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Design of reverse osmosis desalination plant in Puerto Peñasco, Sonora, México

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ABSTRACT

Water scarcity slows down economical and industrial development, and population growth. Desalination by reverse osmosis is a separation process used to reduce the dissolved salt content of saline water to a usable level and offer one solution alternative to this problem. The use of simulators allows to obtain the optimal design in water production and energy consumption. The objective of this study was to select the operation conditions using the IMSDesign simulator, to provide a solution to water scarcity and satisfy the demand of population of Puerto Peñasco, Mexico, with projection by the year 2040. Data entry, such as water quality, membrane modules, economic data and chemical costs were considered. Different membrane modules (SWC4-LD, SWC4-MAX, SWC5-MAX and SWC6-MAX) were tested in the design. Six different arrays were tested to each module. A design was considered optimal when the lowest energy consumption (kWh/m^3), lowest investment cost ($USD/m^3) and the highest elimination of contaminants (%) were obtained according to the concentration parameters (mg/L) established by the Mexican Norm (NOM-127-SSA1-1994) and the World Health Organization. The membrane module and array that complied with these conditions were SWC6-MAX with mixed permeate and energy recovery device. The results obtained were water permeate of $0.49 USD/m^3 and energy demand of 1.91 kWh/m^3. The simulation of a desalination process allows defining the operating condition and membrane type, at the same time, it reduces the operation and investment cost and increases the probability of solving water scarcity in Puerto Peñasco.

Keywords: Desalination; IMSDesign; Reverse osmosis; Scarcity; Water stress

1. Introduction

Water is an irreplaceable resource and greatly important to perform daily activities. Contamination, industrial and demographic growth have caused problems in supply and availability of this hydric resource, representing a challenge; this the reason for which enterprises both private and governmental have placed a great emphasis in its better use and care [1]. If solutions to this problem are not applied, it shall continue to worsen with the pass of time as it is estimated that by the year 2100, the population will increase to 11.2 billion [2].

Globally there is a lot of water, but only 3% is fresh water of which approximately 2% is frozen on the polar icecaps [3]. Moreover, it is estimated that by the middle of the next century, 40% of the population will suffer scarcity of this resource [2]. In Mexico, the availability of drinking water has decreased in the last decades. Nonetheless, one million and a half people still live with deficient water supply [4]. Most quantity of water in the country is found in the southern

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zone (68%), where 23% of the population inhabits. On the other hand, 27% of the population inhabits in the northern zone with only 32% of water [5].

The Sonora state, located in the northeastern of Mexico, is a region dry and with warm climates, with maximum temperatures higher than 40°C. At the same time, the zone shows a non-equitable distribution of its hydric resources since agricultural sector requires around 93% of the water available [6], which affects tourism sectors, such as the case of the Puerto Peñasco city, well known for its beaches and landscapes. Currently, water supply for the city is achieved by pumping from the Sonoyta River, which is performed without any control, triggering overexploitation and salinization of the aquifer [7]. If the population continues using the Sonoyta River as their principal water source, an extreme saline intrusion will turn out over time in this place – one of the most serious problems, causing a negative effect in agriculture and water scarcity in the community and halting tourism activities in this area [13]. For this reason, reuse and water treatment have been important tools to improve use both in industry and in agricultural fields [9,10]. To face this problem exist the technology desalination of brackish or sea water, mainly by reverse osmosis. The 65% of the desalination plants installed in the world use reverse osmosis, however, this technology has limitations for energy consumption, which represents 50%–60% of the total cost. An alternative to reduce the energy cost is the implementation of energy recovery devices (ERDs) [11]. Nowadays, technological development in membranes and process simulation, such software as IPSEpro (GRZ, AUT), MATLAB (MA, USA), IMSDesign (CA, USA) facilitate solution planning for water supply, and have been demonstrated to use are efficient in calculating and optimizing cost energy yield and permeate recovery [12]. IMSDesign (CA, USA) is a qualified tool for analysis and design of reverse osmosis plants, utilizing different types of membranes from the company Nitto Group (CA, USA) [13].

Therefore, the objective of this study was to design a desalination plant by reverse osmosis in northwestern Mexico, capable of producing drinking water that complies with the limits established by the Mexican Norm (NOM-127-SSA1-1994) to supply the demand required by the population of Puerto Peñasco with a projection by the year 2040.

2. Methodology

2.1. Study area

The location for the desalination plant was established at 10 km from the Puerto Peñasco city with coordinates 31° 19′ 36″ N, 113° 32′ 52″ W (Fig. 1).

