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Pilot scale investigation of low pressure nanofiltration and reverse osmosis membrane techniques for the treatment of El-Salaam canal water, Sinai, Egypt

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ABSTRACT

El-Salaam canal water in Sinai, Egypt is a mixture of agricultural drainage water and Nile water. The canal water is characterized by remarkable monovalent, divalent and trivalent ions and moderate total dissolved solids (TDS) (1300–2400 mg/L). Biologically the raw water is characterized by the existence of total coliform and pathogenic bacteria. The present study is concerned with the treatment investigation of El-Salaam canal water by using pilot plant low pressure nanofiltration (LPNF) and low pressure brackish water reverse osmosis (LPBWRO) membrane separation units to produce water for irrigation and drinking purposes. Hence, the raw water is allowed to be pretreated by using 2.5 mg/L nonionic polymer for coagulation then followed by nanofiltration (NF) separation to produce water of quality suitable for irrigation or followed by brackish water reverse osmosis (BWRO) to produce water of quality suitable for drinking purposes. The LPNF treatment system removed 82% of the TDS, 71–74% monovalent ions and 96% of monovalent ions. The LPBWRO system removed 98% of divalent ions (sodium), 98–100% of the divalent ions (calcium and magnesium) and 94% of iron as trivalent ions. Both the NF and BWRO systems remove totally the chemical oxygen demand (COD), biological oxygen demand (BOD), total organic matters (TOC) and suspended solids (SS) the total coliform and the pathogenic bacteria.

Keywords: El-Salam canal; Pretreatment; Nanofiltration; Reverse osmosis; Economic; Design

1. Introduction

During the last years, the Egyptian academy of scientific research and technology (ASRT) funded several research projects considered with investigation of water quality and water pollution control. A project entitled ''Treatment of Nile water in Sinai'' was one of these projects which implemented by a team work from national research centre (NRC). The project aimed to carry out the environmental base line profile which helps in build up analyses database and to put a conclusive scope of the negative impacts that arise from implementation of El-Salam canal project in Sinai. Furthermore, propose measures for control and/or remediation of these hazards by using advanced membrane techniques [1,2]. Based on this objective the water was analyzed chemically and examined biologically during 12 months at seven locations all over the canal. The chemical study proved the high concentration of total dissolved solids, high concentration of dissolved organic matters to unacceptable and harmful limits. Also high biological pollution was remarkable which caused negative impacts for the virgin desert land. So, these analyses and examinations proved that

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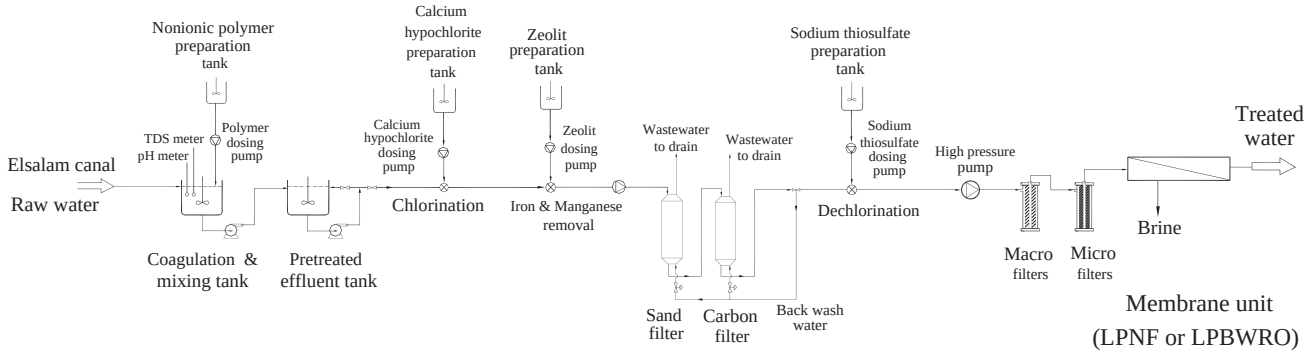

Fig. 1. Pilot scale membrane experimental set up.

