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A comparative examination of MBR and SBR performance for municipal wastewater treatment

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Abstract

In this study, the performance of the membrane bioreactor (MBR) and anoxic–aerobic sequencing batch reactor (SBR) are compared in treating municipal wastewater. The aim of the work was to determine the feasibility of these systems for the removal of organics matter and nutriments from the municipal wastewater. The MBR displayed a superior performance with removal efficiencies exceeding 99% for TSS, 94% for chemical oxygen demand (COD) and an improvement on SBR efficiencies was found. In the same way, the MBR produced an effluent with much better quality than SBR in terms of total nitrogen (TN) and total phosphorus (TP) removal efficiencies. Combining membrane separation and biodegradation processes or the membrane bioreactor (MBR) technology improved pollution removal efficiencies significantly.

Key words: membrane bioreactor (MBR), municipal wastewater treatment, sequencing batch reactor (SBR)

Highlights

- Municipal wastewater treatment.
- Membrane bioreactor process.
- SBR process evaluation.
- Organic pollution removal.
- Reuse in irrigation.

INTRODUCTION

Water is extremely essential for the survival of all living organisms. Like many other developing countries, Morocco is also regarded as a water-stressed country, and is likely to have water scarcity in the near future (Addison *et al.* 2012). The quality and quantity of fresh water is deteriorated by the discharge of untreated municipal wastewater, and according to a recent report, only 12% of the urban wastewater is treated in municipal treatment plants (Morari & Giardini 2009). The exploitation of raw wastewater is risky both from environmental and health perspectives, mainly because it contains biodegradable organic and inorganic matter, toxic substances, and disease-causing agents (Mara 2004).

In recent years, diverse technologies have been introduced for the treatment of municipal, domestic and industrial wastewater (Corcoran *et al.* 2008). The sequencing batch reactor (SBR) is a suitable

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technology for treatment of high concentrations of organic matter in municipal and industrial wastewater treatment (Gu *et al.* 2017). SBR technology is a development of the conventional activated sludge process whereby the treatment steps are combined into a single tank, often referred to as an activated sludge process occurring in time rather than in space (El-Fadel & Hashisho 2014). In general, SBR includes five well-defined phases: fill, react, settle, draw and idle (Lobo *et al.* 2016). The main advantages of SBR in comparison with other biological treatments are high flexibility, simple running, compact layout, better control of shock loads, possibility of achieving anoxic or anaerobic conditions in the same tank, and good oxygen contact with microorganisms and substrates (Orhon *et al.* 2009). Moreover, the operation can be adjusted to obtain aerobic and anoxic conditions in the same tank (Chan *et al.* 2009; Nawaz *et al.* 2013).

On the other hand, several types of membranes have been increasingly used for wastewater treatment (Brepols 2011). The membrane bioreactor (MBR) technology combines a biological treatment process and membrane technology for more effective wastewater treatment (Attiogbe 2013). In the MBR, both microfiltration and ultrafiltration membranes (0.03–0.4 μm) can be used for complete physical removal of microorganisms (Hee-deung *et al.* 2015). The advantage of these methods lies in their non-polluting aspect, their facilitate automation and their ability to simultaneously remove various pollutants in a single processing step (Iorhemen *et al.* 2016). These technologies provide the opportunity to clarify and simultaneously disinfect water without the risk of forming organohalogen compounds (Stephenson *et al.* 2005).

There are similarities between SBR and MBR processes; both are forms of the activated sludge process. There is one fundamental difference, which is the method of separating the liquid from the solid waste. SBR technology relies on gravity settling, while MBR technology uses membranes as a physical barrier for separation (Wang *et al.* 2012).

