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CONCENTRATE REDUCTION IN NF AND RO DESALINATION SYSTEMS BY MEMBRANE-IN-SERIES CONFIGURATIONS- EVALUATION OF PRODUCT WATER FOR REUSE IN IRRIGATION

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Abstract

Wastewater reclamation and reuse became essential to meet the more restrictive discharge limits and to overcome the water scarcity issue. Industrial wastewaters treated by membrane bioreactor (MBR) systems generally include high amounts of salinity, nutrients as nitrogen and phosphorus, heavy metals, hardness, etc. which in most cases, do not fit with discharge and reuse limits. Membrane processes like nanofiltration (NF) and reverse osmosis (RO) are widely adopted for secondary effluent treatment producing high-quality water. Since untreated brine can damage the environment, this work focused on reduction of amount of concentrate by working in membrane-in-series configuration. Tests with two membrane-in-series (NF90+NF90, BW30+BW30, BW30+NF270 combinations) were performed as the concentrate stream of the first one was fed to the second one. Water recoveries were over 80% in each experiment. Water fluxes of 44.0, 41.4 and 73.4 L/m^2.h were obtained with NF90+NF90, BW30+BW30, BW30+NF270 combinations, respectively. Also, salinity rejections represented by electrical conductivity were 93.0%, 97.4% and 42.4% for NF90+NF90, BW30+BW30, BW30+NF270 configurations, respectively. Permeates of BW30+BW30 and NF90+NF90 combinations seem to be useable for agricultural irrigation although soil permeability is an important issue, not only ion concentrations and salinity of water used.

Keywords: Desalination, concentrate reduction, membrane processes, nanofiltration (NF), reverse osmosis (RO), water reuse.

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1.0 INTRODUCTION

Urbanization, agricultural practices and industrialization increases both the water demand and the volume of wastewater produced. Also, researchers draws attention to increasing restriction on discharge limits due to environmental issues and the need to reclaim and reuse wastewaters[1-2]. Membrane bioreactor (MBR) process is replacing conventional activated sludge process as a secondary treatment unit, especially for domestic wastewater treatment, nowadays. Stability of MBR effluent quality represents a favorable approach for water reuse[3]. However, high amounts of salinity, nutrients and hardness make industrial secondary effluents from MBR process not reusable and sometimes not even dischargeable[4]. MBR effluent should be demineralized via one of the desalination methods such as nanofiltration (NF) and reverse osmosis (RO) when the salinity is high prior to reuse of MBR effluent for various purposes. On the other hand, concentrate streams generated from NF and RO processes are of important concern. Indeed, untreated or improperly managed brine can lead to serious negative effects on the environment[5]. Both the need to reclaim water from industrial or domestic effluents and to decrease discharge amount let researchers use membranes for tertiary treatment.

Several flow configurations of NF and RO systems are used to reduce brine generation (Figure 1). Among them, membrane modules can be connected in series, in which the concentrate stream of the first membrane is fed to the second one [6].

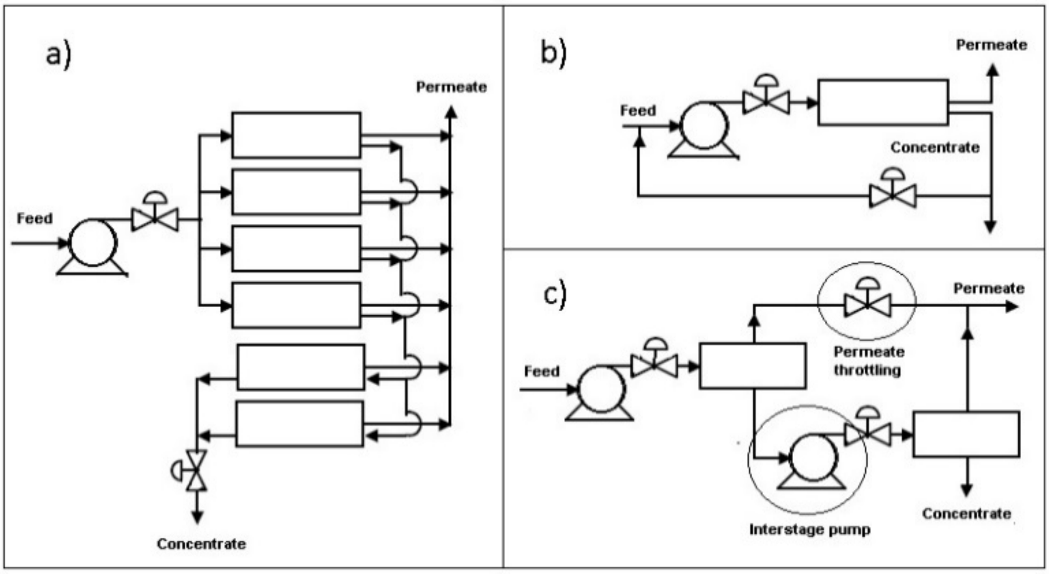

Figure 1. System flow configurations for concentrate reduction: a) pyramidal design b) concentrate recirculation c) membrane-in-series (modified from Hydranautics)[6]

Reuse of wastewater for irrigation is widely used in countries where fresh water resources are becoming insufficient. Nutrient content of secondary effluents and the relative cost of reclaiming water for irrigation unlike reclaiming for drinking purposes make this process favorable [7]. Also, some studies showed that the amount of irrigation water is the first to be decreased rather than drinking or process water when the water supplies started to be insufficient. That being said, water reclamation for agricultural irrigation gains even more importance[8]. However, reclaimed water should obey to water quality guidelines for agricultural irrigation which requires development of a proper water management strategy. For this purpose, some concepts such as soil permeability and salinity of irrigation water should be checked carefully.