El-Salam canal water is not suitable for irrigation or for human and animal drinking and needs treatment [3–5]. Bench scale treatment experiments were carried out by using two methods: physiochemical treatment as conventional method and ultrafiltration (UF) separation method as nonconventional method [6]. Both succeeded to improve the quality of water chemically and biologically to be suitable for irrigation of decorated plants and for noneatable crops and plants [5]. The low pressure nanofiltration (LPNF) membrane and low pressure brackish water reverse osmosis (LPBWRO) are synthesis from polyamide or cellulose acetate. Nanofiltration (NF) pores passes particles of molecular weight in the range of 200–1000 Dalton under pressure of 3–12 bars. The LPNF membrane removes 70–79% divalent and trivalent ions, carbonate, sulphate and phosphate, hardness, heavy metals, viruses, bacteria and minute dissolved organic substances [7]. The LPBWRO a membrane pores passes particles of molecular weight in the range of 100 Dalton under pressure of 20 bars. They remove 98% of monovalent ions such as Na and chloride; remove dissolved organic substances, bacteria, viruses and heavy metals [8]. The present study is concerned with pilot plant treatment experiments of El-Salaam canal water by using LPNF and LPBWRO membrane technologies to produce irrigation water for all types of plants and crops and pure water for drinking and industrial purposes.

2. Materials and methods

2.1. Sampling collections and analyses

El-Salaam canal raw water was collected from a point located at 14.5 km of the East part of Suez canal which is a part of El-Salaam canal in Sinai, Egypt and which is known as El-Sheikh Gaber canal. This area is virgin and not planted yet which will be suitable for new communities. Two raw water samples each of 200 L are collected to be used for LPNF and LPBWRO experiments. The samples were collected, transported and preserved to NRC according to standard methods to be chemically and biologically analyzed [9,10]. The chemical analyses covered the pH, chemical oxygen demand (COD), biological oxygen demand (BOD), suspended solids (SS), total organic matters (TOC), monovalent and divalent ions. The biological examinations include the microbiological water quality, the new pollution indicators and the pathogenic bacteria.

2.2. Experimental set up

Fig. 1 represents the LPNF and LPBWRO experimental set up. It consists of: mixing and coagulation tank (200 L) provided with mechanical agitator, chemical dosing pump, pH-meter and total dissolved solids (TDS)-meter; pretreated-effluent tank (200 L) provided with recycling centrifugal pump (½ hp, 2000 h^{-1}), pipes and valves; chlorination dosing system equipped with dosing pump 5 h^{-1} maximum and calcium hypochlorite preparation tank (10 L); zeolite dosing system for iron and manganese removal equipped with dosing pump 5 h^{-1} maximum and zeolite preparation tank (10 L), centrifugal pump (1 hp, 4000 h^{-1}, 4 bars), pipes and valves; fine sand filter; activated carbon filter; dechlorination dosing system equipped with sodium bisulphite dosing pump and preparation tank (10 L), high-pressure pump (7 bars, 500 h^{-1}), pipes and valves; high-pressure macro cartridge filter (pore size 5 μm, ceramic type); high-pressure micron cartridge filter (pore size 1 μm, ceramic type); separation unit LPNF (Filmtech, spiral wound, type NF-55-2540, 2.54 cm diameter, 30 cm height, thin-film composite (TFC) (polyamide composite), 7 bars, 6 m^3/d) or brackish water reverse osmosis (BWRO) membrane (Filmtech, spiral wound, type TW 30-40-40, TFC (polyamide composite), 16 bars, 6 m^3/d) and permeate and concentrate tanks, both are provided with flowmeter, pH-meter and TDS-meter.