The main objective of this work was to investigate and compare the performance of municipal wastewater treatment using MBR and SBR 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

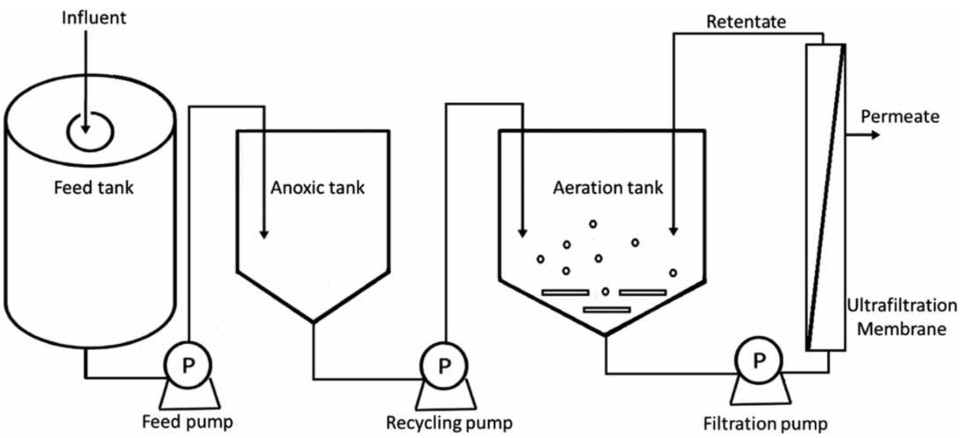

Figure 1 | Schematic diagram of ultrafiltration module.

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tank. Sequenced 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. 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.

Table 1 | Characteristics of the membranes used

Membrane material	Ceramic
Module	Tubular type P10
Membrane area	0.45 m^2
Cut off	15 kD/10 to 20 nm
Membrane length	1,178 cm
Diameter of the channels	6 mm
Flux (design)	67 $L/m^2/h$
Flux (average operation)	55 $L/m^2/h$
Transmembrane pressure (TMP)	0.05–0.15 bar

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 the ceramic membrane from damage.

The SBR experiment was done at the same pilot scale, to work with the SBR process; the aeration tank was completely isolated from the ultrafiltration membrane module during the SBR experiment period. The first tank (anoxic) served as the feeding tank, while the second tank served as the SBR, as shown in Figure 2. The duration of both processes was about 150 days. We operated the MBR and SBR processes in sequence.

The SBR and MBR were 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, during and at the end of each treatment cycle. They were collected periodically and analyzed for various physical, chemical and microbiological parameters in accordance with the standard methods (APHA *et al.* 2005; Bliefert & Perraud 2009; Rodier *et al.*

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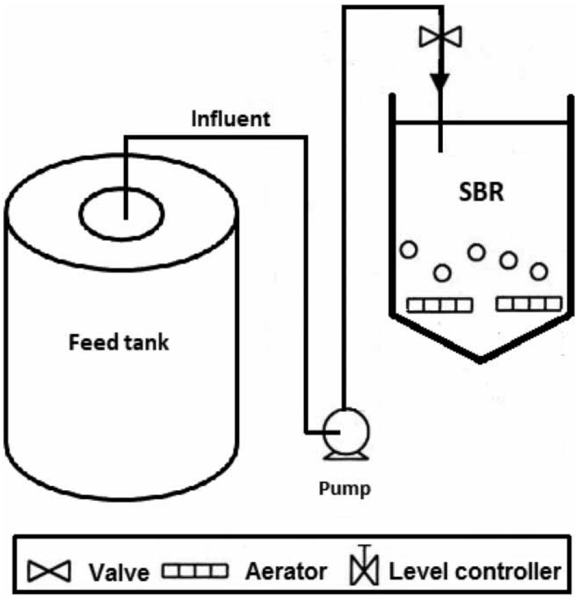

Figure 2 | Schematic diagram of SBR pilot.

2009). 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 BOD_5, total nitrogen (TN) and total phosphorous (TP) were measured with reagent kits (HACH DR4000, USA) twice per week (Bliefert & Perraud 2009). The disinfectant efficacy of the MBR and SBR processes was evaluated by analyzing the presence of the total coliforms using the filter membrane method. Finally, the analysis of heavy metal concentrations was made using the inductively coupled plasma mass spectrometry method (ICP-MS) (Kitanou *et al.* 2018).