2.2. Required demand

In order to know the population growth rate, Eq. (1) was used, according to the database of the National Institute of Statistics and Geography (INEGI, for its abbreviation in Spanish). The projected population (inhabitants) and the water demand (m^3/d) required for the municipality of Puerto Peñasco by the year 2040 were obtained with Eqs. (2) and (3), respectively. Considering a per capita consumption between 0.25–0.28 (m^3/inhabitants d) [14,15].

$$r = \left(\frac{P_{t+h}}{P_t} - 1\right)\frac{1}{h} \tag{1}$$

$$P_{t+h} = P_t\left(1 + rh\right) \tag{2}$$

$$D = P_{t+h} \times D_{\text{pc}} \tag{3}$$

where P_{t+h} is the population at the end of the period; P_t is the population at the start of the period, and h is the time elapsed in the period; r represents growth rate (calculated based on censuses performed in the period 1980–2015); D represents water demand (m^3/d) and D_{pc} demand per capita (m^3/inhabitants d).

2.3. Sampling

Field sampling was performed to know the different water physical–chemical characteristics, which indicated a pH of 8.04 and 33,973 mg/L of total dissolved solids (TDS) in situ, a value very similar to that reported by Correa [16] the area of study from 36,000 to 37,000 mg/L (TDS). HNO_3 was used to preserve samples. The determination of cations and anions was carried out by standardized methods

Fig. 1. Location of the study area Puerto Peñasco, Sonora, Mexico.

and carried out in accredited laboratories. The standardized methods are electric conductivity: 2,510, TDS: 1,030-F, calcium: 3,500-Ca, magnesium: 3,500-Mg, sodium: 3,500-Na, potassium: 3,500-K, carbonates: 2,320 CO_3, bicarbonates: 2,320-HCO_3, sulfates: 4,500-SO_4, chloride: 4,500-Cl, copper: 8,506-Cu, nitrites: 4,500-NO_3, phosphates: 4,500-PO_4, iron: 8,008-Fe, manganese: 4,500-$KMnO_4$.

The results are shown in Table 1.

2.4. Array selection

To know the best design, six different arrays were simulated by entering sampling concentration data. These arrays were conventional, permeate mix, reject recirculation, ERD, permeate mix with reject recirculation and permeate mix with ERD (Fig. 2). The software utilized was IMSDesign from the company Nitto Group (CA, USA), version 2.225.84.

The array with the lowest cost (USD/m³) and lowest energy consumption (kWh/m³) was selected.

2.5. Membrane module selection

To know which membrane modules could be used, four types, SWC4-LD, SWC4-MAX, SWC5-MAX and SWC6-MAX, were compared; those utilized were from the trademark Hydranautics Nitto Group (CA, USA) which have a composite polyamide membrane in spiral configuration and the characteristics shown in Table 2.

The results obtained by simulation were compared with the Mexican Norm in force, selecting the one showing the greatest salt removal (mg/L) and the most adequate pH between 6.8 and 7.2. The conversion calculation and the percentage of salt removal were estimated with Eqs. (4) and (5). The percentages obtained were compared with those recorded in the Kucera study [17].

$$\%\text{Salt removal} = \frac{\text{Fc} - \text{Pc}}{\text{Fc}} \times 100 \tag{4}$$

$$\%\text{Conversion} = \frac{\text{permeate flow}}{\text{feed flow}} \times 100 \tag{5}$$

where Fc was feed concentration (mg/L) and Pc is permeate concentration (mg/L) for equation.

For the design, new membranes were considered with a fouling factor of 1, flux decrease of 7% per year, flux of

Table 1
Characterization of anions and cations

Anions (mg/L)							
HCO_3	SO_4	Cl	F	NO_3	PO_4	SiO_2	B
172	2,767	19,274	2.12	0.51	0.00	0.00	10.10
Cations (mg/L)							
Ca	Mg	Na	Mn	K	Fe	Cu	
340	1,482	9,655	3.50	289.34	2.90	1.46	