Table 1
Chemical analysis of raw water samples #1 and #2 collected from El-Salam canal

S. no.	Substance/or/characteristic	Units	Raw water for nano exp.	Raw water for BWRO exp.
1	pH-value	Unit	7.9	7.3
2	Conductivity	μm hos	1700	3700
3	COD	mg/L	62	56
4	BOD-5	mg/L	43	36
5	SS	mg/L	163	148
6	TOC	mg/L	5.88	5.22
7	TDS at 105 °C	mg/L	1126	2423
8	Sodium ion (Na^+)	mg/L	278	692
9	Potassium ion (K^+)	mg/L	7	9
10	Calcium ion (Ca^{2+})	mg/L	64	107
11	Magnesium ion (Mg^{2+})	mg/L	29	41
12	Chloride (Cl^-)	mg/L	386	1051
13	Bicarbonate (HCO_3^-)	mg/L	181	313
14	Carbonate (CO_3^{2-})	mg/L	12	0
15	Hydroxyl (OH^-)	mg/L	0	0
16	Sulphate ($SO4^{2-}$)	mg/L	156	192
17	Silica (SiO_2), soluble	mg/L	9.11	5.94
18	Iron (Fe^{3+}), soluble	mg/L	0.54	0.68
19	Manganese (Mn^{4+}), sol.	mg/L	0.03	0.02
20	Phosphate (PO_4)	mg/L	2.98	5.81
21	Hardness (as $CaCO_3$)	mg/L	232	370
22	Total hardness	mg/L	401	574

3. Experimental procedure

The pretreatment of raw water is necessary to prevent the damage and the clogging of membrane which is very sensitive and highly cost. The raw water will be chemically and biologically analyzed before and after treatment [9]. The raw water is allowed to pass to screen to separate high particles size then coagulation, flocculation and precipitation is carried out to remove suspended solids (SS) The coagulant used was 2.5 mg/L of nonionic polymer as recommended in the bench scale experiments [6]. Clear water is chlorinated then passes to sand filter, carbon filter, macro filter, micro filter and LPNF or LPBWRO based on the quality of water required. LPNF used in case of obtaining water suitable for irrigation and LPBWRO is used for producing drinking water.

4. Results and discussion

4.1. Wastewater characteristics

Table 1 illustrates the chemical analysis of the two water samples #1 and #2 which collected from El-Salam canal for pilot plant experiments. Sample #1 was used for the NF separation experiments. It is characterized by high SS (163 mg/L), high TDS (1126 mg/l) and high TOC (5.88 mg/L). Sample #2 was used for BWRO separation experiments. It is characterized also by high SS (148 mg/L), high TDS (2432 mg/L) and high TOC (5.22 mg/L). Both samples are characterized by remarkable Na, K, Mg, Ca, chloride and sulphate ions. The biological examinations of El-Salaam canal water is presented in Tables 2 and 3 which indicated the existence of the total coliform, the fecal coliform, the fecal streptococci and pathogenic bacteria. Hence the raw

Table 2
Microbiological investigation of raw water of El-Salaam canal

MPN – index 1 100 mL			Total bacterial/1 mL count		Sample
Fecal streptococci	Fecal coliform	Total coliform	At 37 °C	At 22 °C	
2	70	1.9×10^2	6×10^3	3.4×10^4	Raw water sample #1 (for NF exp.)
2	70	2.0×102	6.1×103	3.3×104	Raw water sample #2 (for BWRO exp.)

Table 3
Pathogenic bacteria in El Salaam canal samples #1 and #2

Raw water	New indicators of pollution/100 mL				Pathogenic bacteria/100ml		
	Total yeast	*Candida albicans*	*A. hydrophila*	Total *Staphylo cocci*	*Salmonellae*	Total *vibrios*	*Listeria* group
Raw water sample #1 (for NF exp.)	1.5×10^3	5	5.4×10^3	4.2×10^2	3.2×10^2	3.5×10^3	6.0×10^2
Raw water sample #2 (for BWRO exp.)	2.6×10^3	1.6×10^2	8.4×10^3	5.8×10^2	4.8×10^2	1.2×10^3	1.2×10^3

water of El-Salam canal, chemically and biologically is not suitable for irrigation purposes.