RESULTS AND DISCUSSION

Municipal wastewater characterization

The influent used in this study, in both MBR and SBR pilots, was municipal wastewater. The quality of municipal wastewater was examined every day during the period of study. Apparently, it was grey in color with a mordant smell. The parameters of the municipal wastewater are listed in Table 2, and they were within the standard limits of the WHO and US EPA (WHO 2006). However, total

Table 2 | Quality of municipal wastewater

Parameter	Influent concentration	Rejection standards[a]	Reuse standards[b]
Temperature, C°	21.5–27	<30	35
pH value	7.5–8.5	5.5–9.5	8.4
Conductivity, μS/cm	1,700–2,155	2,700	1,000
COD, mg/L	647–771	250	100
BOD_5, mg/L	375–450	120	20
TSS, mg/L	417–557	150	<50
TN, mg/L	51–74	40	<5
TP, mg/L	17–23	15	–

[a]Moroccan pollution standards–specific limits for municipal discharge.
[b]This is the maximum permissible values according to Directive FAO and Water reuse standard for irrigation, land watering, Morocco.

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suspended solids (TSS) (417–557 mg/L), 5-day biological oxygen demand (BOD_5) (375–450 mg/L), and chemical oxygen demand (COD) (647–771 mg/L) deviated considerably from their prescribed limits, indicating a high level of contamination. As shown, the wastewater characteristics represent medium strength urban wastewater seen in Morocco and in most cities around the world (Bruursema 2011; MDCE 2014). Furthermore, these values exceed the specific limit values of Moroccan rejection and the reuse standards, hence the necessity for wastewater treatment.

MBR experiments

The influent COD concentration throughout the investigation was found to vary between 647 and 771 mg/L. The COD concentration in the MBR permeate ranged from 21 to 71 mg/L (Figure 3). It should be noted that more than 92% of COD was removed by the MBR process (Table 3). The relatively high effluent concentrations of COD can be attributed to the presence of non-biodegradable compounds in the municipal wastewater. The influent BOD_5 concentration varied between 375 and 450 mg/L. The mean BOD_5 influent value was 361 mg/L. The BOD_5 concentration in the outlet of MBR treatment ranged from 14 to 37 mg/L (Figure 3). The BOD_5 on average eliminated in the MBR was 94% (Table 3). TSS is the indicator of the operational behavior of any biological wastewater treatment plant. The TSS influent concentration was found to vary between 417 and 557 mg/L. The mean TSS influent value was 465 mg/L. TSS concentration was observed to be within a range of 1 to 7.5 mg/L in the permeate (Figure 4). It should be noted that more than 99%