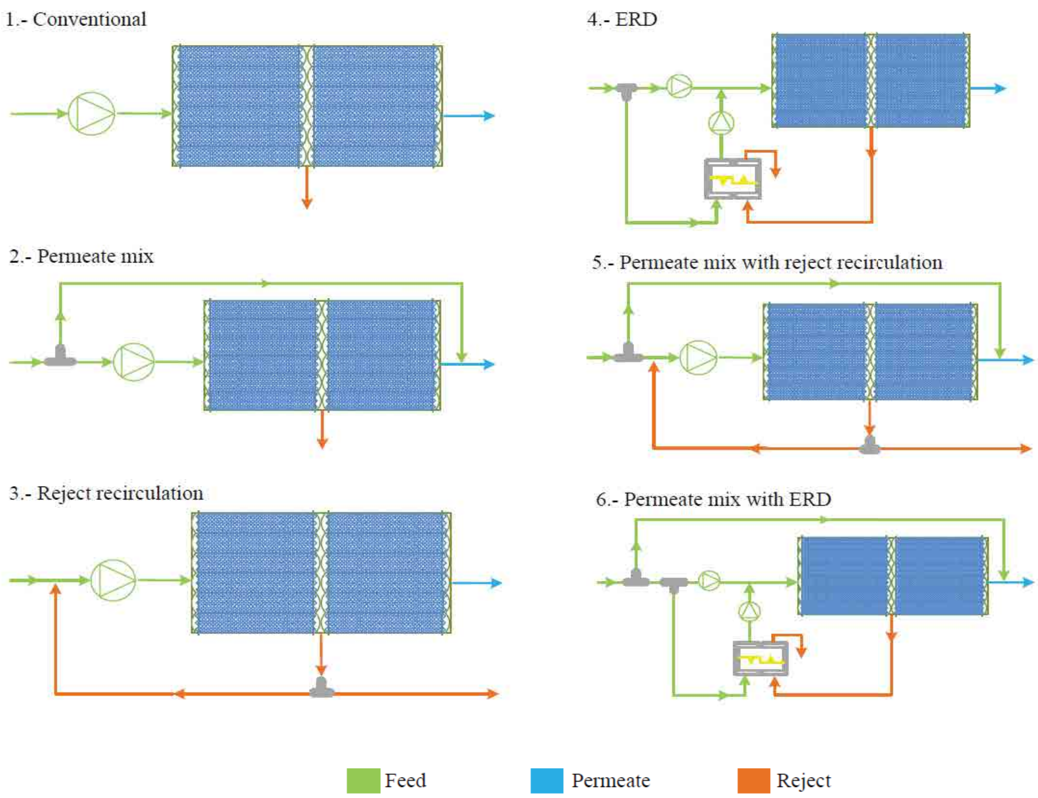

Fig. 2. Arrays utilized for simulation with the purpose of comparing process efficiency.

Table 2
Characteristics of the membranes utilized in each array

Model	Permeate flux m^3/d	Salt rejection %	Area m^2	Maximum pressure psi
SWC4-LD[a]	24.6	99.8	37.2	1,200
SWC4-MAX[b]	27.3	99.8	40.9	1,200
SWC5-MAX[c]	27.3	99.8	40.9	1,200
SWC6-MAX[d]	25[e]–50[f]	99.6	40.9	1,200

[a]http://membranes.com/wp-content/uploads/2017/03/SWC4-LD.pdf.
[b]http://membranes.com/wp-content/uploads/2017/03/SWC4-MAX.pdf.
[c]http://membranes.com/wp-content/uploads/2017/03/SWC4-MAX.pdf.
[d]http://membranes.com/wp-content/uploads/2017/03/SWC6-MAX.pdf.
[e]Low pressure.
[f]Hihg Pressure.

13.5 L-m^2/h, and for pH adjustment of 7.0, H_2SO_4 was used. All the set-up previously mentioned had the purpose of conditioning water before entering reverse osmosis and thus promoting their maximum lifetime.

3. Results and discussion

3.1. Demand required

Average population growth rate from 1980 to 2015 had a value of 0.0374, which represented a projection of 120,317 inhabitants and 37,743 m^3/d estimated by 2040 (Table 3) [17]. The consumption value of m^3/inhabitants was estimated by dividing the growth rate between the number of years to be projected, that is 0.28 for time lapses from 5 and 10 years. For a period of 25 years the consumption is 0.31 m^3/inhabitants.

3.2. Comparing membrane modules

The salinity concentration results in the permeate simulated by the membrane module SWC4-LD, SWC4-MAX, SWC5-MAX and SWC6-MAX software are shown in Table 4–7, respectively.

Water quality ranged from 141.519 to 298.629 mg/L when utilizing this type of membrane module, similar to Changxing Power Station ZLD plant located in China, with a concentration of water product <500 mg/L [19].

The membrane modules SWC4-MAX and SWC5-MAX showed a valid elimination for all parameters analyzed. The TDS were removed in the different arrays from 143.320 to 299.859 and 203.42 to 287.66 mg/L respectively; complying with the limit recommended of 600 mg/L [20].