4.2. Pilot scale integrated NF membrane separation process

4.2.1. Chemical analyses

Table 4 represents the chemical analysis of raw water sample before and after the integrated NF-membrane separation process also a comparison between the results of treatment and the WHO guideline (2004). It was found that SS, COD, BOD, TOC and manganese ions are completely removed. The TDS and the total hardness were removed by 81% and 92%, respectively. The LPNF achieve high removal efficiency for divalent and trivalent ions, where, the maximum ions rejection was reached at 74% for sodium, 71% for potassium, 95% for calcium, 96.6% for magnesium, 80% for iron,

Table 4
Chemical analysis of raw water sample and after the Integrated NF-Membrane Separation Process

S. No.	Substance/or/ characteristic	Units	Raw water sample #1	After pretreatment	Removal (%)	After NF process	Removal (%)	WHO Guideline (2004)	
								Maximum	Desirable
1	Color	–	Yellowish	Yellowish	0	colorless	100	Non	Non
2	Turbidity	NTU	45	30	33.3	0	100	25	5
3	Odor	–	Non	Non	Non	Non	–	Non	Non
4	pH-value	Unit	7.9	7.9	0	6.1	–	6–9.5	7–8.5
5	Conductivity	µm hos	1700	1700	0	330	80.59	–	–
6	COD	mg/L	62	55.8	10	0	100	3	0
7	BOD-5	mg/L	43	38.7	10	0	100	2	0
8	SS	mg/L	163	139	15	0	100	5	0
9	TOC	mg/L	5.88	4.82	18	0	100	0.1	0
10	TDS at 105 °C	mg/L	1126	1126	0	217	80.73	1000	<500
11	Sodium ion ($Na^{+)}$	mg/L	278	278	0	72	74.10	200	20
12	Potassium ion (K^+)	mg/L	7	7	0	2	71.43	50	10
13	Calcium ion (Ca^{2+})	mg/L	64	64	0	3	95.31	200	75
14	Magnesium ion (Mg^{2+})	mg/L	29	29	0	1	96.55	150	30
15	Chloride (Cl^-)	mg/L	386	386	0	86	77.72	600	25
16	Bicarbonate (HCO_3^-)	mg/L	181	181	0	31	82.87	300	100
17	Carbonate (CO_3^{2-})	mg/L	12	12	0	0	0	200	50
18	Hydroxyl (OH^-)	mg/L	0	0	0	0	0	10	Non
19	Sulphate ($SO4^{2-}$)	mg/L	156	156	0	19	87.82	400	50
20	Silica (SiO_2), soluble	mg/L	9.11	9.11	0	2.41	73.55	25	10
21	Iron (Fe^{3+}), soluble	mg/L	0.54	0.54	0	0.11	79.63	0.3	Non
22	Manganese (Mn^{4+}), sol.	mg/L	0.03	0.03	0	0	100	0.1	Non
23	Phosphate (PO_4)	mg/l	2.98	2.98	0	0.82	72.48	5	0.5
24	Hardness (as $CaCO_3$)	mg/L	232	232	0	10	95.69	500	100
25	Total hardness	mg/L	401	401	0	32	92.02	–	–

Table 5
Microbiological investigation of raw water before and after the integrated NF-membrane separation process

MPN –index 1 100 mL			Total bacterial/1 mL count		Sample
Fecal streptococci	Fecal coliform	Total coliform	At 37 °C	At 22 °C	
2	70	1.9×10^2	6×10^3	304×10^4	Raw water
2	20	1.1×10^2	3.6×10^2	7.6×10^2	After coagulation
Nil	(71.4%)	(80%)	(97.7%)	(97.7%)	Removal %
–	Nil	2.3×10	2.8×10^2	2.8×10^2	After chlorination
Nil	(100%)	(79.1%)	(63.1%)	(63.1%)	Removal %
–	Nil	Nil	20	20	After nanofiltration
–	–	100%	(92.8%)	(92.8%)	Removal %

77.7% for chlorides, 82.8 % for bicarbonate, 87.8% for sulphate. About 73.5% for silica and 92% of the total hardness was removed. These results are in good agreement with Szoke et al. [11], they wrote that NF membrane above pH 4 probably has negative charge, so the rejections of the investigated anions are determined by its counteraction with the charged surface. This effect leads to generally low rejection of salts containing monovalent anion and bivalent cation, while the salts containing multivalent anions are efficiently rejected by the membrane.