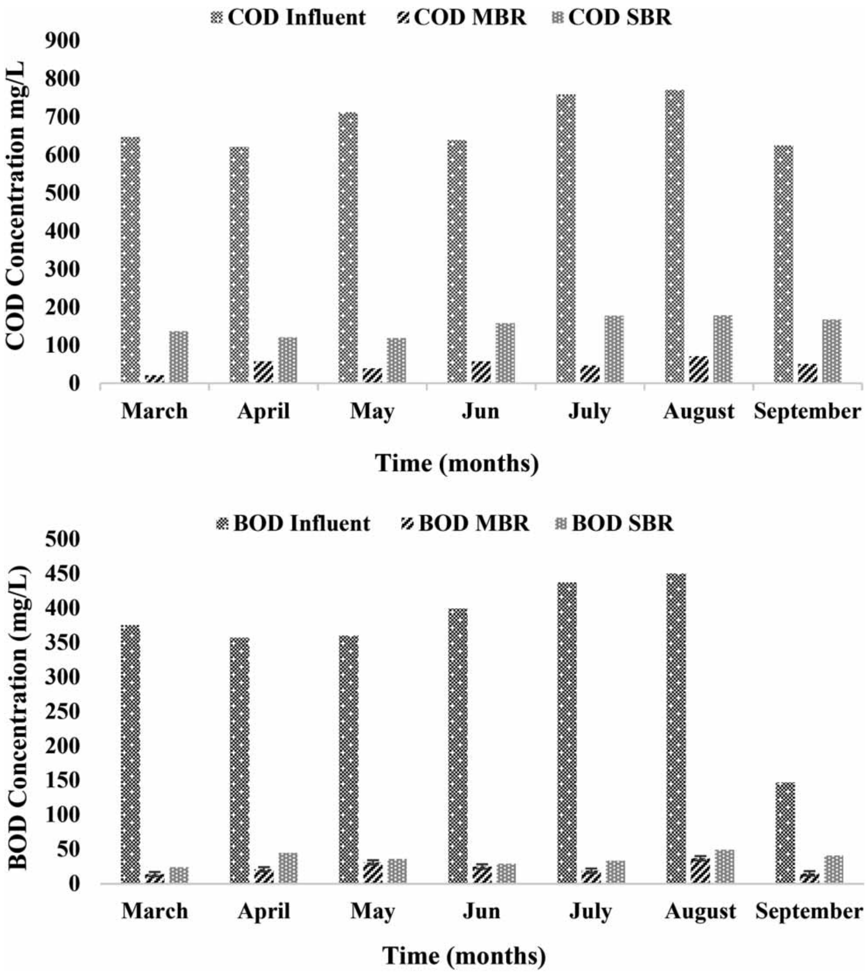

Figure 3 | COD and BOD concentrations average value in the influent, MBR and SBR effluent.

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

			Treated water			
Parameter	**Unit**	**Influent**	**MBR**	**MBR removal efficiency (%)**	**SBR**	**SBR removal efficiency (%)**
COD	mg/L	709	46	93.5	158	77.7
BOD_5	mg/L	412.5	25.5	93.8	54	86.9
TSS	mg/L	487	4.3	99.2	36.8	92.4
TN	mg/L	62.5	5.7	91	25	60
TP	mg/L	20	3	85	4.5	77.5

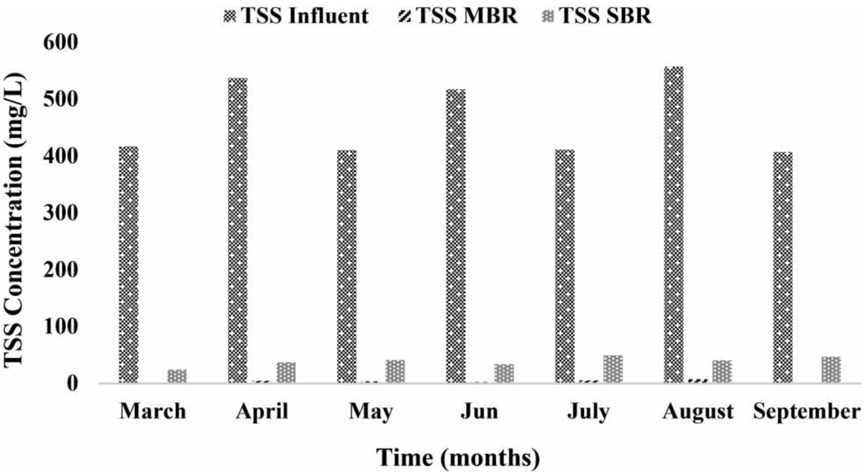

Figure 4 | TSS concentrations average value in the raw water, MBR and SBR effluent.

of TSS were removed by the MBR treatment (Table 3). The mean value of the TN influent concentration was 52 mg/L, which decreased to 5.9 mg/L (Figure 5) at the outlet of the MBR treatment. Therefore, 89% of TN was removed by MBR (Table 3). 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 to cell disintegration. This occurs during the nitrification and denitrification process (Yuan *et al.* 2016). The influent TP concentration throughout the investigation was found to vary between 17 and 23 mg/L. The TP concentration in the MBR permeate ranged from 2.8 mg/L. However, the influent TP mean concentration was 22 mg/L, decreasing to 2.8 mg/L in the MBR permeate (Figure 5). However, more than 88% of TP was removed using the MBR process (Table 3).

