Comparative study of membrane bioreactor (MBR) and activated sludge processes in the treatment of Moroccan domestic wastewater

ABSTRACT
The study was based on an external pilot-scale membrane bioreactor (MBR) with a ceramic membrane compared to a conventional activated sludge process (ASP) plant. Both systems received their influent from domestic wastewater. The MBR produced an effluent of much better quality than the ASP in terms of total suspended solids (TSS), 5-day biological oxygen demand (BOD₅) and chemical oxygen demand (COD), total phosphorus (TP) and total nitrogen (TN). Other effluent quality parameters also indicated substantial differences between the ASP and the MBR. This study leads to the conclusion that in the case of domestic wastewater, MBR treatment leads to excellent effluent quality. Hence, the replacement of ASP by MBR may be justified on the basis of the improved removal of solids, nutrients, and micropollutants. Furthermore, in terms of reuse the high quality of the treated water allows it to be reused for irrigation.

INTRODUCTION
The world is facing a global water quality crisis. Continuing population growth and urbanization, rapid industrialization, and expanding and intensifying food production are all putting pressure on water resources and increasing the unregulated or illegal discharge of contaminated water within and beyond national borders (Corcoran et al. 2008). Therefore, the interest in wastewater treatment is increasing with the growing focus on the need for water conservation. In addition, urbanization is creating a demand for more compact wastewater treatment plants (Templeton & Butler 2011).

Activated sludge treatments are often used for municipal and domestic wastewater purification, and show high organic matter removal efficiency. However, activated sludge treatments are highly sensitive to external disturbances of a physical and/or chemical nature and this often results in high concentrations of suspended solids and turbidity in the effluent, reducing the amount of active biomass in the bioreactor (Metcalf & Eddy 2003).

Currently, the reuse of wastewater has become an environmentally and economically viable option, due to increasingly restrictive parameters for wastewater discharge, the imposition of charges both for the collection of water and for the discharge of effluents, and the reduced availability and quality of water resources (Bixio et al. 2006). This being the case, one of the most promising technologies for wastewater treatment and reuse are membrane separation systems and the combination of these systems with other technologies (Iorhemen et al. 2016).

Membrane bioreactors (MBRs) consist of biological reactors combined with membrane separation processes, usually with microfiltration or ultrafiltration (UF). In other words, this hybrid system is a biochemical engineering process involving a suspended growth bioreactor for biochemical reactions (Lorain et al. 2010) and a porous membrane for the separation of treated water and biomass. There are two types of MBR technologies: external MBRs, in which the membrane modules are
placed outside the bioreactor, and submerged MBRs, where the membrane module is placed inside the bioreactor (Rajindar 2015).

Among the advantages of MBRs, is the fact that they are compact and modular systems, with low sludge production, that completely remove suspended solids independently of the sedimentability characteristics of the biomass. They also generate high quality treated wastewater (Cicek 2003). MBRs have become the wastewater treatment technology that overtook the conventional activated sludge process (ASP) (Attiogbe 2013) and they can be used for both municipal and domestic wastewater treatment. Lerner et al. found that in comparison with ASP, the MBR process can produce an effluent of much better quality in terms of organic matter, suspended solids, and nutrients (Lerner et al. 2007). Since MBR systems have been introduced for biological wastewater treatment, it is important to evaluate their performance in heavy metal removal. Some researchers found that an MBR system using UF membranes for the treatment of wastewater increased metal removal efficiency compared to the conventional activated sludge system (Battistoni et al. 2007). The wastewaters from MBRs may be reused directly for unrestricted irrigation (Hee-deung et al. 2015). The disadvantages associated with MBR include high investment cost and relatively difficult operation and maintenance. Membrane fouling problems require frequent cleaning procedures with chemicals, and therefore intermittent operation of the system (Gkotsis et al. 2014).

The main objective of this work was to investigate and compare the performance of domestic wastewater treatment using ASP and MBR operating under comparable conditions.

