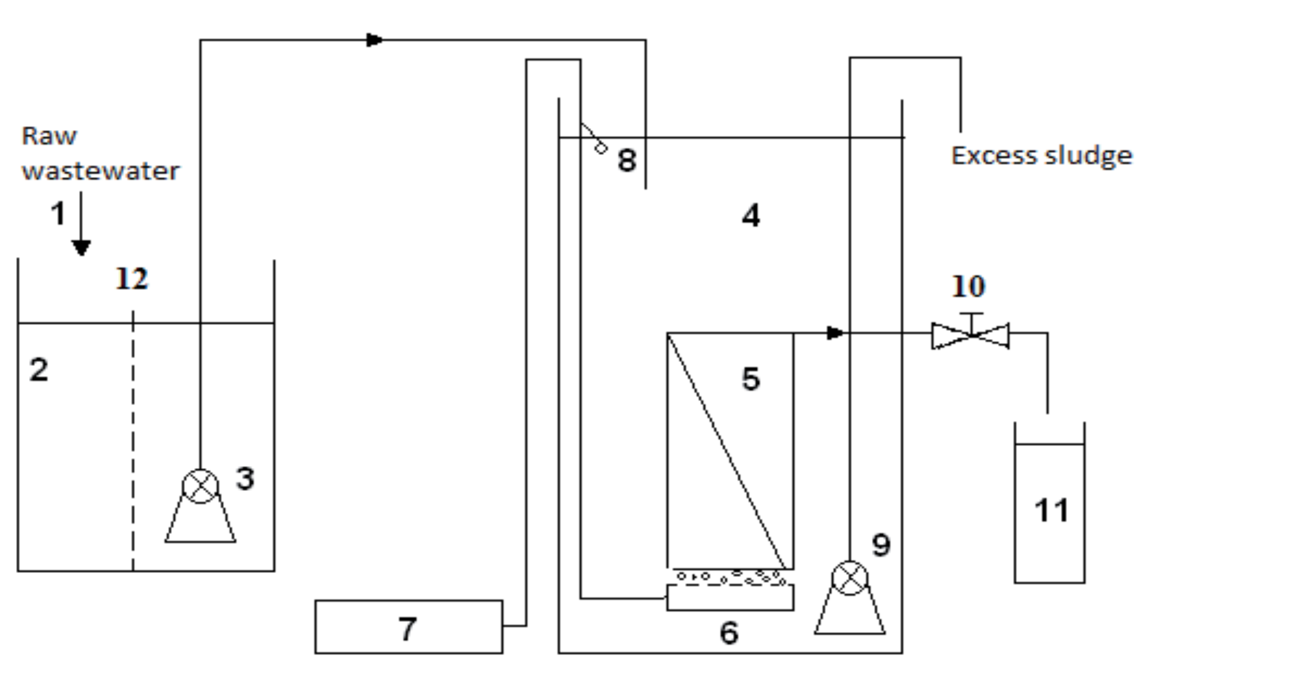

Figure 1: Schematic of the pilot MBR installation

1. Raw wastewater, 2. Feed tank, 3. Submerged pump, 4. Aerobic biological tank, 5. Kubota microfiltration membranes, 6. Air diffuser, 7. Air compressor, 8. Level detector, 9. Sludge withdrawal pump, 10. Automatic permeate valve, 11. Permeate collection tank, 12. Grit screen.

consists of biodegradation of the pre-treated influent by microorganisms in a continuous tank where oxygen supply is controlled. Following the bioreactions, the water / biomass mixture is passed to a settling tank to ensure the separation of the treated water from the biomass by gravitational setting (Wei et al, 2003; Wisniewski, 2007). The treatment efficiency is usually limited by the difficulties in separating suspended solids (Xing et al, 2000). A membrane bioreactor (MBR) is a biological wastewater treatment process in which the conventional gravity separators are replaced by microfiltration or ultrafiltration membrane modules. MBRs have become a popular biological wastewater treatment technology because they offers numerous advantages over the conventional activated sludge process, such as excellent effluent quality, a compact footprint, a more concentrated biomass, and a reduced sludge yield (Alain et al, 2008). Because membranes are an absolute barrier for bacteria, and in the case of UF also for viruses, the MBR process provides a considerable or complete level of physical disinfection (Melin et al, 2006).