Tables 4–7 of permeate concentration pointed out that all the parameters with the exception of pH were found within the permissible limits established by the Mexican Norm (NOM-0127-SSA1-1994), which does not consider boron concentration within the parameters. Nonetheless, according to WHO [20], the accepted limits are 2.6 [21]. In this sense with a second stage of reverse osmosis, or applying ion exchange resins, it will be possible to lower the concentration to acceptable limits.

The total investment cost of the design was $35,752,546 USD for SWC4-LD membrane modules, $35,755,848 USD for SWC4-MAX; $35,765,543 USD for SWC5-MAX and $34,832,948 USD for SWC6-MAX, almost one million dollars less for the most current membrane, which shows advances in engineering. However, we must add the costs in the collection of raw water and energy use in the pre-treatment and post-treatment, so that the final cost should be added from 10% to 15%. In this context, the approximate total cost for preliminary planning purposes is $39,057,890 USD.

The total cost of the investment obtained is compared with other investment costs of several RO plants in the world, reported by [22]. They found that an RO plant in Fujairah 2 in the United Arab Emirates (UAE) with a capacity of 136,000 m^3/d has an investment cost of $ 190 million; in Skikda in Algeria with a capacity of 100,000 m^3/d has an investment cost of $ 110 million; in Palmachim, Israel with a capacity of 110,000 m^3/d has an investment cost of $110 million; in Alicante, Spain with a capacity of 65,000 m^3/d has an investment cost of $89 million. In Guaymas, Mexico, a desalination plant with a capacity of 17,280 m^3/d has an investment cost of $42 million [23]. On the other hand, for a plant with a projection of 43,200 m^3/d in the Binational project of Puerto Peñasco and Arizona, it is estimated among US$15–$20 million in engineering services for the desalination system design and technology [24].

It is evident that the costs depend on factors such as the membrane model, the type of water inlet to the process, whether it is an open intake or a beach well, the brine discharge and elimination method, the concentration of feed water, the quality and the type of materials used in the civil works and structures of the desalination plant, equipment and automation of the process, credit and financing rates, etc.

The results of energy consumption per m^3 of water product in each array are shown in Fig. 3.

The arrays 1, 2, 3 and 5 showed an increase in energy demand with values from 3.58 to 4.01 kW/m^3. On the other hand, arrays 4 and 6 showed a lower consumption with the results obtained of 1.73 to 1.91 kW/m^3; these values were close to those established by Voutchkov [25] who reported that the minimum energy to desalinize water from the Pacific Ocean was 2.5 kWh/m^3. This is due to the fact that the rejected water comes out with pressure, and when this water is recirculated with the feed water, the high-pressure pump reduces the energy supply to desalinate the seawater. This is directly reflected in the consumption of energy and energy (Table 8).

Table 3
Population and demand per capita in different years, utilized to project population and demand by the year 2040

Year	1980	1990	2000	2010	2015	2040
Inhabitants	26,275	26,625	37,416	42,134	62,177	120,317
Demand (m^3/d)	7,357	7,455	10,476	11,797	17,409	37,743

Table 4
Permeate concentration utilizing the membrane SWC4-LD

Feed	Concentration mg/L	Array						NOM
		1	2	3	4	5	6	
Ca	340.660	0.369	1.943	0.317	0.380	1.944	1.692	NA
Mg	1,482.540	1.607	8.455	1.613	1.655	8.462	7.365	NA
Na	9,655.800	50.182	94.603	50.386	51.672	94.806	88.681	200
Mn	3.500	0.004	0.020	0.004	0.004	0.020	0.017	0.15
K	289.340	1.879	3.208	1.887	1.935	3.216	3.042	NA
Fe	2.900	0.003	0.017	0.003	0.003	0.017	0.014	0.3
HCO_3	172.460	1.361	2.244	1.366	1.400	2.249	1.910	NA
SO_4	2,767.630	2.949	15.734	2.961	3.037	15.746	13.703	400
Cu	1.460	0.002	0.008	0.002	0.002	0.008	0.007	2
Cl	19,224.540	81.358	169.886	81.689	83.774	170.215	157.640	250
NO_3	0.510	0.016	0.018	0.016	0.017	0.018	0.018	10
F	2.120	0.025	0.035	0.025	0.026	0.035	0.034	1.5
B	10.100	1.764	1.802	1.768	1.806	1.807	1.838	2.4
CO_3	19.536	0.000	0.086	0.000	0.000	0.086	0.020	NA
TDS	33,973.000	141.519	298.059	142.037	145.711	298.629	275.981	1,000
pH	8.04	5.40	5.60	5.34	5.40	5.60	5.20	6.5–8.5

