REVERSE OSMOSIS DESALINATION PLANT IN NUWEIBA CITY (CASE STUDY)

Berge Djebedjian [*], Helmy Gad [*], Ibrahim Khaled [**] and Magdy Abou Rayan [*]

[*] Mechanical Power Engineering Department, Faculty of Engineering, Mansoura University, El-Mansoura 35516, Egypt
E-mail: bergedje@mans.edu.eg , he_gad@yahoo.com , mrayan@mans.edu.eg
[**] Sinai Development Authority, Egypt

ABSTRACT

Due to the continuously increasing demand of fresh water in the desert and remote areas, the development of non-conventional water resources in Egypt is essential. The most advanced and charming desalination system is the reverse osmosis (RO) system. In this paper, a 5000 m^3/day RO desalination plant in Nuweiba City in Sinai, Egypt is taken as a case study. The measured data of the plant are recorded during 5 years of its normal operation. Also, experimental tests are carried out in site to investigate the influence of the main design and operating parameters on the plant performance. The RO system is found to be sensitive to the variation in the feed water temperature, pressure and salinity. The used maintenance schedule is also seen to be suitable for the plant, since the change in plant performance during the operation period is not noticeable. On the other hand, a cost analysis is carried out on the RO plant components. The major factors affecting the product water cost of this plant are the capital cost and power consumption. Surprisingly, the chemical treatment cost is one of the lowest in percentage. In this case, the power consumption cost is 35% and capital cost is 33.6% and that of maintenance and repairs represent only 5% while the chemical treatment represents 10% of the total cost.

Keywords: Desalination, RO reverse osmosis plant, Case study.

INTRODUCTION

Desalination is a process removing dissolved minerals from the saline water. Many technologies have been developed for the sea and brackish water desalination, including thermal, reverse osmosis (RO), electrodialysis and vapor compression systems. The most common and widely used process is the reverse osmosis. All desalination processes involve three liquid streams; the saline feed water, low-salinity product water (permeate), and the very saline concentrate (brine). The RO plants produce water with salinity from 10 to 500 ppm TDS. The market share of RO desalination systems has significantly increased in recent years due to the progress in membrane technology.

The RO desalination plant consists of four major systems: pretreatment system, high-pressure pumps, membrane systems, and post-treatment. Pre-treatment system removes all suspended solids to keep salt precipitation and microbial growth minimum on the membranes. Pre-treatment involves chemical feed followed by coagulation, flocculation, sedimentation and sand filtration. Micro filtration and ultra filtration may also be used. High-pressure pumps supply the pressure needed to enable the water to pass through the membrane and have the salt rejected. The reverse pressure ranges from 17 to 27 bar for brackish water, and from 52 to 69 bar for seawater. RO membranes are two types; spiral wound and hollow fiber. Spiral wound elements are actually constructed from flat sheet membranes. In the hollow fiber design, a large number of hollow fiber membranes are placed in a pressure vessel. This type is not widely used like the spiral wound membranes for desalination. The post-treatment is often employed to ensure meeting the health standards for drinking water as well as recommended aesthetic and anti-corrosive standards. Post-treatment consists of stabilizing the water (adjusting the pH and disinfection) and preparing it for distribution.

The major parameters affecting the RO plant performance are the feed water temperature, pressure and salinity. The membrane compaction, fouling and maintenance also affect membrane performance. The influence of operating parameters on the RO plant performance has taken much attention from researchers [1-5]. The RO desalination system has also subjected to extensive theoretical work [6-8]. Numerical results have also shown the effects of operating conditions and concluded that increasing the operating pressure and feed flow will generally lead to higher water recoveries and salt rejection. However, increasing the pressure beyond a certain maximum value led to the deterioration of the quality of the product water.

