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Evaluation of Performance of Wastewater Treatment Plant at KACST, Riyadh Saudi Arabia

Saad A. Al-Jlil, Hamad Alromaih, Fahad Alshabonah, Fahed Alsoubaei, Abdullah Alshamary and Hussan Hazzazy
National Center for Water Technology (NCWT), King Abdulaziz City for Science and Technology (KACST), P.O. Box 6086, Riyadh, Kingdom of Saudi Arabia

Corresponding Author: Saad A. Al-Jlil, National Center for Water Technology (NCWT), King Abdulaziz City for Science and Technology (KACST), P.O. Box 6086, Riyadh, Kingdom of Saudi Arabia

ABSTRACT

The study was carried to evaluate the performance of Wastewater Treatment Plant (WTP) at KACST consisting of Membrane Bio-reactor (MBR), Nano-filtration (NF) and Reverse Osmosis (RO) processes for wastewater treatment to determine its reuse characteristics. Water samples were collected from raw sewage effluent, Membrane Bio-reactor (MBR), Reverse Osmosis (RO) and Nano-filtration (NF) water treatment processes. Experimental results showed that some water quality parameters reduction (%) was 96.5, 95.17, 80.1, 98.29 and 94.37 for Ca, Mg, Na, SO_4 and Cl, respectively in the new RO membrane- product water. Whereas in the case of new NF membrane, the reduction (%) in some water quality parameters was 75.56, 75.34, 32.85, 97.22 and 11.59 for Ca, Mg, Na, SO_4 and Cl, respectively. The removal efficiency (%) of RO-Membrane for some ions was 61.2, 70.4, 58.8, 33.33 and 57.93 for Ca, Mg, Na, Cl and SO_4, respectively. While for NF-membrane, it came to 33.58, 59.26, 47.81, 22.89 and 50.61% for Ca, Mg, Na, Cl and SO_4, respectively. The significant reduction in the ion removal efficiency might be subjected to fouling and bio-fouling of the membrane bio-reactor (MBR), RO and NF membranes due to the presence of organic pollutants coupled with wear and tear of membranes after 9-years of installation. The study findings provided concrete clue for replacing the existing wastewater treatment methods with more advanced methods using ceramic membranes. The research further highlighted the necessary to replace the NF and RO membranes used in these two water treatment techniques.

Key words: Membrane Bio-reactor (MBR), Nano-filtration (NF), Reverse osmosis (RO), catins, anions, removal efficiency, membrane fouling, organic pollutants

INTRODUCTION

Saudi Arabia is an arid country with limited and non-renewable water resources. Currently with rapid urban and rural expansion, the demand for water supply has increased manifolds due to more water use in domestic, agriculture and industrial sectors. Consequently, wastewater production has increased tremendously and crating safe disposal problems. According to an estimate millions cubic meters of wastewater is being produced in different regions of Kingdom of Saudi Arabia (Anonymous, 1984; Al-Degaither, 1992). The main sources of waste effluents include sewage water, agricultural drainage water, leaking of water supply networks, irrigation runoff losses, industrial waste effluents and aquaculture wastewaters. It is an admitted fact that wastewaters contain biological, organic and inorganic pollutants to varying degrees. There are chances that land disposal of different types of waste effluents can create environmental and health hazards.

Currently, to meet the growing need of water for various uses and to minimize the environmental hazards from the land disposal of waste effluents, it is important to explore alternate means of water supply to augment the existing water supplies. Presently a number of wastewater treatment methods such as sedimentation, aeration, polymerization, chlorination, Reverse Osmosis (RO), Nanofiltration (NF), Microfiltration (MF) and Membrane Bio-Reactor (MBR) using hollow fiber membranes are followed to purify different types of wastewaters (Abu-Rizaiza *et al*., 1995). The product water from these wastewater treatment technologies can beneficially be used in agriculture, industrial cooling and steam generation for different production processes.