Table 5
Permeate concentration in the one utilizing membrane SWC4-MAX

Feed water	Concentration mg/L	Array						NOM
		1	2	3	4	5	6	
Ca	340.660	0.374	1.948	0.376	0.385	1.688	1.436	NA
Mg	1,482.540	1.628	8.476	1.635	1.676	7.347	6.248	NA
Na	9,655.800	50.825	95.243	51.072	52.328	88.115	81.981	200
Mn	3.500	0.004	0.020	0.004	0.004	0.017	0.015	0.15
K	289.340	1.903	3.232	1.912	1.959	3.021	2.847	NA
Fe	2.900	0.003	0.017	0.003	0.003	0.014	0.012	0.3
HCO_3	172.460	1.379	2.262	1.385	1.418	2.121	2.007	NA
SO_4	2,767.630	2.987	15.772	3.002	3.076	13.664	11.612	400
Cu	1.460	0.002	0.008	0.002	0.002	0.007	0.006	2
Cl	19,224.540	82.409	170.932	82.810	84.847	156.635	143.946	250
NO_3	0.510	0.002	0.002	0.002	0.002	0.002	0.002	10
F	2.120	0.025	0.035	0.025	0.026	0.033	0.032	1.5
B	10.100	1.784	1.822	1.789	1.826	1.821	1.851	2.4
CO_3	19.536	0.000	0.090	0.000	0.000	0.075	0.060	NA
TDS	33,973.000	143.320	299.860	144.020	147.550	298.630	275.980	1,000
pH	8.040	5.40	5.60	5.40	5.40	5.60	5.50	6.5–8.5

For the selection of the best membrane module, all the previous configuration parameters were considered. Regarding, the cost of investment and energy consumption between arrangements 4 and 6, the values did not vary significantly. However, the membrane module SWC6-MAX was selected on SWC4-LD, SWC4-MAX and SWC5-MAX because it showed a higher pH level in the permeate which lowers remineralization costs, also presents better removal of TDS and lower investment cost between the four membrane modules compared.

3.3. Production costs per membrane module

The necessary costs to obtain the required drinking water utilizing membrane module SWC6-MAX are shown in Fig. 4.

The lowest rates were obtained with matrices 4 and 6 with a value of 0.49 USD/m^3 each, coinciding with the report of Mancilla [21], it indicates that for a plant with a size of 15,000 to 60,000 m^3/d, the cost of water production is 0.48–1.62 US $/$m^3$.

Table 6
Permeate concentration in the one utilizing membrane SWC5-MAX

Feed water	Concentration mg/L	Array						NOM
		1	2	3	4	5	6	
Ca	340.660	0.530	1.318	0.532	0.546	1.320	1.334	NA
Mg	1,482.540	2.307	5.737	2.315	2.376	5.745	5.806	NA
Na	9,655.800	72.007	94.219	72.250	74.142	94.461	96.349	200
Mn	3.500	0.005	0.014	0.005	0.006	0.014	0.014	0.15
K	289.340	2.696	3.360	2.705	2.775	3.369	3.440	NA
Fe	2.900	0.005	0.011	0.005	0.005	0.011	0.011	0.3
HCO_3	172.460	1.714	2.121	1.719	1.764	2.127	2.172	NA
SO_4	2,767.630	4.241	10.646	4.256	4.367	10.660	10.772	400
Cu	1.460	0.002	0.006	0.002	0.002	0.006	0.006	2
Cl	19,224.540	116.879	161.163	117.274	120.345	161.558	164.622	250
NO_3	0.510	0.023	0.024	0.023	0.024	0.024	0.025	10
F	2.120	0.036	0.041	0.036	0.037	0.040	0.042	1.5
B	10.100	2.976	2.992	2.978	3.036	2.995	3.052	2.4
CO_3	19.536	0.000	0.012	0.000	0.000	0.012	0.012	NA
TDS	33,973.000	203.420	281.660	204.100	209.430	282.340	287.660	1,000
pH	8.040	5.200	5.300	5.200	5.200	5.300	5.300	6.5–8.5