Hafez and El-Manharawy [9] presented a techno-economic study to estimate the fixed and operating costs of five seawater RO plants of 250, 500, 2000, 3500 and 4800 m^3/d in Egypt. They found that the production cost resulted from small seawater RO desalination plants is much higher than the world cost. The study indicated that the economic larger seawater RO desalination capacity (>20,000 m^3/d) should be considered during the development strategy and planning of the new tourist projects.

Abou Rayan and Khaled [10] presented a case study of the operation and maintenance of a 2000 m^3/d RO desalination plant over 6 years of operation. They concluded that the reverse osmosis system is sensible to changes in feed water temperature, and the product quality is sensitive to the change in feed water pressure. Djebedjian et al. [11] carried out an extensive experimental work to study the effect of the same parameters (feed water pressure, temperature and salinity) on the performance of RO element.

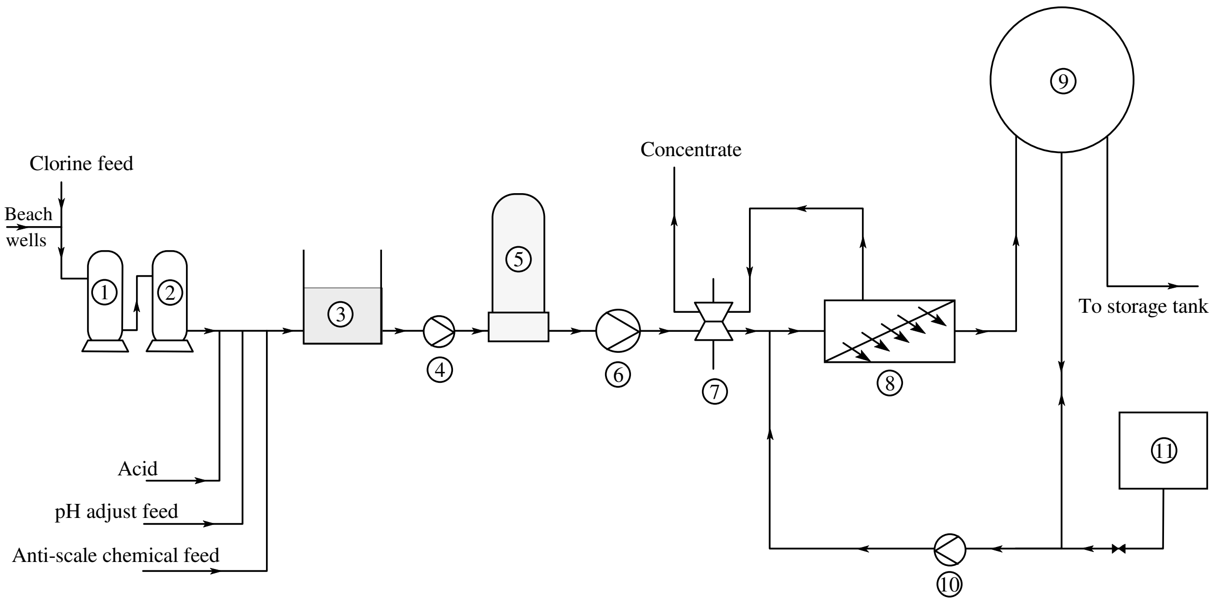
From the preceding review, it is clear that more experimental work is needed for more precise evaluation of the system performance. The present case study is carried out to study the influence of main design and operating parameters on the RO plant performance. The considered plant has been constructed at Nuweiba City in south Sinai, Egypt and started the actual production on August 2001. The system is conceived in such manner to conserve energy. The energy rejected from the discharged brine is recovered in the recovery turbine. The required electrical power for the plant is supplied from the local electrical power network. The saline water is supplied from 8 beach wells near the coast of Aqaba Gulf. The salinity of feed sea water is in the order of 44000 ppm. The plant consists of 5 units; each has a capacity of 1000 m^3/day. The following objectives are also studied:

1. The cost analysis of the RO plant.
2. The evaluation of the overall system reliability for long-term automatic operation for a certain maintenance procedure.

The plant is still working under continuous operation without any significant operational problems.