High sodium concentration disperses the soil clay and causes the soil to become hard and compact when the soil is dry and reduces the rate of water penetration when the soil is wet. The low infiltration rate can cause deficiencies of several nutrients. In contrast, the effect of calcium and magnesium is to cause flocculation of soil clay, thus promoting and maintaining good soil structure. Thus, the Sodium Adsorption Ratio (SAR) is a standart indicator of the flocculation or dispersion of aggregates in soil, which is directly influencing the structure of the soil and hence the permeability. SAR is defined in Equation 1 as an expression of the sodium hazard of irrigation water [8].

$$\mathrm{SAR} = \frac{[\mathrm{Na}^+]}{\sqrt{\frac{[\mathrm{Ca}^{2+}]+[\mathrm{Mg}^{2+}]}{2}}} \qquad \text{(Equation 1)}$$

where the concentrations are in meq/L. Infiltration of irrigation water to the soil is not only connected to SAR but also to electrical conductivity (EC). FAO and WHO guidelines offer a relation between SAR and EC to assess the suitability of irrigation water.

The values given in Table 1 were illustrated in Figure 2 for better understanding of the effect of irrigation water on soil permeability. Classes I, II and III correspond to degrees of restriction on use as none, slight to moderate and severe, respectively. It must be noted that Class I water means the water will not have negative effects on soil permeability but does not say anything about salinity. While high EC can toxicate plants, low EC will mean low amount of minerals for plant to sustain its life. Therefore, a suitable irrigation water should obey to both SAR-EC classification and salinity criteria.

Potassium adsorption ratio (PAR) is another parameter to be investigated to assess the effect of potassium ion to soil clay dispersion, which is calculated by Equation 2[11].

Table 1. Classification of irrigation water regarding soil permeability [9]

Parameter	**Degree of Restriction on Use**		
	None	**Slight to Moderate**	**Severe**
SAR	**EC (mS/cm)**		
0-3	>0.7	0.2-0.7	<0.2
3-6	>1.2	0.3-1.2	<0.3
6-12	>1.9	0.5-1.9	<0.5
12-20	>2.9	1.3-2.9	<1.3
20-40	>5.0	2.9-5.0	<2.9

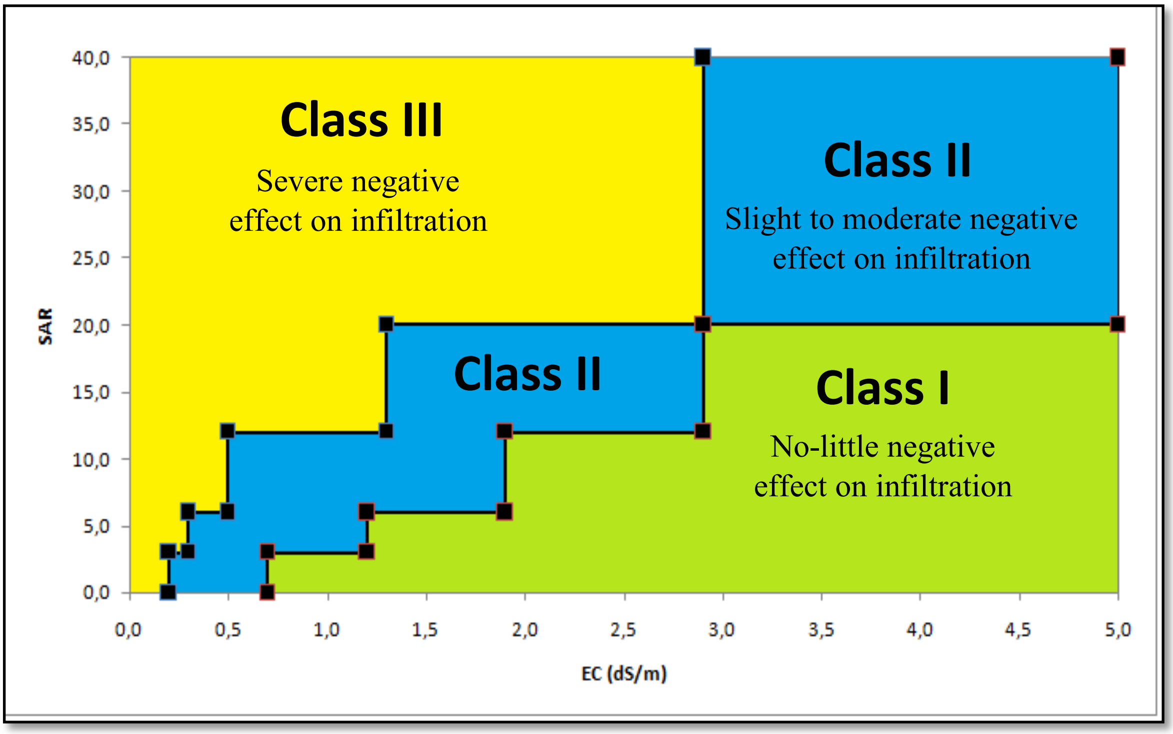

Figure 2. Illustration of SAR-EC classification for irrigation water [10]

$$\mathrm{PAR} = \frac{[\mathrm{K}^+]}{\sqrt{\frac{[\mathrm{Ca}^{2+}]+[\mathrm{Mg}^{2+}]}{2}}} \qquad \text{(Equation 2)}$$

FAO, WHO and USEPA guidelines and regulations offers also other parameters for assessing suitability of water for agricultural irrigation. Three documents are cross-checked and Table 2 contains standards that fit with all of them.