Table 7
Permeate concentration in the one utilizing membrane SWC6-MAX

Feed	Concentration mg/L	Array						NOM
		1	2	3	4	5	6	
Ca	340.660	0.885	1.155	0.887	0.0911	1.157	1.181	NA
Mg	1,482.540	3.854	5.026	3.860	3.966	5.035	5.141	NA
Na	9,655.800	120.091	127.665	120.365	123.649	127.938	131.219	200
Mn	3.500	0.009	0.012	0.009	0.009	0.012	0.012	0.15
K	289.340	4.495	4.721	4.505	4.627	4.731	4.853	NA
Fe	2.900	0.008	0.010	0.008	0.008	0.010	0.010	0.3
HCO_3	172.460	3.254	3.404	3.260	3.346	3.410	3.496	NA
SO_4	2,767.630	7.067	9.259	7.083	7.278	9.276	9.470	400
Cu	1.460	0.004	.005	0.004	0.004	0.005	0.005	2
Cl	19,224.540	194.726	209.840	195.170	200.497	210.284	215.606	250
NO_3	0.510	0.038	0.038	0.038	0.039	0.039	0.040	10
F	2.120	0.059	0.061	0.059	0.061	0.061	0.063	1.5
B	10.100	2.731	2.735	2.788	2.798	2.834	2.784	2.4
CO_3	19.536	0.000	0.016	0.000	0.000	0.016	0.016	NA
TDS	33,973.000	339.320	366.050	340.140	349.280	366.860	376.000	1,000
pH	8.04	5.70	5.70	5.70	5.70	5.70	5.80	6.5–8.5

The decrease of the total amount was probably the result of better use of pressure of the same system by using the ERD. In all the arrays, the energy cost was found from 55% to 72% of the total cost, which agreed greatly with that reported by Alghoul et al. [26], who described that energy consumption value varied from 45% to 60%. Array 6 was selected over the rest because it showed the lowest energy demand and the best TDS removal.

3.4. Optimum design

The optimum design was composed by membrane modules SWC6-MAX, utilizing a permeate mix and ERD array (Fig. 5).

The parameters measured during the reverse osmosis process are shown in Table 8.

The final design that includes the pre-treatment, treatment and post-treatment stages is shown in Fig. 6.

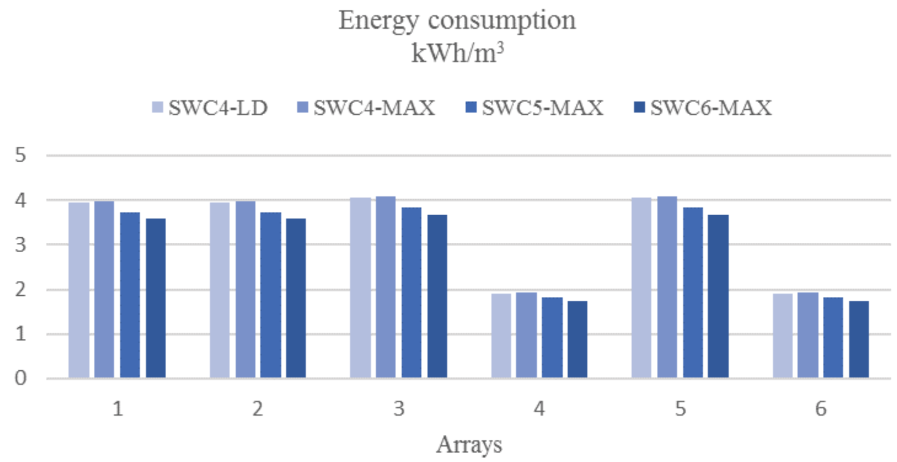

Fig. 3. Energy consumption per m^3 in the different arrays utilizing the four membrane modules to compare existing demand.

Table 8
Operation parameters in each stage of the optimum design of the desalination system

	Caudal m^3/d	Pressure psi	TDS mg/L	pH	Electrical conductivity µs/cm
1	84,024	0.00	33,979	8.04	53,193
2	150	0.00	33,979	8.04	53,193
3	83,856	0.00	33,979	8.04	53,193
4	38,184	0.00	33,978	7.00	53,198
5	38,184	767.25	33,978	7.00	53,198
6	83,856	767.25	34,938	7.00	54,615
7	46,128	754.20	63,368	7.24	95,887
8	46,128	0.00	61,605	7.24	93,357
9	45,672	0.00	33,978	7.00	53,198
10	45,672	767.25	35,741	7.00	55,798
11	37,728	0.00	168	5.07	318
12	37,896	0.00	301	5.20	615
13	37,896	0.00	324	6.50	644

The letters P, F, C and pH indicate places where the variables of pressure, flow, permeate concentration and pH are, respectively, monitored.