SBR experiments

The removal efficiency of COD, BOD_5, TSS, TN and TP in the samples is shown in Table 3. During the 7 months of operation, the mean concentrations of COD, BOD_5, TSS, TN and TP in the outlet of SBR treatment were 151.4, 37, 39, 25.2 and 4.6 mg/L, respectively (Figures 3–5). It should be noted that more than 78, 90, 92, 52 and 79% of COD, BOD_5, TSS, TN and TP were removed by the SBR process.

Comparison of MBR and SBR treatment

The performance of the SBR and MBR technologies for the municipal wastewater treatment was demonstrated at laboratory pilot scale. The results of investigation showed that the MBR exhibited higher removal efficiencies than the SBR (COD: 93 vs. 78%; BOD_5: 94 vs. 87%; TSS: 99 vs. 93%; TN: 91 vs. 60%; TP: 85 vs. 78%) (Table 3). For COD, TSS and TN, discharge standards are attained in both processes, indicating that depending on the intended use of the treated wastewater (EPA 2012).

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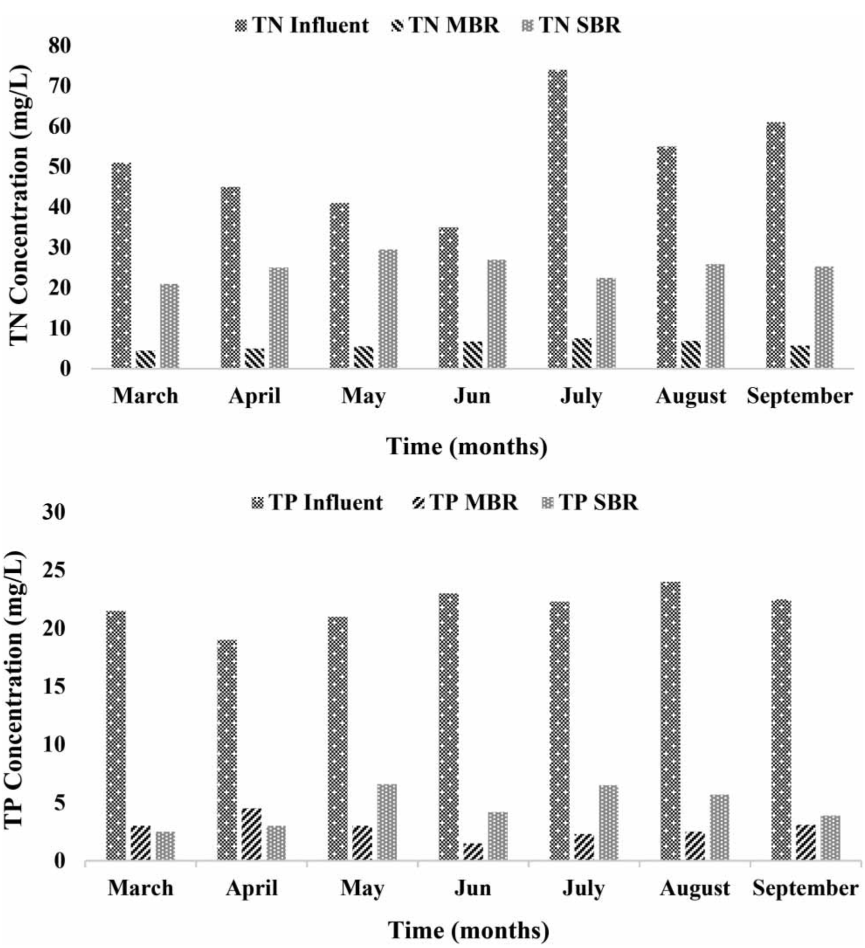

Figure 5 | TN and TP concentrations average value in the influent, MBR and SBR effluent.