Among the various wastewater treatment technologies, RO and NF processes are highly sophisticated, reliable and applicable for wastewater purification according to the purpose of its uses. Because these processes can remove major salt cations and anions thus reducing the salt concentration of highly saline waters to less saline waters acceptable for safe use in agriculture, landscape development and industrial cooling. Therefore, the main objective of this research was to study the performance of Wastewater Treatment Plant (WTP) at King Abdulaziz City for Sceinec and Technology (KACST) consisting of Membrane Bio-reactor (MBR), Nano-filtration (NF) and Reverse Osmosis (RO) units to improve quality of wastewater by removing major cations and anions such as calcium, magnesium and chloride to acceptable limits for various uses. Also to determine the reduction in the performance of RO and NF processes due to membrane fouling and bio-fouling.

MATERIALS AND METHODS

The experiment was carried at Wastewater Treatment Plant (WTP), National Center for Water technology (NCWT), King Abdulaziz City for Science and Technology (KACST) during 2012-2013.

Collection of wastewater samples: Wastewater samples were collected from four different places for experimentation on weekly basis. The sampling points were main reservoir storage tank (raw wastewater), product water from Membrane Bio-Reactor (MBR) containing hollow fiber membrane nodules, product water from Reverse Osmosis (RO) and Nano-Filtration (NF). The water samples were immediately transfer to the analytical laboratory after collection for physical and chemical analysis. The details of WTP, KACST is presented in Fig. 1.

Analysis of wastewater samples: Water samples were analyzed for pH, electrical conductivity, cations and anions, Dissolves Oxygen (DO), Fluoride (F) and Nitrates (NO_3). The cations and anions (chloride, fluoride, sulphate, nitrate and phosphate) were determined by using Dionex 300 Ion chromatography. The instrument used was Dionex ion chromatography with column As-14 (4mm), guard column AS-12, suppressor-ASR-1, fluent mixture of carbonate and bicarbonate, deionized water and nitrogen gas. The results of different parameters such as Cl, SO_4, NO_3, PO_4 and F were expressed in mg L^{-1}. The total dissolved solids (TDS) were estimated by using Oven Heraeus Instruments. The pH was measured by using Hach HQ D40.

Specific experimentation: In addition to the above, specific experiment was run to determine the cations and anions removal efficiency of some major cations and anions such as Ca, Mg, Na,