This design had 2,838 membrane modules distributed in 473 pipes with six membrane modules each one, achieving a conversion of 45% similar to that of Ras Abu Fontas A3 plant, located in Qatar, with a conversion from 42% to 45% [26]. The desalination plant for Puerto Peñasco shall operate at a pressure of 767.25 psi, similar to that of Blue Hills SWRO plant in Bahamas, which operates at 820.91 psi [26]. On the other hand, the demand of 37,743 m^3/d shall be covered with water quality that complies with the permissible limits established by the Mexican Norm (NOM-0127-SSA1-1994; Table 9).

The analysis of feed and permeate concentration in water showed that the desalination plant design was efficient with respect to salt removal (99.18%); the values obtained in the removal process of reverse osmosis agreed with that reported by Kucera [17] and Dévora Isiordia et al. [15].

The optimum design proposed for the desalination plant of Puerto Peñasco had a projected cost of $39,057,890 USD. The evaluation of the process showed that water production cost with permeate mix and ERD was of $0.49 USD/$m^3$ with an energy demand of 1.91 kWh/m^3. In contrast with the reported in the binational project of desalination technology in the Arizona-Sonora, for a plant with a projection of 43,200 m^3/d for the year 2020, a water production cost will be of $2.29 USD/$m^3$ [24] and as reported by the National Research Council (NRC) in 2008 [27], this seawater desalination process will require of 3.4 to 4.5 kWh/m^3. It is evident that in the management of desalination projects, before adopting the technology as a solution, measures of conservation and storage of surface water and rain should be guaranteed, establish limits of urban growth and therefore of water consumption. It is necessary to establish fair price schemes and the incorporation of renewable energies such as solar to reduce social and environmental risk.

3.5. Post-treatment

The post-treatment was performed with the purpose of controlling pH levels with $NaHCO_3$ to increase them and

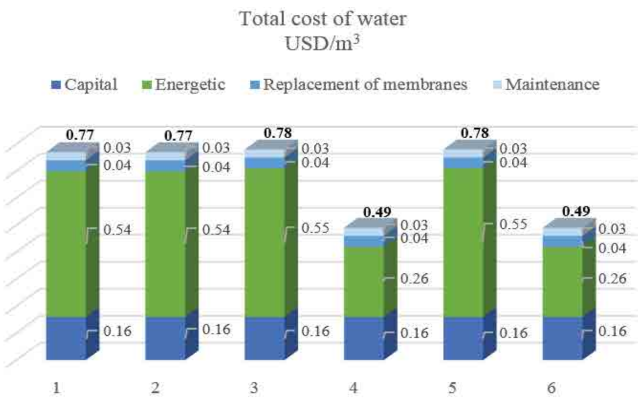

Fig. 4. Total water cost, membrane module SWC6-MAX.

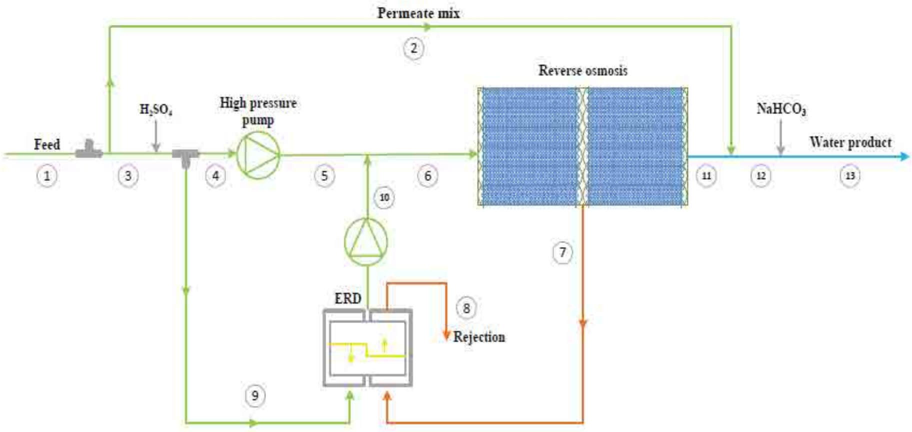

Fig. 5. Optimum array: mix of permeate with ERD utilizing membrane module SWC6-MAX that showed the best conditions of cost and production.