Table 2. Standard limits for agricultural irrigation [12-14]

Parameter	Unit	Degree of Restriction on Use		
		None	Slight to Moderate	Severe
EC	mS/cm	<0.7	0.7-3	>3
SAR	-	Check Table 1		
TDS	g/L	<0.45	0.45-2	>2
NO_3-N	mg/L	<5	5-30	>30
TN	mg/L	<5	5-30	>30
PO_4-P	mg/L	-	<2 or <5	-
PAR	-	<5	5-10	>10
HCO_3	mg/L	<90	90-500	>500
Boron	mg/L	<0.7	0.7-3	>3
Chloride	mg/L	<106.5	>106.5	-
Sodium	mg/L	<69	>69	-
Free Cl	mg/L	<1	1-5	>5
TSS	mg/L	<50	50-100	>100
pH	-	6-9		
Turbidity	NTU	<2		

It must be noted that chloride and sodium standards are taken for sprinkler irrigation since it is already more efficient than surface irrigation.

Although different plants have different tolerance levels to various components of water (fruit plants have low tolerance to ion toxicity and boron while harsh-climate plants like date palm are highly resistant), Table 2 can be used as a preliminary information for the evaluation.

Previously, we checked the desalination performances of different NF and RO membranes by using a cross-flow flat-sheet membrane test unit. Permeates of RO membrane (GE-Osmonics AG membrane) and NF membranes (GE-Osmonics HL, DL membranes) were compared with irrigation water standards for its reuse in irrigation [15]. Elsewhere, application NF and RO processes for reclamation and reuse of industrial wastewater treated with MBR process was investigated using a mini-pilot scale membrane test system. The qualities of permeates obtained by BW30-RO and NF-90 membranes were evaluated according to irrigation water standards [16]. At the same time, effect of membrane type on product water quality for industrial usage as cooling and boiling feed water as well as process water in paper and textile industries was studied [17]. Also, effect of pressure on desalination of MBR effluents with high salinity by using NF and RO processes for reuse in irrigation was reported [18].

Concentrate management in pressure driven membrane processes is an important and challenging task to be solved. Besides the product water, the brine generation from the membrane filtration processes is of important environmental concern. Indeed, an appropriate concentrate management is required to avoid serious negative effects on environment [5].

Ocean concentrate disposal is possible if specific discharge regulation are observed [19]. Another method to eliminate the generated brine is leaving it to natural evaporation process creating a solid waste [20]. However, this process requires high time and area and can be not feasible when high amounts of concentrate are to be treated [21]. Therefore, is necessary to reduce, as much as possible, the concentrate amount before further treatments or discharge.

Many different flow configurations of RO systems were utilized to reduce the brine generation. Membrane modules can be connected in series with or without an interstage pump or permeate throttling, connected in a pyramidal design, etc. Also the concentrate recirculation configuration allow to increase the water recovery recycling part of the concentrate stream [6]. These configurations are shown in Figure 1.

In our previous study, effect of concentrate recirculation on the product water quality of integrated MBR+ NF processes in sequential mode was investigated for wastewater reclamation and industrial reuse [22]. Using the same membrane tests system, MBR-treated industrial wastewater was further processed by BW30, a brackish water RO membrane in concentrate recirculation configuration. Membrane and system performances were assessed, including product water quality and the concentrate retention ratio [23]. The aim of this study is to reduce the amount of concentrate stream of RO and NF processes while assessing alternative use of the permeate stream for agricultural irrigation and hence to establish a two-way solution for problems of industrial-scale operations. For this, various combinations of different membrane pairs were employed in batch mode of operation by feeding concentrate stream of the first membrane to the second membrane in membrane-in series mode.

2. MATERIAL AND METHODS

In this study, three different membranes (NF90, NF270 and BW30) were used in such two membrane-in series configurations as NF90+NF90, BW30+BW30, BW30+NF270 combinations using the same mini pilot system for water recovery from MBR effluent at wastewater treatment plant of ITOB Organized Industrial Zone, Menderes-Izmir, Turkey. The concentrate stream of the second membrane and the total permeate were recycled to the feed tank to operate in batch mode. Concentrate stream of the first membrane was fed to the second membrane in this membrane-in-series configuration to increase the water recovery (as shown in Figure 1c without throttling or interstage pump). Properties and informations about the membranes employed are given in Table 3.

Table 3. Membrane properties [24]

Membrane	Manufacturer	Material	NaCl rejection (%)	pH Interval	Max Temperature (°C)	Max Pressure (bar)
BW30-RO	Dow-Filmtec	Polyamide Thin-Film Composite	99.5	2-11	50	41
NF90-NF	Dow-Filmtec	Polyamide Thin-Film Composite	95.0	2-11	45	41
NF270-NF	Dow-Filmtec	Polyamide Thin-Film Composite	50.0	2-11	45	41

Experiments were carried out using a mini pilot system installed at wastewater treatment plant. Photographs of the mini pilot membrane test system are given in Figure 3.

MBR effluent discharged from wastewater treatment plant was used as feed stream for the membrane tests using mini pilot membrane test system. Properties of MBR effluent used as feed are given in Table 4.

The flow configuration used during membrane tests is depicted in Figure 4. It must be noted that while this pilot test system has six membranes, only five of them (two NF 90, two BW 30 and one NF 270) were used for tests.

The MBR effluent utilized as feed was collected in a 500 L of feed tank and pumped to the membrane test system. Average feed flow rate supplied by the pump was 4.33 L/min varied by 6% margin. Permeate and concentrate streams were fed back to the feed tank and experiments were carried out in batch mode for 6 h. The applied pressure at the inlet of the first membrane of the pair is 20 bar for all experiments.