4.2.2. The biological examination

Table 5 represents the results of the microbiological examination of raw water before and after treatment system. After coagulation/flocculation the removal % of the total bacterial counts were 97.7% at 37 °C and 22 °C. For the total coliform and fecal coliform the removal % were 80% and 71%, respectively, and the fecal streptococci is removed totally. After chlorination the total bacterial counts were 63% at 37 °C and 22 °C. For the total coliform and fecal coliform the removal % for both were 63%. The NF removed 92% of total bacterial counts at 37 °C and 22 °C and removed totally the total coliform and fecal coliform.

4.3. Effect of pilot scale integrated reverse osmosis (RO) membrane separation process

4.3.1. The chemical analyses

Results of the chemical analyses of the pilot scale integrated treatment (pretreatment and RO membrane separation process) are presented in Table 6. The results analyses proved that integrated system removed 100% of SS, COD, BOD, TOC, hardness, calcium, magnesium and manganese, 94% of iron and sulphate ions, 98% of sodium, 99% of potassium, 87% of silica 98% of phosphate and 98% of TDS. The comparison of the performance of NF and RO processes reveals that the efficiency of RO greatly exceeded the NF in separation of TDS where RO succeeded in removal of 98% of TDS and NF removes only 81% of TDS. Also the separation of monovalent ions by RO membrane was high compared to NF membrane. On the other hand, pH value was decreased to about 6.4 in both NF and RO system; this is reveled to separation of dissolved gases especially CO_2 and SO_3 from water by both NF and RO membrane.

4.3.2. The Biological examination

4.3.2.1. Microbiological examination

Table 7 represents the results of the microbiological examination of raw water before and after treatment system. After coagulation/flocculation the removal % of the total bacterial counts were 5% at 37 °C and 85% at 22 °C. For the total coliform, fecal coliform and fecal streptococci the removal % were 100%. After integrated system (pretreatment and BWRO treatment) the biological indicators were removed completely.

4.3.2.2. The bio-indicators and the pathogenic bacteria

Table 8 represents the examination of raw water before and after treatment for the new indicators of pollution and the pathogenic bacteria. The treatment removed totally the pathogenic bacteria.

5. Conclusion and recommendation

The LPNF treatment system removed 82% of the TDS, 71–74% monovalent ions and 96% of divalent ions. The LPBWRO system removed totally the divalent ions and 96% of the monovalent ions. Both the LPNF and LPBWRO systems removed totally the COD, BOD, TOC and SS and the pathogenic bacteria. The LPNF system produces water chemically and biologically suitable for irrigation purposes, while LPBWRO

Table 6
Chemical analysis of raw water sample and after the Integrated BWRO-membrane separation process