Table 9
Removal percentage in physical–chemical parameters in the optimum array compared with the Mexican Norm and literature

Feed	Concentration mg/L	Array 6	NOM	Removal %	Reference [15]%
Ca	340.660	1.181	NA	99.65	93–99
Mg	1,482.540	5.141	NA	99.65	93–98
Na	9,655.800	131.219	200	98.64	92–98
Mn	3.500	0.012	0.15	99.66	96–98
K	289.340	4.853	NA	98.32	92–96
Fe	2.900	0.010	0.3	99.66	96–98
HCO_3	172.460	3.496	NA	97.97	96–99
SO_4	2,767.630	9.470	400	99.66	96–99
Cu	1.460	0.005	2	99.66	96–99
Cl	19,224.540	215.606	250	98.88	92–98
NO_3	0.510	0.040	10	92.16	–
F	2.120	0.063	1.5	97.03	81.67
B	10.100	4.884	2.4	51.64	30–50
CO_3	19.536	0.016	NA	99.92	–
TDS	33,973.000	376.000	6.5–8.5	99.89	–

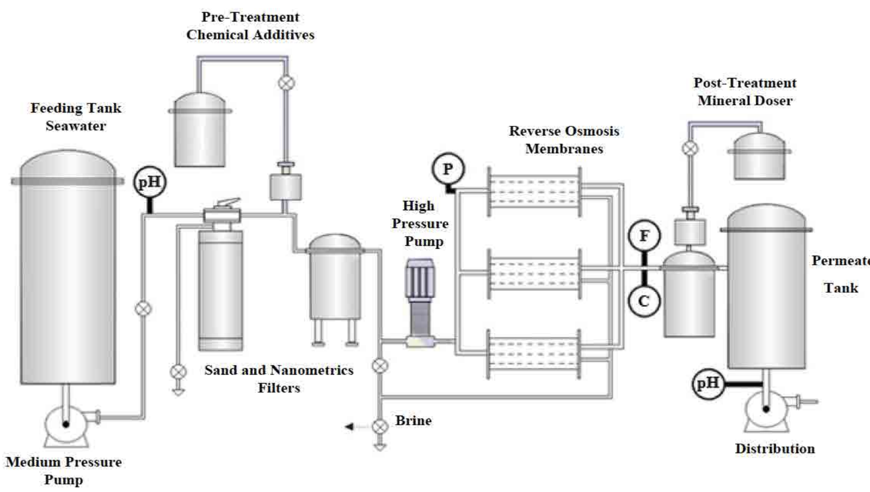

Fig. 6. Final design of a reverse osmosis plant, with pre-treatment and post-treatment.

Table 10
Saturation of salts precipitated and Langelier index to measure corrosivity and incrustation in membrane modules

Saturations			
TDS calculated (mg/L)	372.9	$CaSO_{4(\%)}$	0.01
Osmotic pressure (psi)	3.91	$BaSO_{4(\%)}$	0.00
$Ca_3(PO_4)_2$ SI	0.00	$SrSO_{4(\%)}$	0.00
CCPP (mg/L)	–19.01	$CaF_{2(\%)}$	0.00
Langelier SI	–2.52	$Silica_{(\%)}$	0.00

CO_2 to decrease them as required, such as the desalination plant located in Al Ghalila, Ras Al Khaimah with a capacity of 68,130 m^3/d, utilizing CO_2 in pH regulation [28]. The corresponding saturations are shown in Table 10.

The Langelier saturation index was used in water stabilization to control corrosion; a value of –2.52 indicated that water showed a very slight tendency to incrustation according to that reported by Correa [16], in which a value of –2 did not show incrustations.

4. Conclusion

The objective of this study was achieved by obtaining an optimal design for a proposed desalination plant for the city of Puerto Peñasco, Sonora, Mexico. With the simulation tool, the variety of existing arrangements is made clear. This design was based on the use of the membrane module SWC6-MAX with a mixture of permeate and an ERD matrix because it showed lower energy demand and lower investment cost. In addition, it met the parameters established in the Mexican Standard and the WHO. The selected optimal design showed the lowest production cost of \$0.49 USD/m^3, an investment cost of \$39,057,890 USD and an energy demand of 1.91 kWh/m^3 of permeated water. In desalination, it is necessary to establish fair price schemes and the incorporation of renewable energies such as solar to reduce social and environmental risk. In conclusion, using the IMSDesign simulator in the design of the desalination system, results are obtained that can be a starting point in future projects that will ensure that the population of Puerto Peñazco obtains the quality of water it needs in a projection until the year 2040. Water resource for economic development and quality water coverage for basic activities.

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