Samples of feed, permeate and concentrate streams were taken at each hour for lab analysis while the field analysis (EC, TDS, salinity, pH) were performed online by means of a conductometer and a pH-meter for all samples at each 15 min. The quality parameters such TSS, color, turbidity, COD, SiO_2, total nitrogen, nitrite-N, phosphate-P and ammonium-N concentrations were measured by using Hach-Lange chemical measurement kits by means of DR 3900 benchtop VIS model spectrophotometer. Most cation (Ca^{2+}, Mg^{2+}, K^+ and Na^+) concentrations were measured by an atomic absorption spectrometer (Shimadzu AA-7000) while anion concentrations (NO_3^-, Cl^- and SO_4^{2-}) were measured by an ion chromatography (Shimadzu LC-10Ai). Bicarbonate concentration was measured by titrating samples with 0.05 M HCl solution using methyl orange indicator. Permanent hardness were measured by titration of samples with pre-prepared 0.01 M Na_2EDTA solution while using eriochrome black T as indicator.

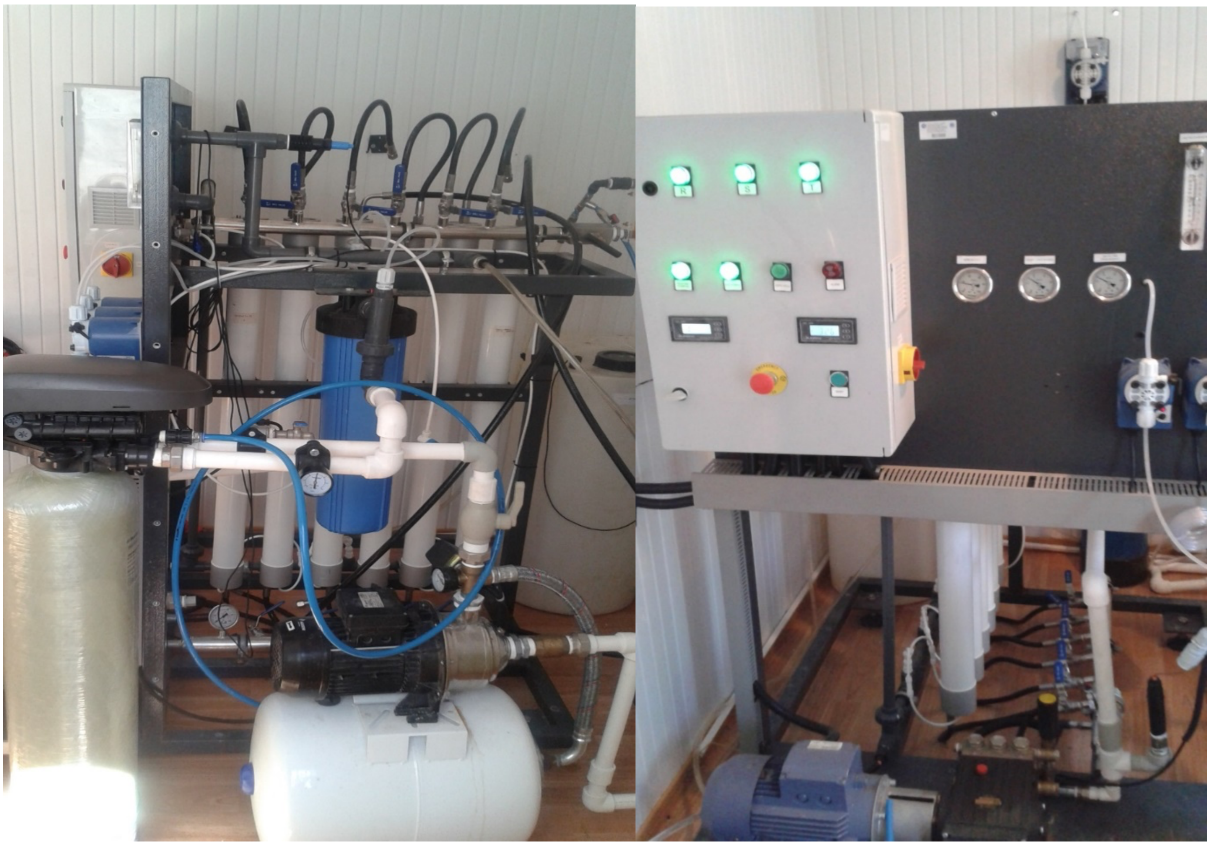

Figure 3. Photographs of mini pilot membrane test system

Table 4. Properites of the MBR effluent used as feed for membrane tests

MBR Effluent	**Two membrane-in series tests**		
Parameter	**BW30 to BW30**	**NF90 to NF90**	**BW30 to NF270**
TSS (mg/L)	1.3 ± 0.2	2.0 ± 0.3	1.0 ± 0.2
Color (mg/L Pt-Co)	12.0 ± 1.4	25.5 ± 3.2	9.0 ± 1.5
Turbidity (NTU)	0.2 ± 0	1.1 ± 0.2	0.5 ± 0.2
COD (mg/L)	19.6 ± 1.5	17.5 ± 1.3	20.4 ± 1.5
SiO_2 (mg/L)	5.9 ± 1.9	7.2 ± 2.5	6.8 ± 2.3
HCO_3 (mg/L)	16.8 ± 0.9	15.0 ± 1.0	15.3 ± 0.9
Na (mg/L)	395 ± 17	399 ± 21	462 ± 23
Ca (mg/L)	101 ± 5	100 ± 5	113 ± 5
K (mg/L)	130 ± 12	139 ± 13	92.0 ± 12
Mg (mg/L)	22.8 ± 0.9	25.5 ± 1.1	34.7 ± 1.4
SO_4 (mg/L)	339 ± 41	406 ± 43	442 ± 37
Cl (mg/L)	488 ± 35	495 ± 34	497 ± 39
Hardness (mg/L $CaCO_3$)	367 ± 9	358 ± 11	448 ± 12
NO_3-N (mg/L)	35.0 ± 1.2	38.0 ± 1.1	35.6 ± 1.2
Total Nitrogen (TN) (mg/L)	36.8 ± 3.4	38.5 ± 4.1	38.5 ± 3.6
NO_2-N (mg/L)	0.03 ± 0	<0.02	0.03 ± 0