This research aims to study the performance of the most widely commercialised MBR technology, that of Kubota, applied to domestic wastewater treatment in Tunisia.

Water quality analyses

Physical-chemical analyses

Chemical oxygen demand (COD) was determined according to standard method as described by Knechtel. Total suspended solids (TSS) and volatile suspended solids (VSS) were determined according to the standard methods (APHA, 1992). Total Kjeldahl nitrogen (TKN) was determined according to the standard method (Kjeldahl, 1883). Total organic carbon (TOC) was measured with a Dohrmann (DC 190) analyzer.

Microbial estimation

Total coliforms (TC), faecal coliforms (FC) and faecal streptococci (FS), total coliforms (TC), faecal coliforms (FC) and faecal Streptococci (FS) were estimated according to ISO 4832 (1991) and AFNOR (NF T90-411, 1989) water standard methods. Most probable number (MPN) determination of Salmonella (S) was carried out by modified method of Yanko et al. (1995). Helminth eggs and protozoan cysts were extracted from wastewater by sedimentation–flotation techniques.

Experimental setup

The MBR pilot plant was placed in situ at the municipal wastewater treatment plant of South Sfax (WWTP) and treated the same influent coming to the full sized plant. The system tested was a single tank submerged membrane bioreactor (SMBR) (Figures 1 and 2). The average operational volume of the MBR was 1.38 m^3. The membranes used were Kubota microfiltration membranes with a pore size of 0.4 µm, made from chlorinated polyethylene, and with an operating membrane area of 5.6 m^2. Filtration was continuous and the hydraulic head above the membranes was used to drive filtration, which was regulated by an automatic valve and a flow meter on the permeate line. Air was supplied to the filtration tank as coarse bubbles, for both membrane scouring and biomass maintenance. The gassing rate was 4.2

$m^3.h^{-1}$, which corresponds to the recommended value for Kubota membranes of 10 litres of air/membrane panel/ minute. The solids retention time (SRT) was 30 days, the average hydraulic retention time (HRT) was 1.01 days, and the average membrane flux was 12 $l.m^{-2}.h^{-1}$.

Treatment performance

Raw wastewater characterisation

The raw wastewater is pre-treated (with oil/fat, sand/grit removal and fine screening) urban wastewater of South Sfax municipal wastewater treatment plant. The physical and chemical characteristics of the influent are given in Table 1, along with the two national Tunisia standards for water discharge in the public domain, e.g. parkland irrigation or river discharge (NT 106.02), or reuse for unrestricted irrigation (NT106.03).

As pointed out in Table 1 the influent presented an inconstant composition. The COD and BOD5 concentrations are higher than the Tunisian standards NT 106.02 and NT 106.03 for hydraulic public domain and wastewater reuse in irrigation respectively. Heavy metals concentrations exceeded the required standard values for plumb (Pb), chrome (Cr) and nickel (Ni).

Table 1: Influent characteristics, and Tunisian National Standards for Water Discharge / Reuse.

Parameters	Influent waste water	NT 106.02	NT 106.03
pH	7.5 – 8.25	6.5-8.5	6.5-8.5
EC (mS/cm)	4.32 – 7.88	-*	7
TSS (mg/ l)	21 – 1700	0.03	0.03
Turbidity (NTU)	40 – 494	-	-
COD (mg O_2/l)	215 – 1134	90	90
BOD_5 (mg O_2/l)	90 – 480	30	30
TOC (mg/l)	80.4 – 428.6	-	-
TKN (mg/l)	35 – 141	100	-
NH^{4+} (mg/l)	25 – 66	-	-
NO^{3-} (mg/l)	0.4 – 2.2	-	-
NO^{2-} (mg/l)	0.03 – 31	-	-
P (mg/l)	8 – 22	-	-
Cu (mg/l)	absent	0.5	0.5
Hg (mg/l)	0.708	0.001	0.001
Pb (mg/l)	0.198	0.1	1
Cr (mg/l)	0.724	0.01	0.1
Ni (mg/l)	0.6	0.2	0.2

- indicates no restrictions regarding this component.

Figure 2: Photo of the pilot MBR installation

Physico-chemical performance

MLSS concentration

At start up the system was operated with sludge age of 15 days, which resulted in a MLSS concentration of 4.5 g/l (data not shown). After that the sludge age was adjusted to 30 days and the biomass concentration increased progressively a mean value of 9.5 g/l (Figure 3).