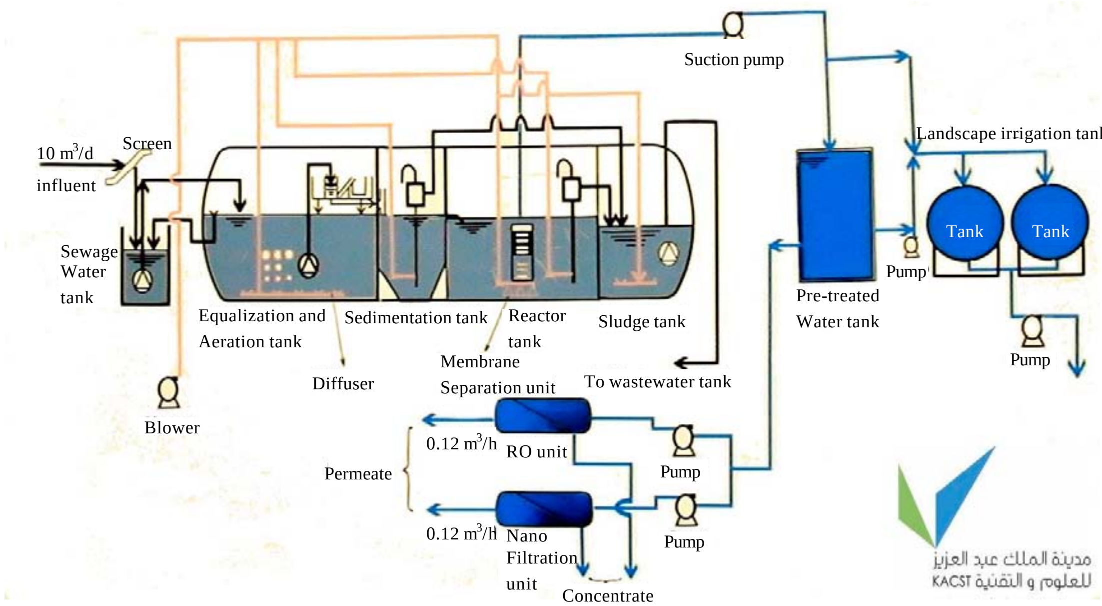

Fig. 1: Details of wastewater treatment plant, KACST

Cl and SO_4 ions from the product water of Membrane Bio-reactor (MBR). Because these ions are source of hardness and salinity in drinking and irrigation waters.

Data analysis: Data were analyzed by ANOVA and regression techniques for treatment evaluation at 5% level of significance according to SAS (2001).

RESULTS AND DISCUSSION

Raw wastewater: Mean values of different water quality parameters were pH (7.71), Electrical conductivity (1.450 dS m^{-1}), total dissolved solids, TDS (928 mg L^{-1}), Ca (192 mg L^{-1}), Mg (44 mg L^{-1}), Na (195 mg L^{-1}), K (14 mg L^{-1}), Cl (269 mg L^{-1}, F (11.45 mg L^{-1}), NO_3 (156 mg L^{-1}), SO_4 (252 mg L^{-1}), HCO_3 (455 mg L^{-1}), dissolved oxygen, DO (0.09 mg L^{-1}) and total alkalinity (354 mg L^{-1}) during the experimental period (Table 1). The values of bicarbonates show that wastewater from KACST is rich in carbonaceous materials due to the presence of appreciable amount of organic compounds which needs aeration and activated sludge treatment to decompose organic materials. by oxidation and due to the action of micro-organisms present in the activated sludge to decompose organic materials and due to the action of micro-organisms present in the activated sludge. The application of activated sludge is basically the addition of micro-organisms which multiply by consuming organic materials present in the wastewatewaters.

Product Water from Membrane Bio-Reactor (MBR): Mean values of different water quality parameters were pH (7.61), Electrical conductivity (1.353 dS m^{-1}), total dissolved solids, TDS (893 mg L^{-1}), Ca (134 mg L^{-1}). Mg (27 mg L^{-1}), Na (182 mg L^{-1}), K (4.78 mg L^{-1}), Cl (201 mg L^{-1}, F (7.18 mg L^{-1}), NO_3 (186 mg L^{-1}), SO_4 (164 mg L^{-1}), HCO_3 (76 mg L^{-1}), dissolved oxygen, DO (6.35 mg L^{-1}) and total alkalinity (63 mg L^{-1}) during the experimental period (Table 1). The wastewater is primarily treated in the Membrane Bio-Reactor (MBR) to purify water from organic

Table 1: Mean chemical composition of sewage water in different treatment processes at wastewater treatment plant (WTP)

Parameters	R W	P W	RO	NF
PH	7.71	7.61	6.05	6.46
EC dS m^{-1}	1.450	1.353	1.011	1.179
TDS mg L^{-1}	928	893	607	710
DO mg L^{-1}	0.09	6.35	6.23	6.48
Temperature °C	23.82	24	29.5	29.6
T. Alk. mg L^{-1}	354	63	16	22
Ca mg L^{-1}	192	134	52	89
Mg mg L^{-1}	44	27	8	11
Na mg L^{-1}	195	182	75	95
K mg L^{-1}	14	4.78	4	6.5
F mg L^{-1}	11.45	7.18	0.73	0.95
NO_3 mg L^{-1}	156	186	137	145
SO_4 mg L^{-1}	252	164	69	81
HCO_3 mg L^{-1}	455	76	25	26
Cl mg L^{-1}	269	201	134	155

RW: Sewage water from main tank, PW: Treated water from membrane bio-reactor, RO: Reverse osmosis product water, NF: Nano-filtration product water, EC: Electrical conductivity, TDS: Total dissolved solids, T. Alk.: Total alkalinity

compounds. The combined action of aeration, activated sludge and the hollow-fiber membrane is to clean the wastewater from biological and organic pollutants. It was observed that all the cations and anions decreased while NO_3 contents increased with MBR this treatment. The substantial increase in NO_3 contents indicate that the nitrogen in organic form was converted to nitrate due to nitrification and oxidation process. But there is no significant change in the total water salinity due to these treatments.