PO_4-P (mg/L)	<0.5	<0.5	<0.5
NH_4-N (mg/L)	<0.2	<0.2	<0.2
EC (µS/cm)	4200 ± 75	4300 ± 78	3800 ± 74
TDS (mg/L)	1400 ± 21	1400 ± 19	1500 ± 18
Salinity (‰)	1.4 ± 0	1.4 ± 0	1.5 ± 0
pH	7.7 ± 0.3	7.6 ± 0.3	7.7 ± 0.3

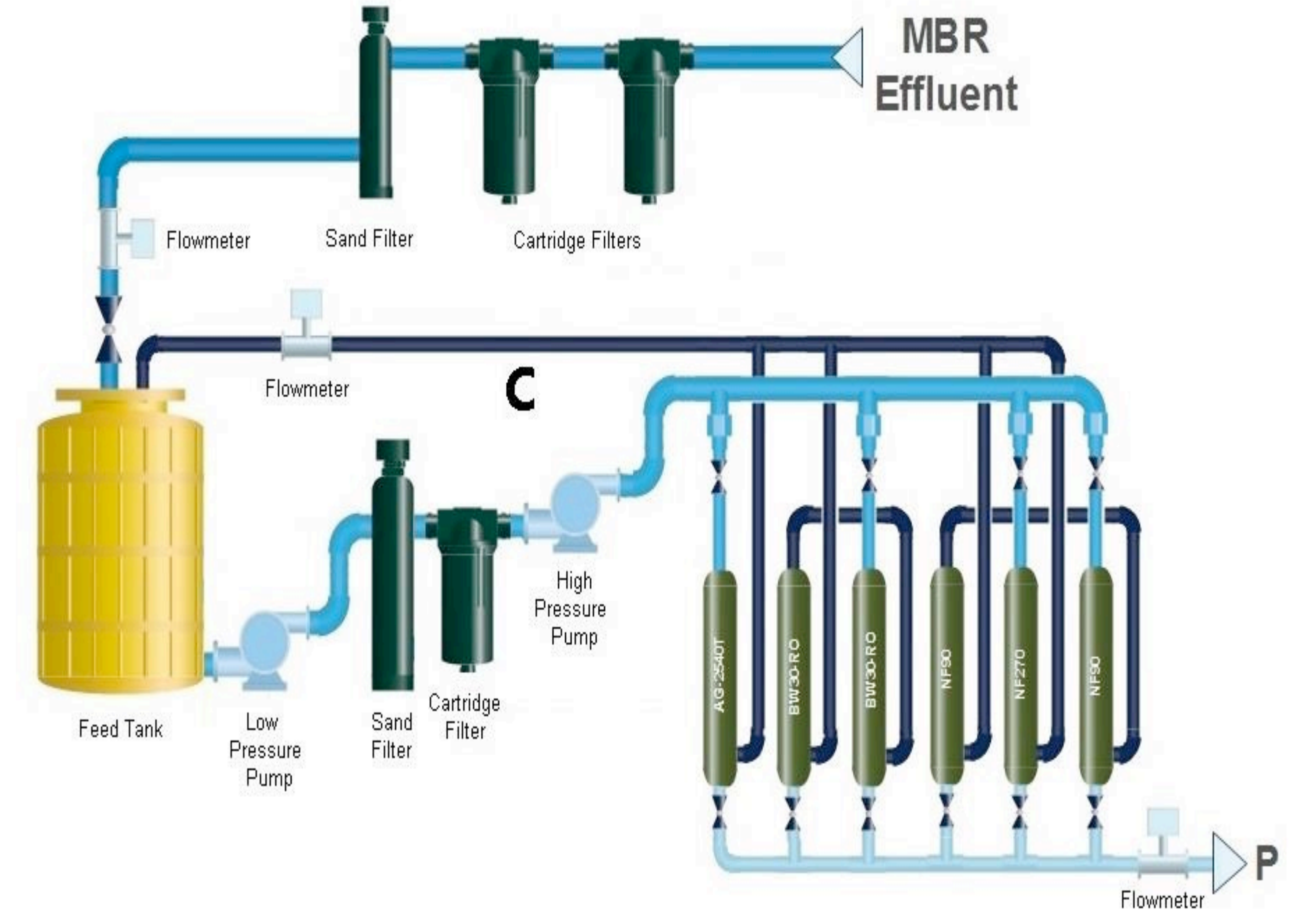

Figure 4. Flow congifuration in mini-pilot membrane test system
(F: Feed, C: Concentrate, P: Permeate)

Water recovery is calculated by Equation 3:

$$\text{Water recovery (\%)} = \frac{\mathrm{P}}{\mathrm{M}} \qquad \text{(Equation 3)}$$

Permeate flux is calculated by Equation 4. Permeate fluxes are normalized according to a standart temperature via Equation 5:

$$\mathrm{J_P}\left(\frac{\mathrm{L}}{\mathrm{m^2.h}}\right) = \frac{\mathrm{P}}{\mathrm{A}} \qquad \text{(Equation 4)}$$

$$\mathrm{J}_{P_{\mathrm{adj}}} = \frac{\mathrm{J_P}}{1.03^{(\mathrm{T}-25)}} \qquad \text{(Equation 5)}$$

Rejection for any parameter is calculated by Equation 6

$$R\,(\%) = \frac{C_f - C_p}{C_f} \qquad \text{(Equation 6)}$$

where P is permeate flow rate, M is MBR effluent flow rate, J_p is the permeate flux, A is the active membrane surface area, T is temperature (°C), R is the rejection of a component/parameter, C_f and C_p are concentrations or values of any parameter in feed and permeate, respectively.