MATERIALS AND METHODS

Operation and pilots configuration

The MBR pilot plant used was manufactured by Cossimi in France. A schematic of the MBR is shown in Figure 1. The bioreactor was made up of an anoxic tank of 20 L and an aeration tank of 40 L. The flow was regulated with two level sensors to maintain a constant volume (0.5 L/h) of liquid in the reactor. A peristaltic pump controlled by these levels fed the pilot with wastewater from the feed tank. Sequecd aeration was carried out by four diffusers placed at the bottom of the aeration reactor, providing the necessary oxygen for good treatment. The aeration cycles were fixed by the oxygen transmitters that controlled the air blowing in, and the aeration range was 0.2–0.5 L/min, alternating between aerobic and anoxic conditions (about 15 cycles per day). A constant hydraulic retention time (HRT) of 15 hours was maintained in the system throughout the study.

The UF membrane employed in the study was ceramic tubular (Membralox®) allowing the separation of the treated effluent and the purifying biomass, and it was placed outside the bioreactor. The characteristics of the membrane are listed in Table 1. Ceramic UF membranes are by far the most widely used for physical removal of particles in the size range of 0.01–10 μm from liquid, because of their advantages, including chemical and thermal stability, physical strength, and a longer operational life (Mancha et al. 2014). The membrane was cleaned after each use following the manufacturers’ recommendation. Before starting the membrane chemical cleaning, the aeration tank was completely isolated from the rest of the system.

Figure 1 | Schematic diagram of the ultrafiltration module.
system. Then, citric acid solution and alkali solution were prepared and put in the cleaning tank, each solution being recirculated through the membrane for about 20 min.

Operating at a constant flow, an increase in clogging is associated with an increase in the transmembrane pressure. The pressure was measured by means of pressure sensors and pressure gauges placed at the outlet of the recirculation pump just before the membrane module inlet, at the outlet of the membrane module and in the permeate collecting circuit. The optimal pressure range was 0.05–0.15 bar. Before the treatment, it was imperative to carry out the pretreatment step to protect ceramic membrane from damage.

The activated sludge system for domestic wastewater treatment is shown in Figure 2. First of all, a preliminary treatment was used. This step was based on screening (2–3 mm) and grit removal. It is an important step for several reasons: to protect the mechanical equipment and pumps from abrasive wear, reduce accumulation of grit in settling tanks and prevent pipe clogging by deposition of grit. Then, the removal of wastewater suspended impurities was treated in an ASP based on a biological treatment system comprising an aeration tank followed by secondary clarifier. It was designed for an average flow of 1 L/s and peaks of 3 L/s. The basin consisted of five adjacent cells with a unit volume of 19 m³. The basins were operated in parallel for the activated sludge treatment. The raw water entered via the weir gate of the distribution channel. The aeration tanks were supplied with air by two lobe boosters with a nominal flow of 240 m³/h each. Air was distributed in each of the cells by means of medium bubble diffusers aligned on a single stainless steel aeration ramp and arranged to induce spiral stirring. The sludge produced in the aeration basins was separated in a circular secondary decanter 3.7 m in diameter with a thickening cone with walls inclined at 60°; the supernatant of the decanter was the treated water, and was conveyed to the outlet. The sludge was aspirated at the bottom of the thickening cone and recirculated at the top of the basins. The duration of both processes was about 90 days. We operated the MBR and ASP processes simultaneously, and operated the MBR in sequence.

**Domestic wastewater**

The influent used in this study, in both the MBR pilot and the ASP, was domestic wastewater. The parameters of the domestic wastewater are listed in Table 2, and they were within the standard limits of WHO and US-EPA (WHO 2006). However, total suspended solids (TSS) (350–414 mg/L), 5-day biological oxygen demand (BOD₅) (217–497 mg/L), and chemical oxygen demand (COD) (527–745 mg/L) deviated considerably from their prescribed limits, indicating a high level of contamination. Pollution loads were all assumed to be of domestic origin. As shown, the wastewater characteristics represent medium-strength urban wastewater seen in Morocco and in most

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**Table 1 | Characteristics of the membrane used**

<table>
<thead>
<tr>
<th>Characteristics of the membrane used</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Membrane material</td>
<td>Ceramic</td>
</tr>
<tr>
<td>Module</td>
<td>Tubular type P10</td>
</tr>
<tr>
<td>Membrane area</td>
<td>0.45 m²</td>
</tr>
<tr>
<td>Cut off</td>
<td>15 kD/10 to 20 nm</td>
</tr>
<tr>
<td>Membrane length</td>
<td>1,178 cm</td>
</tr>
<tr>
<td>Diameter of the channels</td>
<td>6 mm</td>
</tr>
<tr>
<td>Flux (design)</td>
<td>67 L/m²/h</td>
</tr>
<tr>
<td>Flux (average operation)</td>
<td>55 L/m²/h</td>
</tr>
<tr>
<td>Transmembrane pressure (TMP)</td>
<td>0.05–0.15 bar</td>
</tr>
</tbody>
</table>

**Figure 2 | Schematic diagram of the conventional activated sludge system.**
cities around the world (Bruursema 2011; MDCE 2014). Furthermore, these values exceed the specific limit values of Moroccan domestic rejection and the reuse standards, hence the necessity for wastewater treatment.