To maintain a biomass concentration around 9.5 g/l a regular manual sludge withdrawal was performed, which maintained the SRT at 30 days. Sudden increases or decreases in the biomass concentration in Figure 3 may be due to the time of taking a sample (immediately after biomass removal or after a shutdown of the reactor), or due to large fluctuations in the feed wastewater COD (see Figure 4).

COD removal efficiency

COD is the most important parameters studied to assess the efficiency of a wastewater treatment process. Influent and permeate COD was monitored and illustrated in Figure 4.

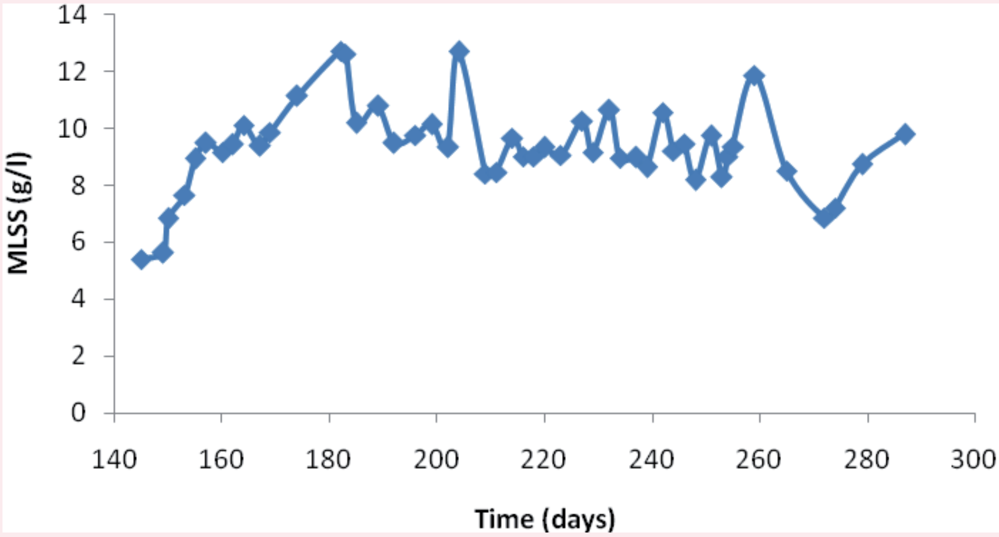

Figure 3: MLSS evolution throughout the MBR operation.

The average effluent COD was < 90 mg/l, but it should be noted that this limit was exceeded occasionally. This can be justified by an abnormal operation of the system (eg a short term flux increase, the entry of an industrial effluent...). Influent COD oscillated from 215 mg/l to 1135 g/l. Low feed COD values were due to dilution caused by rain and high values can be explained by the illegal discharge of industrial wastewater into the sewer system. Using this SMBR treatment process the COD removal efficiency averaged 96 % which is in agreement with the results of several investigators, who reported COD removal efficiencies of more than 95 % (Ogochi et al, 2000; Gander et al, 2000; Al-Malack, 2007). The permeate quality meets the standards related to reuse in unrestricted irrigation in terms of COD concentration.

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Microbiological performance

The pathogen removal efficiency of the MBR process was assessed. Several target bacteria species were used as markers of the presence of faecal contaminants or food poisoning organisms. A wide range of microorganisms were present in the raw wastewater and analysis of the permeate showed that the microfiltration membrane succeeded in retaining the selected target micro-