Water recovery of individual membranes were calculated by manual flow readings of permeate streams and concentrate stream of the first membrane performed in each 10 min with 30 s of sampling time. Manually calculated permeate flow rates are then divided with the feed amount to each membrane (feed flow rate to the first membrane, concentrate flow rate produced by the first membrane to the second membrane) to calculate water recoveries.

MBR effluent and product waters obtained from various two membrane-in series configurations (NF90+NF90, BW30+BW30, BW30+NF270) were also evaluated for their reuse in agricultural irrigation according to FAO, WHO and USEPA guidelines and regulations.

3.0 RESULTS AND DISCUSSION

The system performances for different two membrane-in series configurations were compared in terms of permeate flux, solute rejections and permeate quality. System water recoveries were kept almost constant as 81.5-81.6%. Average permeate flux was only slightly higher for the NF90+NF90 combination compared to the BW30+BW30 system, while the salinity removal was 92.9% in the first case and 97.4% in the second one. This was due to the high performances of NF90 membrane, which are close to typical performances of brackish water RO membranes. Significant increase in the permeate flux was obtained with a BW30+NF270 system. However, the permeate quality was severely affected, obtaining 42.9% of salinity rejection.

Table 5. System performances in the different configurations

System configuration		BW30 to BW30	NF90 to NF90	BW30 to NF270
Average water recovery (%)	1st Membrane	48.5%	39.4%	28.4%
	2nd Membrane	64.0%	69.6%	74.3%
	TOTAL	81.5%	81.6%	81.6%
Average normalized permeate flux (L/m^2.h)	1st Membrane	51.5 ± 0.5	60.5 ± 0.6	43.2 ± 0.4
	2nd Membrane	35.1 ± 0.4	65.0 ± 0.7	80.9 ±0.8
	TOTAL	86.6	125.6	124.1
Salinity rejection (%)*		97.4	93.7	42.9

*Individual salinity rejections of the membranes are unknown because the system configuration does not allow to take samples between membranes but only to measure flux.

Since by definition, water permeability is the inverse of the resistance of the membrane to the permeate flow (closely related to pore diameters), permeate flux of NF270 is much bigger than NF90 and BW30. While the salt rejection of NF90 is defined close to reverse osmosis membranes with its nearly 200 Da; NF270 is loosest NF membrane produced by Dow with its 400 Da, hence lower salt rejection was already expected [25].

Although the fluxes of NF90+NF90 and BW30+BW30 combinations are nearly equal and salinity rejection performance of BW30+BW30 pair is higher, it must also be noted that NF membranes require lower applied pressure than RO membranes. In this case, 20 bar of operating pressure was applied for effective comparison between membranes. However, 10-15 bar of operating pressure is mostly used in real NF applications.

Average rejections of some selected parameters from MBR effluent using various two membrane-in series configurations are given in Table 6.

Table 6. Percent average rejections of some selected quality parameters

Parameter	BW30 to BW30	NF90 to NF90	BW30 to NF270
TSS	~100	~100	~100
Color	~100	~100	88.9 ± 0.8
Turbidity	64.2 ± 3.4	74.8 ± 3.5	49.3 ± 2.4
COD	29.8 ± 3.5	49.7 ± 7.1	75.5 ± 9.1
SiO_2	87.8 ± 2.5	90.3 ± 2.3	13.2 ± 0.4
HCO_3	84.2 ± 1.1	87.1 ± 1.5	47.9 ± 0.9
Na	94.7 ± 0.6	91.2 ± 1.2	50.4 ± 0.8
Ca	98.5 ± 1.1	98.7 ± 1.2	62.1 ± 1.0
K	96.1 ± 2.0	92.2 ± 2.3	40.7 ± 1.5
Mg	>99.9	>99.9	83.9 ± 1.9
SO_4	>99.5	>99.5	>99.5
Cl	97.3 ± 1.1	94.0 ± 1.4	21.7 ± 0.7
Hardness	>99.7	97.5 ± 0.5	76.1 ± 0.9
NO_3-N	89.1 ± 1.3	77.1 ± 1.1	13.0 ± 0.4
TN	86.2 ± 7.4	71.7 ± 6.7	18.6 ± 3.1
Conductivity	97.0 ± 0.4	92.9 ± 0.3	41.4 ± 0.3
TDS	97.3 ± 0.4	93.4 ± 0.3	42.6 ± 0.3
Salinity	97.4 ± 0.5	93.7 ± 0.3	42.9 ± 0.3

Feed and permeate compositions along with their evaluations for degrees of restriction on agricultural irrigation were given in Table 7.