The bioreactor was inoculated with 15 L of secondary aerobic sludge (15–25 °C) from the wastewater treatment plant, without previous acclimatization to psychrophilic conditions. The initial concentration of sludge in the bioreactor was around 10 g/L TSS. The reactor was then fed with wastewater from the same wastewater treatment plant.

### Analytical methods

Samples of wastewater were taken before and at the end of each treatment cycle. They were collected periodically and analysed for various physical, chemical and microbiological parameters in accordance with the Standard Methods (APHA et al. 2005; Bliefert & Perraud 2009; Rodier et al. 2009; Bruursema 2011). Quality parameters such as COD (Hach DR2800 Spectrophotometer), TSS and volatile suspended solids were determined following sample filtration through 0.45 μm; these parameters were measured every day. The BOD₅, total nitrogen (TN) and total phosphorous (TP) were measured with reagent kits (HACH DR4000, USA) twice per week (Bliefert & Perraud 2009). Also, the disinfectant efficacy of the ASP and MBR processes was evaluated; analyses of total coliforms were carried out in the bacteriology laboratory using the filter membrane method. The analysis of heavy metal concentrations was by the inductively coupled plasma mass spectrometry method (ICP-MS).

### RESULTS AND DISCUSSION

#### Removal of COD, BOD₅ and TSS

Figure 3 summarizes the comparison of the MBR and ASP performance in COD and BOD₅ removal. The influent COD concentration throughout the investigation was found to vary between 527 and 745 mg/L. The COD concentration in the ASP effluent and MBR permeate ranged from 147 to 179 mg/L and 15 to 52 mg/L, respectively. The influent BOD₅ concentration throughout the investigation was found to vary between 217 and 497 mg/L.

Figure 4 illustrates the concentration of TSS in wastewater, ASP effluent and MBR permeate. TSS is the indicator of the operational behavior of any biological wastewater treatment plant. The influent TSS concentration throughout the investigation was found to vary between 350 mg/L and 414 mg/L. The mean TSS influent value was 371 mg/L. TSS concentration was observed to be within a range of 29 mg/L to 49 mg/L in the ASP effluent and 7.5 mg/L to 3 mg/L in the MBR permeate. However, in the ASP effluent the TSS concentrations fluctuated. It should be noted that the sludge residence time in the MBR was shorter than in the ASP. The higher MBR suspended solids removal effectiveness was the result of the fact that

![Figure 3](http://iwaponline.com/wst/article-pdf/78/5/1129/494649/wst078051129.pdf)
separation of bio-solids by membranes is independent of the bio-sludge flocculation and settling ability. The results indicate that, as expected, the MBR was more efficient than the ASP in the removal of suspended solids.

**Nutrient removal**

TP removal in the MBR pilot was checked by comparison with the ASP. Figure 5 shows that there was a significant difference in the average between the TP concentrations in the influent and in the MBR permeate. The influent TP concentration throughout the investigation was found to vary between 9.2 and 7.5 mg/L. The TP concentration in the ASP effluent and the MBR permeate ranged from 1.9 mg/L to 3 mg/L and 0.9 mg/L to 2.5 mg/L, respectively. However, the mean value of the TP concentration in the influent was 8.3 mg/L, which decreased to 2.6 mg/L at the outlet of the ASP treatment. Also, a significant decrease in TP concentration was recorded in the MBR permeate: 1.6 mg/L.

Most of the TN in domestic sewage is present as N-NH₄⁺ (APHA et al. 2005). The influent TN concentration throughout the investigation was found to vary between 45.4 and 60 mg/L. The TN concentration in the ASP effluent and the MBR permeate ranged from 1.9 mg/L to 3 mg/L and 0.9 mg/L to 2.5 mg/L, respectively. However, the influent TN mean concentration was 54 mg/L, decreasing to 24.5 mg/L in the ASP and to 4 mg/L in the MBR permeate. This decrease in the nitrogen content throughout the operation of the MBR could be due to both the hydrolysis of the accumulated particulate organic matter and also to cell disintegration. This occurs during the nitrification and denitrification process (Yuan et al. 2016).