In regulating the reuse of treated wastewater, chemical parameters must be considered alongside the biological parameters. These settings are also related to the protection of health and the environment (soil, water, etc.). The important chemical parameters to consider are the following: TSS, biodegradable organic compounds (COD and BOD), nutrients (TN and TP), bacteriological test (total coliforms), and elements metal traces or heavy metals. Table 4 summarizes the mean values

Table 4 | Quality of MBR and SBR outcome and standards

Parameter	SBR effluent	MBR permeate	Rejection standards	Reuse standards
COD, mg/L	158	46	250	100
BOD_5, mg/L	54	25.5	120	20
TSS, mg/L	37	4.3	150	<50
TN, mg/L	60	5.7	40	<5
TP, mg/L	77.5	3	15	–
Iron (Fe), mg/L	3.8	2.5	5	5
Lead (Pb), mg/L	0.7	0.1	1	5
Zinc (Zn), mg/L	2	1.3	5	2
Copper (Cu), mg/L	1.2	0.2	2	0.2
Nickel (Ni), mg/L	0.4	0.1	5	0.2
Faecal coliforms, $\log_{10}$ CFU/100 mL	5.8	0.7	–	3.69

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of the MBR and SBR outcome quality in comparison with reuse standards (Kitanou *et al.* 2017). The COD on average eliminated in the MBR was 94% comparing to 78% in the SBR. Similar results were achieved in a study by Saxena and Kazmi using MBR and SBR for wastewater treatment (Saxena & Kazmi 2015). In addition, the DBO_5 removal efficiency was 94% in MBR permeate, more than in SBR effluent at 87%. The same results was reported in a study made by Arabi *et al.* in MBR treatment (Arabi *et al.* 2020). BOD_5 is used to measure the oxygen demand for the natural breakdown of the organic matter present in water. The TSS removal efficiency in the MBR was 99% and in the SBR it was 92%. However, several studies reported TSS abatement rates of up to 92%, depending on the type of water treated, organic compounds, membrane type and imposed treatment conditions (Seyhi *et al.* 2011). Furthermore, the TN removal efficiency in the SBR was 60% and in the MBR permeate it was 91%. The removal efficiency of TP removal in the SBR was 77% and in the MBR it was 85%. The same results were found by Gonzales and co-workers (González-Camejo *et al.* 2018). Also, many studies report that removal rates of TN and TP of up to 97 and 99% can be respectively obtained, depending on the operating conditions and the type of effluent treated (Subasini & Janani 2016; Pelaz *et al.* 2018). This removal of nitrogen and phosphorus in the MBR could be beneficial if the effluent is to be used for irrigation purposes (Katsou *et al.* 2011). These results demonstrate that the UF treatment is more effective than SBR in treating municipal wastewater. Furthermore, it has been demonstrated that the SBR process in a single reactor at a low temperature is a suitable process for the simultaneous removal of nitrogen and organic matter. For heavy metal removal from wastewater, some heavy metals (zinc, iron, copper, lead and nickel) was analyzed. The results in the MBR processes show that the concentrations of heavy metals present in the permeate conform to the irrigation reuse standards. However, membrane processes have proven their competitiveness in the removal of metals from wastewater because of their low energy requirement, small volume of concentrate, and high selectivity (Çalik *et al.* 2020). 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 (Abhang *et al.* 2013). Faecal coliforms, which are generally used as indicators to determine the degree of disinfection (EPA 2012), were also monitored during the experiment. The SBR effluent concentration was around 6-$\log_{10}$ CFU/100 mL, while the MBR permeate was lower than one $\log_{10}$ CFU/100 mL, thus confirming that SBR requires additional treatment to achieve the microbial requirements for water reuse purposes. Therefore, heavy metal and bacteria removal are 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).

CONCLUSION

In this study, the performance of MBR and SBR wastewater treatment processes in removing pollution from municipal wastewater was investigated. The comparative assessment assists in technology selection depending on the desired effluent quality in terms of allowable pollution load. When comparing the SBR and MBR results in this study, the MBR exhibited significantly better performance in removing COD, BOD_5, TSS, TN and TP. The SBR experiment did not reach the highest efficiency; nevertheless, results were better in MBR treatment, and water quality satisfied required reuse standards. While the SBR technology offers some advantages in terms of cycle time, operational simplicity, low cost, and low land occupation, its performance is constrained when considering municipal wastewater treatment. The MBR technology with the membrane separation, improved removal efficiencies significantly. Therefore, it can be concluded that MBR system is among the most suitable options for municipal wastewater treatment with regard to water quality.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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