Table 7. Average feed and permeate compositions compared with agricultural irrigation standards

Parameter	**Unit**	**Average Feed**	**Permeate**			**Degree of Restriction on Use**		
			BW30 to BW30	**NF90 to NF90**	**BW30 to NF270**	**None**	**Slight to Moderate**	**Severe**
EC	mS/cm	4.1	0.1	0.2	1.7	<0.7	0.7-3	>3
SAR	-	8-10	3.8	7.7	8.6			
TDS	g/L	1.4	<0.1	0.1	0.9	<0.45	0.45-2	>2
NO_3-N	mg/L	36.2	3.8	8.7	31.0	<5	5-30	>30
T-N	mg/L	37.9	5.1	10.9	31.3	<5	5-30	>30
PO_4-P	mg/L	<0.1	<0.1	<0.1	<0.1	-	<2 or <5	-
PAR	-	1.0	0.3	0.8	1.2	<5	5-10	>10
HCO_3	mg/L	15.7	2.7	1.9	7.9	<90	90-500	>500
B	mg/L	2.3	<0.5	1.1	2.0	<0.7	0.7-3	>3
Cl	mg/L	493.3	13.4	29.6	389	<106.5	>106.5	-
Na	mg/L	418.7	21.0	35.2	229	<69	>69	-
Free chlorine	mg/L	<0.1	<0.1	<0.1	<0.1	<1	1-5	>5
TSS	mg/L	1.4	0	0	0	<50	50-100	>100
pH	-	7.7	6.4	6.8	7.2	6-9		
Turbidity	NTU	0.6	0.1	0.3	0.2	<2		

It is obvious that MBR effluent is not suitable for agricultural irrigation due to excessive amounts of sodium and chloride ions (causing ion toxicity), salinity and nitrate. BW30+NF270 combination produced water with excess sodium, chloride and nitrate ions although their concentrations are not as much as in MBR effluent. The permeates of BW30+BW30 and NF90+NF90 pairs are good irrigation waters for boron-sensitive and salinity-sensitive plants.

Previous studies [10, 26, 27] suggested to mix permeate streams with MBR effluent in certain amounts to increase its soil permeability and to remineralize it. Therefore, theoretical mixtures are calculated for both permeate of NF90+NF90 combination with MBR effluent and permate of BW30+BW30 combination with MBR effluent. Soil permeability (SAR-EC classification) graphs were shown in Figures 5 and 6.

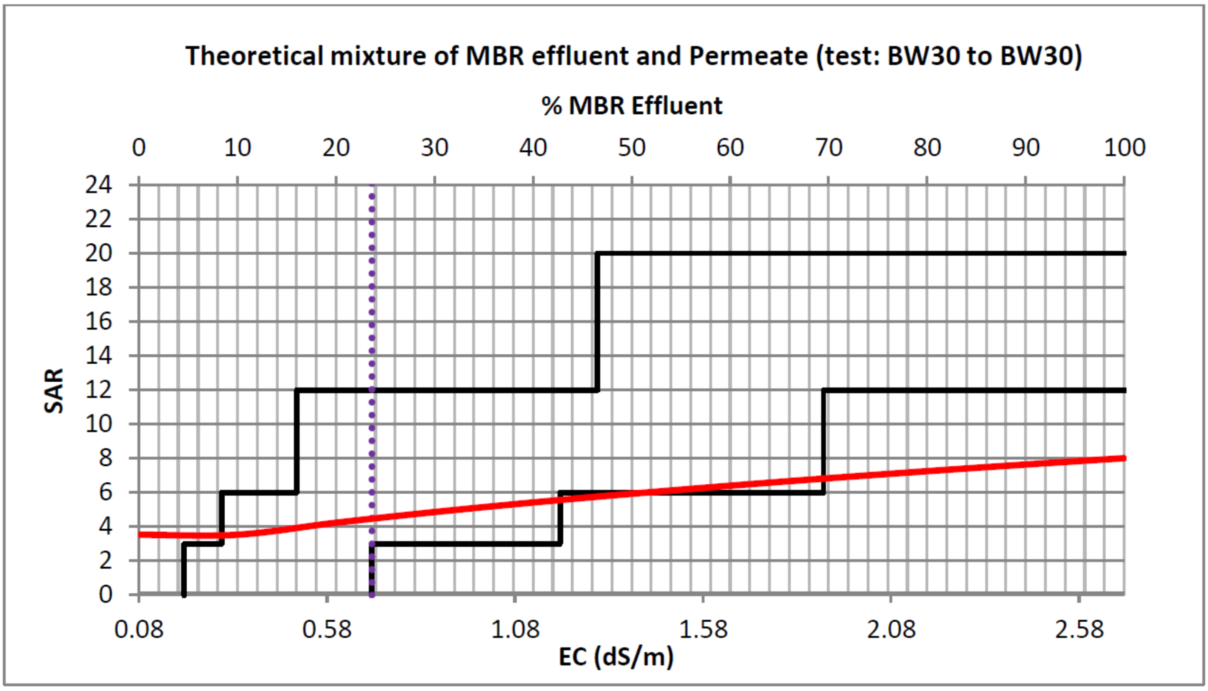

Figure 5. SAR-EC classification of theoretical mixture of MBR effluent and permeate of BW30+BW30 combination