RO-Product water: Mean values of different water quality parameters were pH (6.05), Electrical conductivity (1.011 dS m^{-1}), total dissolved solids, TDS (607 mg L^{-1}), Ca (52 mg L^{-1}). Mg (8 mg L^{-1}), Na (75 mg L^{-1}), K (4 mg L^{-1}), Cl (134 mg L^{-1}, F (0.73 mg L^{-1}), NO_3 (137 mg L^{-1}), SO_4 (69 mg L^{-1}), HCO_3 (25 mg L^{-1}), dissolved oxygen, DO (6.23 mg L^{-1}) and total alkalinity (16 mg L^{-1}) during the experimental period (Table 1). The removal efficiency of some water quality parameters was 32% (TDS), 61.2% (Ca), 70.4% (Mg), 58.8% (Na), 89.83% (F), 57.93% (SO_4), 26.34% (NO_3) and 33.33% (Cl) in the RO-product water (Table 1). The data analysis indicated that the efficiency of RO-water treatment technique decreased substantially. This decrease might be attributed to the RO-membrane fouling and deterioration of membrane with the passage of time. Because the removal efficiency of the RO-membrane was significantly less than the original specified cations and anions removal efficiency (Table 2).

NF-Product water: Mean values of different water quality parameters were pH (6.46), Electrical conductivity (1.179 dS m^{-1}), total dissolved solids, TDS (710 mg L^{-1}), Ca (89 mg L^{-1}). Mg (11 mg L^{-1}), Na (95 mg L^{-1}), K (6.5 mg L^{-1}), Cl (155 mg L^{-1}), F (0.95 mg L^{-1}), NO_3 (145 mg L^{-1}), SO_4 (81 mg L^{-1}), HCO_3 (26 mg L^{-1}), dissolved oxygen, DO (6.48 mg L^{-1}) and total alkalinity (22 mg L^{-1}) during the experimental period (Table 1). The removal efficiency in some water quality parameters was 20.49% (TDS), 33.58% (Ca), 59.26% (Mg), 47.81% (Na), 86.77% (F), 50.61% (SO_4), 22.04% (NO_3) and 22.89% (Cl) in the NF-product water. The analysis indicated that the efficiency of NF-water treatment technique decreased substantially. This decrease could be attributed to the

Table 2: Removal efficiency of ro and nf membranes processes for major cations and anions in wastewater purification

Ion species	MBR	RO	Removal efficiency by RO (%)	NF	Removal efficiency by NF (%)
Manufacturing removal efficiency					
Ca^{2+}	54	1.9	96.5	13.2	75.56
Mg^{2+}	37.3	1.8	95.17	9.2	75.34
Na^{+}	96.5	19.2	80.1	64.8	32.85
Cl^{-}	136.87	7.7	94.37	121	11.59
SO_4^{-2}	176.37	3	98.29	4.9	97.22
Performance after 9 years					
Ca^{2+}	134	52	61.2	89	33.58
Mg^{2+}	27	8	70.4	11	59.26
Na^{+}	182	75	58.8	95	47.81
Cl^{-}	201	134	33.33	155	22.89
SO_4^{-2}	164	69	57.93	81	50.61

MBR: Product water from membrane bio-reactor, RO: Reverse osmosis process, NF: Nano-filtration process

fouling of NF-membrane and its deterioration with the passage of time. Because the removal efficiency of various cations/anions by the NF-membrane was significantly less than the original specified cations and anions removal efficiency (Table 2).