**Effectiveness of pollution abatement**

The removal efficiency of TSS, COD and BOD₅ in the samples is shown in Table 3. During the 3 months of operation, the mean concentrations of TSS, COD and BOD₅ in the wastewater influent were 371 mg/L, 619 mg/L and 373 mg/L, respectively. It should be noted that more than 99%, 95% and 93% of TSS, COD and BOD₅ were removed by the MBR process. The COD on average eliminated in the ASP was 74% comparing to 95% in the MBR. This parameter measures the concentration of suspended and dissolved organic and inorganic compounds (Rodier et al. 2009). In a study by Valderrama et al., of an MBR process, total COD removal was 97% on average (Valderrama et al. 2012). BOD₅ is used to measure the oxygen demand for the natural breakdown of the organic matter present in water (Rodier et al. 2009). The BOD₅ removal efficiency was 84% in the ASP and 95% in the MBR. Also, the average TSS eliminated in the ASP was 90% compared to 99% in the MBR. Furthermore, the TN removal efficiency in the ASP was 53% and in the MBR it was 93%. The removal efficiency of TP in the ASP was 70% and in MBR it was 81%. This removal of nitrogen and phosphorus in the MBR could be beneficial if the effluent is to be used for irrigation purposes. Chen et al. suggested that the forward osmosis membrane process could provide another option for resolving this challenge as it can almost totally reject N and P contaminants (Chen et al. 2014). Regarding the conductivity, reductions...
in this parameter was recorded, in the ASP effluent and the MBR permeate with the respective averages of 12% and 24%. This decrease is attributed to natural water mineralization (Shakir et al. 2017). The averages are near Moroccan water quality standards for irrigation (S.E.E.E. 2007). These results demonstrate that the MBR treatment is more effective than the ASP in treating domestic wastewater.

The comparison of MBR and ASP for domestic wastewater treatment revealed that the MBR could produce an effluent of much better quality in terms of suspended solids and turbidity. The very low and uniform TSS concentration in the MBR effluent could exclude the need for filtration in order to reach more stringent wastewater discharge standards. The other basic parameters (COD, BOD5, TP and TN) did show substantial differences between the processes, leading to the conclusion that MBR is a perfect wastewater treatment process. Weiss and Reemtsma carried out a comparative study of the performances of a laboratory-scale MBR system and conventional activated sludge system for pollutant removal from municipal wastewater (Weiss & Reemtsma 2012). Their results indicated that for most of the studied compounds, the MBR treatment was clearly superior to ASP with significant removal efficiencies of the contaminants present in the raw water.

### Heavy metal and bacteria removal

Table 4 summarizes the mean values of heavy metal and total coliform removal. For the study of heavy metal removal from wastewater, we analysed some heavy metals (zinc, iron, copper, lead and nickel). The analyses in both processes show that the concentrations of the heavy metals present in the ASP effluent and the MBR permeate conform to the irrigation reuse standards. Moreover, for the MBR, the UF membrane was able to retain suspended solids. Consequently, the metal ions attached to sludge flocs were effectively retained by the UF membrane. These results are consistent with those indicating the maximum concentration of trace elements in irrigation water by the EPA (EPA 2012). However, membrane processes such as ultrafiltration, nanofiltration and reverse osmosis have proven their competitiveness in the removal of metals from wastewater because of their low energy requirement, small volume of concentrate, and high selectivity (Abhang et al. 2013). Toxic metals, when present, can cause health risks by transfer and accumulation from water, via plants and animals to humans. So the removal of toxic metals makes wastewater safe for reuse and contributes to water sustainability (Fu & Wang 2011).