S. no.	Substance/or/ characteristic	Units	Raw water sample #1	After pretreatment	Removal (%)	After BWRO process	Removal (%)	WHO Guideline (2004)	
								Maximum	Desirable
1	Color	–	Yellowish	Yellowish	0	colorless	100	Non	Non
2	Turbidity	NTU	45	30	33.3	0	100	25	5
3	Odor	–	Non	Non	Non	Non	–	Non	Non
4	pH-value	Unit	7.3	7.3	0	6.4	–	6–9.5	7–8.5
5	Conductivity	μm hos	3700	3700	0	0	100.00	–	–
6	COD	mg/L	56	50.4	10	0	100.00	3	0
7	BOD-5	mg/L	36	32.4	10	0	100.00	2	0
8	SS	mg/L	148	133	15	0	100.00	5	0
9	TOC	mg/L	5.22	4.28	18	0	100.00	0.1	0
10	TDS at 105 °C	mg/L	2423	2423	0	42	98.27	1000	<500
11	Sodium ion (Na^+)	mg/L	692	692	0	13.89	97.99	200	20
12	Potassium ion (K^+)	mg/L	9	9	0	1.93	78.56	50	10
13	Calcium ion (Ca^{2+})	mg/L	107	107	0	0	100.00	200	75
14	Magnesium ion (Mg^{2+})	mg/L	41	41	0	0	100.00	150	30
15	Chloride (Cl^-)	mg/L	1051	1051	0	18.96	98.20	600	25
16	Bicarbonate (HCO_3^-)	mg/L	313	313	0	6.04	98.07	300	100
17	Carbonate (CO_3^{2-})	mg/L	0	0	0	0	00.00	200	50
18	Hydroxyl (OH^-)	mg/L	0	0	0	0	00.00	10	Non
19	Sulphate (SO_4^{2-})	mg/L	192	192	0	0	100.00	400	50
20	Silica (SiO_2), soluble	mg/L	5.94	5.94	0	0.76	87.21	25	10
21	Iron (Fe^{3+}), soluble	mg/L	0.68	0.68	0	0.04	94.12	0.3	Non
22	Manganese (Mn^{4+}), sol.	mg/L	0.02	0.02	0	0	100.00	0.1	Non
23	Phosphate (PO_4)	mg/L	5.81	5.81	0	0.07	98.80	5	0.5
24	Hardness (as $CaCO_3$)	mg/L	370	370	0	0	100.00	500	100
25	Total hardness	mg/L	574	574	0	0.87	99.85	–	–

system succeeded to treat water to be suitable for drinking water. It is recommended to construct new complex plant with different technology to produce different quality of treated water to be reuse for the different purposes of human life.

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Table 7
Microbiological investigation of raw water and after the integrated BWRO-membrane separation process

MPN – index 1 100 mL			Total bacterial/1 mL count		Sample
Fecal streptococci	Fecal coliform	Total coliform	At 37 °C	At 22 °C	
2	70	1.9×10^2	6×10^3	3.4×10^4	Raw water
Nil	Nil	Nil	5.7×10^3	5.1×10^3	After pretreatment
(100%)	(100%)	(100%)	(5%)	(85%)	Removal %
(100%)	(100%)	(100%)	5.7×10	2.6×10^2	After RO
(100%)	(100%)	(100%)	(98.5%)	(94.9%)	Removal %
(100%)	(100%)	(100%)	(99%)	(99%)	Accumulated removal %

Table 8
Determination of new bio-indicators in addition to some pathogenic bacteria in El Salam canal of raw water and after the integrated BWRO-membrane separation process

Number of sample	New indicators of pollution/100 mL		Pathogenic bacteria/100 mL		
	Total yeast	*Candida albicans*	*Salmonellae*	Total *vibrios*	*Listeria* group
Raw water	2.6×10^3	1.6×10^2	4.8×10^2	1.2×10^3	1.2×10^3
After sand filtration	1.0×10^2	ND	2.8×10^2	8.6×10^2	1.8×10^2
Removal %	96.2	100	41.7	28.3	85.0
After coagulation	1.9×10^2	56	2.7×10^2	1.6×10^2	1.4×10^2
Removal %	92.7	65.0	43.8	86.7	88.3
After chlorination	14	ND	16	ND	60
Removal %	92.6	100	94.1	100	57.1
After RO	ND	ND	ND	ND	ND
Removal %	100	100	100	100	100

Nomenclature

UF	Ultrafiltration
NF	Nanofiltration
BWRO	Brackish water reverse osmosis
SS	Suspended solids
COD	Chemical oxygen demand
BOD	Biological oxygen demand
TOC	Total organic matters
TDS	Total dissolved solids

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