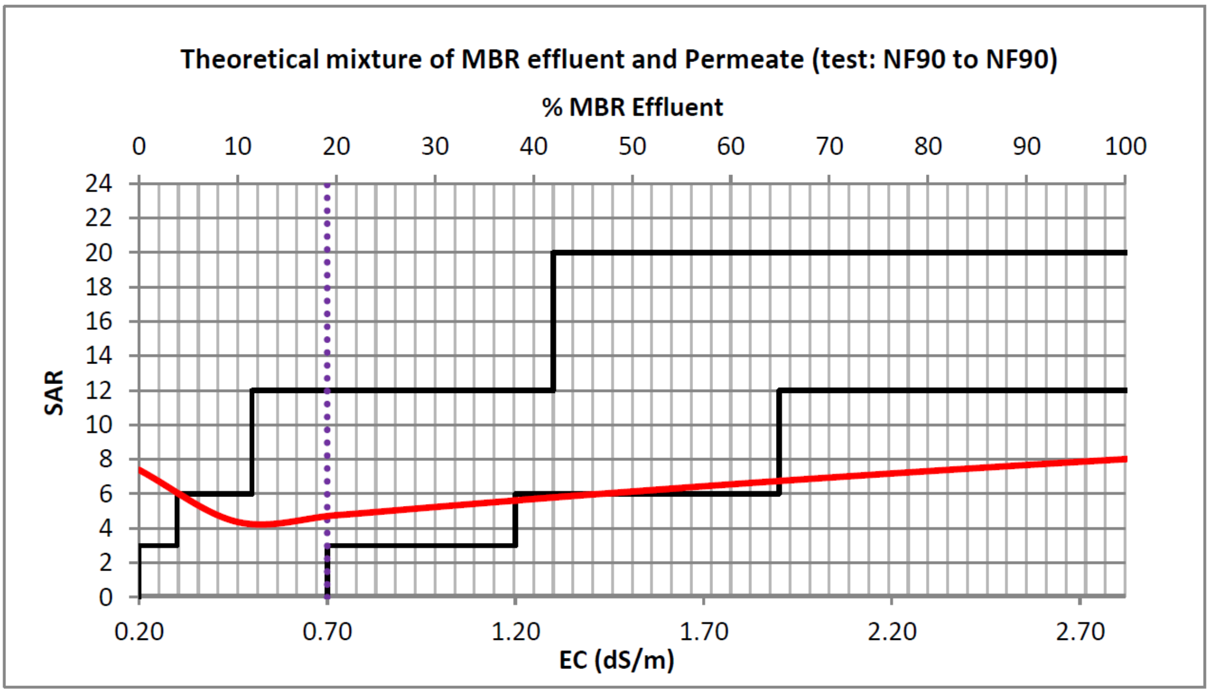

Figure 6. SAR-EC classification of theoretical mixture of MBR effluent and permeate of NF90+NF90 combination

Water with a first class soil-permeability seems to be unachievable without high salinity (vertical dotted lines are salinity criteria), but close to first class soil-permeability together with a fit to other irrigation standards which are achievable. This can be obtained by a theoretical mixtures of 85-95% of NF90+NF90 and BW30+BW30 permeates mixed with 15-5% of MBR effluent. Percentage of MBR effluent can be increased if the resistance of the plant for salinity and boron is high.

While MBR effluent is toxic to the plants, especially for salt-sensitive plants, NF90 and BW30 permeates do not include enough minerals to sustain the plant life. Theoretical mixtures using 15-5% of MBR effluent and 85-95% of BW30+BW30 or NF90+NF90 permeates are thought to solve this problem and create useable water for agricultural irrigation.

Findings are partially in contrast with the findings of other researchers using theoretical mixtures approach for the agricultural irrigation although their focus was on the treatment of domestic wastewaters, while this study is based on secondary-treated industrial wastewaters. While they thought the sustainability of plant life would be better if the permeate is re-mineralized via addition of some MBR effluent, but there was no any indicator for its effect on soil permeability.

SAR values –when combined with EC values- mathematically proved the comments of other researchers and shows the need of demineralization of NF90 and BW30 pair permeates for agricultural irrigation purposes. Figures 5 and 6 (created from placement of research findings on Figure 2) show a plausible way to assess the suitability of use of any type of water in agricultural irrigation.

Table 8. Properties of optimum theoretical mixtures of NF90+NF90 and BW30+BW30 permeates with MBR effluent

Two membranes-in series configuration	**Unit**	**BW30+BW30**	**NF90+NF90**
MBR effluent (%)		12	9
EC	mS/cm	0.4	0.4
SAR	-	3.9	4.3
TDS	g/L	0.2	0.2
NO_3-N	mg/L	7.6	11.3
TN	mg/L	8.9	13.4
PO_4-P	mg/L	0.1	0.1
PAR	-	0.4	0.5
HCO_3	mg/L	8.9	13.4
B	mg/L	<0.5	0.5-1.0
Cl	mg/L	70.3	71.4
Na	mg/L	65.8	68.0
Free chlorine	mg/L	<0.1	<0.1
TSS	mg/L	0.2	0.2
pH	-	6.5	6.9
Turbidity	NTU	0.1	0.3

SAR-EC criteria of those theoretical mixtures can be checked from Figures 5 and 6 showing that they are in second class of water quality which is close to the first class of water quality.

4.0 CONCLUSIONS

Water recoveries were obtained as 81.5% for BW30+BW30 pair and 81.6% for other two pairs (NF90+NF90, BW30-NF270) by the application of membrane-in-series configuration which are much higher than water recovery that is usually obtained by one membrane at around 40-50% without considerable fouling.

Among various two membrane-in series configurations, NF90+NF90 and BW30+BW30 combinations are found to be favorable with 93.0% and 97.4% of conductivity rejections, respectively while BW30+NF270 pair was not successful to decrease salinity of MBR effluent with its only 42.4% of conductivity rejection.

Even though the concentrate stream is more saline than the feed solution (MBR effluent), its amount is reduced more than 81.5%. The rest (less than one fifth of before) would be easier to be dealt with natural evaporation or any other waste management option.

Theoretical mixtures of MBR effluent and BW30+BW30 or NF90+NF90 permeate as 15-5% of MBR effluent and 85-95% of permeate of BW30+BW30 or NF90+NF90 pair were found suitable theoretical mixture for use in agricultural irrigation.

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