Faecal coliforms, which are generally used as indicators to determine the degree of disinfection (EPA 2012), were also monitored during the experiment. Figure 6 shows that the ASP effluent concentration was around 5 log10 CFU/100 mL, while the MBR permeate was lower than 1 log10 CFU/100 mL, thus confirming that ASP requires additional treatment to achieve the microbial requirements for water reuse purposes. The same result was reported for an effluent treated by MBR in Morocco (Nahli et al. 2016). The small size of the pores of the UF membrane makes it possible to

### Table 3 | Removal efficiencies of the contaminants present in the influent

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Raw water</th>
<th>Treated water</th>
<th>ASP</th>
<th>ASP removal efficiency (%)</th>
<th>MBR</th>
<th>MBR removal efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity</td>
<td>μS/cm</td>
<td>1,220</td>
<td>1,080</td>
<td>12</td>
<td>930.5</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>TSS</td>
<td>mg/L</td>
<td>371</td>
<td>39.3</td>
<td>90</td>
<td>4.5</td>
<td>99</td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td>mg/L</td>
<td>619</td>
<td>59.5</td>
<td>74</td>
<td>36.7</td>
<td>95</td>
<td></td>
</tr>
<tr>
<td>BOD5</td>
<td>mg/L</td>
<td>373</td>
<td>30.3</td>
<td>84</td>
<td>26.1</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>TN</td>
<td>mg/L</td>
<td>54</td>
<td>25.4</td>
<td>53</td>
<td>3.9</td>
<td>93</td>
<td></td>
</tr>
<tr>
<td>TP</td>
<td>mg/L</td>
<td>8.3</td>
<td>2.51</td>
<td>70</td>
<td>1.6</td>
<td>81</td>
<td></td>
</tr>
</tbody>
</table>

### Table 4 | Heavy metal and bacteria removal

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ASP effluent</th>
<th>MBR permeate</th>
<th>Rejection standards</th>
<th>Reuse standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron (Fe), mg/L</td>
<td>2.5</td>
<td>2.5</td>
<td>5</td>
<td>5.0</td>
</tr>
<tr>
<td>Copper (Cu), mg/L</td>
<td>0.2</td>
<td>0.1</td>
<td>2</td>
<td>0.2</td>
</tr>
<tr>
<td>Zinc (Zn), mg/L</td>
<td>1.1</td>
<td>0.5</td>
<td>5</td>
<td>2.0</td>
</tr>
<tr>
<td>Lead (Pb), mg/L</td>
<td>0.1</td>
<td>0.1</td>
<td>1</td>
<td>5.0</td>
</tr>
<tr>
<td>Nickel (Ni), mg/L</td>
<td>0.2</td>
<td>0.1</td>
<td>5</td>
<td>0.2</td>
</tr>
<tr>
<td>Faecal coliforms, log10 CFU/100 mL</td>
<td>4.7</td>
<td>0.5</td>
<td>–</td>
<td>3.69</td>
</tr>
</tbody>
</table>
block all bacterial species. The results of this study indicated that the MBR system can achieve better microbial removal in far fewer steps than the ASP to lower levels than the reuse standards. MBRs can consistently achieve efficient removal of suspended solids and coliform bacteria. Valderrama et al. also compared ASP and MBR systems treating wastewater (Valderrama et al. 2012), and their results confirmed that the effluent from the MBR met water reuse standards in terms of bacteria removal.

CONCLUSION

This study evaluates the treatment of wastewater by an ASP system and an MBR pilot. The results indicate that an MBR pilot plant can achieve high removal efficiencies in domestic wastewater treatment and that MBR permeate is suitable for urban, agricultural and recreational reuse according to the quality criteria for water reuse.

The developments of MBR technology occurred principally from the limitations of the ASP process, in which, the final products are treated water and excess sludge. Treated water is usually discharged into lakes or rivers, while excess sludge is disposed of on land. The limiting step is the separation of sludge from the treated water. Therefore, the contamination of the effluent may be significant because there is no physical barrier between the sludge and the treated water. To overcome the limitations of conventional treatment with activated sludge, MBR technology can be successfully employed.

As water reuse and reclamation increases, MBR technology can make reclaimed water more accessible by achieving wastewater treatment standards. With the use of MBR instead of ASP, most of the pollution in wastewater can be removed from the effluent. Furthermore, the effluent reaches most of the quality specifications defined by international guidelines and regulations for water reuse and reclamation.

Although MBR is widely viewed as being a state-of-the-art technology, it is also sometimes seen as high-risk and prohibitively costly compared to ASP and other more established technologies. Presently, there is a number of examples of successful MBRs. This technology is in full optimization and its future looks very promising in various applications. It is a potential alternative for treating wastewater, especially for reuse in irrigation.

REFERENCES


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