Removal efficiency of cations and anions: The removal efficiency of RO and NF membranes is presented (Table 2). The manufacturing removal efficiency (%) of RO-Membrane for different selective ions was 96.5, 95.17, 80.1, 94.37 and 98.29% for Ca, Mg, Na, Cl and SO_4, respectively. Whereas, it was 75.56, 75.34, 32.85, 11.59 and 97.22% for Ca, Mg, Na, Cl and SO_4, respectively for the NF-membrane. However, after a period of 9-years of installation, the removal efficiency (%) of RO-Membrane for some selective ions came to 61.2, 70.4, 58.8, 33.33 and 57.93 for Ca, Mg, Na, Cl and SO_4, respectively. While for NF-membrane, it came to 33.58, 59.26, 47.81, 22.89 and 50.61% for Ca, Mg, Na, Cl and SO_4, respectively. There was a significant reduction in the ion removal efficiency after 9-years of installation. This could be subjected to membrane fouling and bio-fouling due to the presence of some organic pollutants in the Membrane Bio-Reactor (MBR) product water and also due to wear and tear of the membrane over a long period of time.

The results obtained from RO and NF wastewater treatment processes showed that the removal of divalent ions was considerably higher than the monovalent caions/anions (Table 2). It was further observed that modest removal was observed for monovalent ion species by NF process as compared to the RO where strong rejection was observed for monovalent cations and anions by RO. The results agree with those of Khedr (2009) who concluded that nano filtration and low energy reverse osmosis are proper water treatment technologies for the elimination of radioactive isotopes and heavy metal cations from drinking water. Similar conclusions were drawn by Albino and Donald (1988) who stated that reverse osmosis technology is most suitable for brackish and seawater desalting.

CONCLUSION

The reduction in some water quality parameters was 96.5% (Ca), 95.17% (Mg), 80.1% (Na), 98.29% (SO_4) and 94.37% (Cl) in the new RO membrane- product water. Whereas in the case of new NF membrane, the reduction in some water quality parameters was 75.56% (Ca), 75.34% (Mg), 32.85% (Na), 97.22% (SO_4) and 11.59% (Cl). After 9-years of installation, the removal efficiency (%) of RO-Membrane for different selective ions was 61.2, 70.4, 58.8, 33.33 and 57.93

for Ca, Mg, Na, Cl and SO_4, respectively. While for NF-membrane, it came to 33.58, 59.26, 47.81, 22.89 and 50.61% for Ca, Mg, Na, Cl and SO_4, respectively. The removal of divalent ions was considerably higher than the monovalent caions/anions as shown from the composition of product water from RO and NF water treatment process. There was a significant reduction in the ion removal efficiency after 9-years of installation of RO and NF Membranes. This might be attributed to membrane fouling and bio-fouling due to the presence of some organic pollutants in the product water of Membrane Bio-reactor (MBR) process and due to wear and tear of the membrane over a long period of time. The study findings provided concrete clue for the replacement of the existing wastewater treatment methods with more advanced methods using ceramic membranes. The research further highlighted the necessary to replace the NF and RO membranes used in these two water treatment techniques.

Recommendations and suggestions: Based on the study findings, the following recommendations are made for consideration while using RO and NF membrane processes for water and wastewater purification.

- Replace the RO and NF membranes when the water purification and the ion removal efficiency is less than 50 percent to avoid economical losses
- Observe the performance of new membrane after installation and make backwash when the ion removal efficiency of membrane is less than 10%
- Conduct training program of technicians working in RO and NF systems maintenance including the backwash and fouling problem
- Scheduling the membrane cleaning on regular basis to achieve high performance efficiency
- Autopsy of the old membrane to determine the possible reasons for reduction in ion removal efficiency of RO and NF membranes
- Substitute the RO and NF membranes with the improved ceramic membranes

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