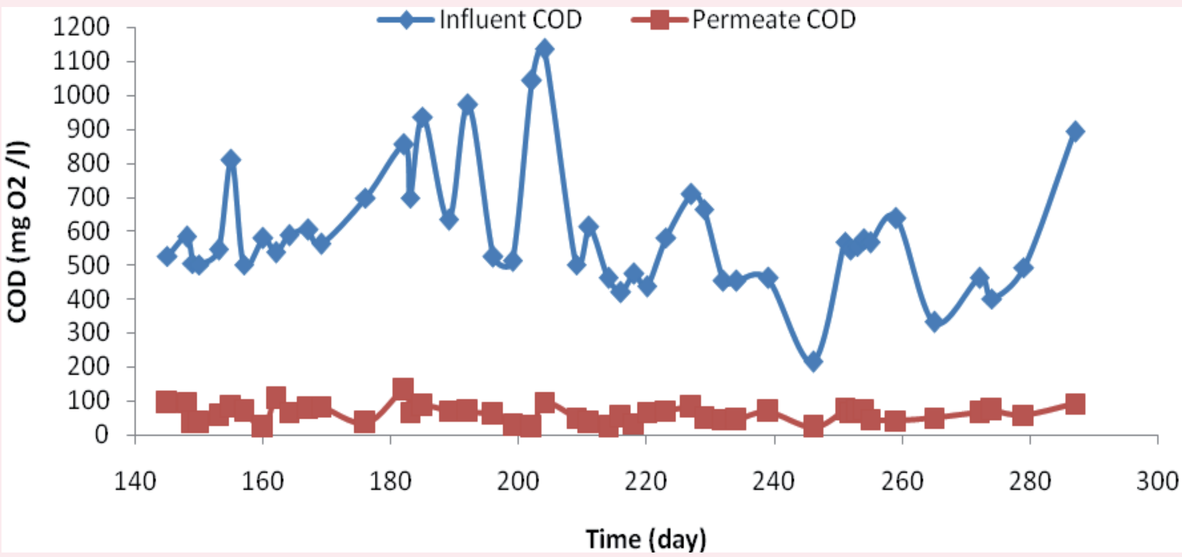

Figure 4: COD evolution throughout the MBR operation.

Table 2: Feed wastewater and permeate (treated water) microbial analysis.

Micro-organism	Influent waste water	Treated water (average)
Aerobic mesophilic bacteria (CFU/ml)*	54 x 10^7 to 90 x 10^7	40**
Total coliforms (CFU/ml)	10 x 10^5 to 53 x 10^5	0
Faecal coliforms (CFU/ml) or (MPN/ml)	34 x 10^4 to 11 x 10^5	0
Faecal Streptococci (MPN/ml)	25 x 10^5 to 25 x 10^6	0
Staphylococcus (CFU/ml)	7 x 10^2 to 13 x 10^3	0
Pseudomonas (CFU/ml)	6 x 10^1 to 6 x 10^2	0
Salmonella	Present	Absent
Helminth eggs (ova/l)	160 to 250	0
Protozoan cysts (cysts/l)	620 to 1100	0

* CFU – colony forming units
** this value is suspected as a result of recontamination of permeate as the significant majority of permeate samples did not contain any bacteria.

organisms – see Table 2. The permeate is pathogen free, and hence meets the requirements for unrestricted irrigation.

Conclusion

This study has confirmed that the biological treatment of urban wastewater by membrane bioreactor has a satisfactory performance because it gives good removal of COD and a complete retention of pathogens. The high quality of the permeate, proved by its pathogen-free character and low COD concentration, confirms its appropriateness for unrestricted irrigation of ground based human crops. The MBR system outperformed the full sized activated sludge plant, treating the same municipal wastewater, in respect of treated water quality and the opportunity for reuse.

Acknowledgement

This work was carried out under the framework of the PURATREAT Project - an EC-funded (Contract No. 015449) research initiative that aimed to study the application of Membrane Bioreactors as an alternative to the conventional treatment of urban wastewaters in the Southern and Eastern Mediterranean regions.

Description of overall project

- The objective of the PURATREAT project was to study a new approach to the operation of membrane bioreactors. This study included a comparison of three leading membrane bioreactor technologies. The operating procedure studied was aimed at minimising energy consumption and reducing maintenance costs, whilst at the same time reclaiming wastewater for reuse in irrigation. These characteristics could make membrane bioreactors working in these conditions suitable to be operated in peri-urban areas of the Mediterranean basin, where expenditure in public services is a critical factor.
- The project started on 01/01/2006 and finished on 30/06/2009.
- Partners: Technologies Transfer Zentrum Bremerhaven (TTZ), Germany (Coordiantor); Centre of Biotechnology of Sfax (CBS), Tunisia; University of Bath, UK; European Membrane Institute, the Netherlands; National Agency for Sanitation, Tunisia; University of Cadi Ayad, Morocco; University of Al-Baath, Syria; Bioazul, Spain; King Saud University, Saudi Arabia; The Inter-Islamic Network on Water Resources Development and Management, Jordan.
- The pilot trials of the MBR systems were conducted by CBS in Sfax, Tunisia.

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