EXPERIMENTAL PROCEDURE

The plant consists of the following main systems; the intake, the raw water pretreatment unit and cartridge filters, the RO membrane unit and the post treatment system as illustrated in Fig. 1. The beach wells are constructed according to standards, and are equipped with submersible pumps. The depth of the well is about 100 meters. A 10" diameter PVC pipe is introduced in the bore hole.



1- Sand filter	2- Carbon filter	3- Raw water tank
4- Feed pump	5- Cartridge filter	6- H. P. pump
7- Turbocharger	8- RO membrane	9- Aerated tank
10- Flushing pump	11- Chemicals tank	

Figure 1. A schematic diagram of RO desalination plant in Nuweiba City

Saline water is pumped from the beach wells through the deep well pumps to a PVC header and then to the sand filters (activated carbon filters) as shown in Fig. 1. During this process, the water is sterilized to prevent the growth of bacteria and algae. Activated carbon (AC) filtration is most effective in removing organic contaminants from saline water. AC filtration is recognized by the Water Quality Association (WQA) as an acceptable method to maintain drinking water contaminants within the limits of the Environmental Protection Agency (EPA) and national drinking water standards.

Under normal circumstances when shutdown occurs, the permeate pumps will start and flush out the sea water from the membranes. The system has been designed so that only one unit of the plant can be cleaned at a time. Recirculation of the cleaning fluids is handled by only one chemical cleaning pump. Post treatment of the product water consists of chlorinating to allow chlorine residual and pH adjustment within the acceptable range of 7.5 to 8.5 ppm. The plant is provided with one cartridge filter which ensure that particles larger than 5 microns, carried over from the dual media filters will not enter the membranes. This filter is constructed from stainless steel for total corrosion resistance.

The hydraulic turbocharger is a turbine mounted on a common shaft with a centrifugal pump. The turbine recovers and uses the hydraulic energy from the high pressure brine to drive the integral centrifugal pump. The pump impeller boosts the pressure of the feed stream. The pump-turbine root is free to seek its own speed of rotation.

The membranes stainless steel skid consists of 15 vessels; each one contains 5 elements of membranes of spiral wound type. The membrane is only a skin of about 0.0025 mm thick. The membranes are rather porous plastic with active chemical sites. Its permeability is affected by water chemical contents, temperature, pressure and salinity. The pressure required to operate the RO plant in Nuweiba City is 60-70 bar.

During the normal operation of the RO plant, the following data have been recorded daily from 2001 up to now:

1- The pressure before and after each filter, pump, turbocharger and RO element.
2- Temperature before and after each RO element.
3- Thermal conductivity before and after each RO element. Salinity of a stream is calculated from the measured thermal conductivity.
4- The mass flow rate of both the product water and brine.

On the other hand, site experimental work has been carried out on one RO unit of the plant to study the effect of feed water temperature, pressure and salinity on the productivity of the unit. The change in the salinity of feed water was carried out by adding product water to the feed saline water. The pressure of the feed water was changed by the pump and by passing the feed water. To study the effect of temperature of the feed water, tests are carried out during different times of the year with different ambient temperatures. The product mass flow rate, pressure and temperature are measured by the same instrumentation attached to the RO desalination plant.

RESULTS AND DISCUSSION

To study the effect of a certain parameter on the system performance, other parameters are kept constant during the experimental work. Results of the site experimental work that explain the influence of the main operating parameters are graphically depicted in Figures 2 to 6. The effect of the feed water pressure on the productivity is shown on Fig. 2 at a feed water temperature 28°C and salinity 44000 ppm. The productivity increases as the feed pressure increases. The productivity is expressed as a percentage of the nominal value of the unit (1000 m^3/day or 41.67 m^3/hr). The productivity increases from 7.2 to 124.8 % corresponding to an increase in the feed pressure from 41.37 to 72.4 bar respectively. The relation is almost linear between the feed pressure and the productivity.

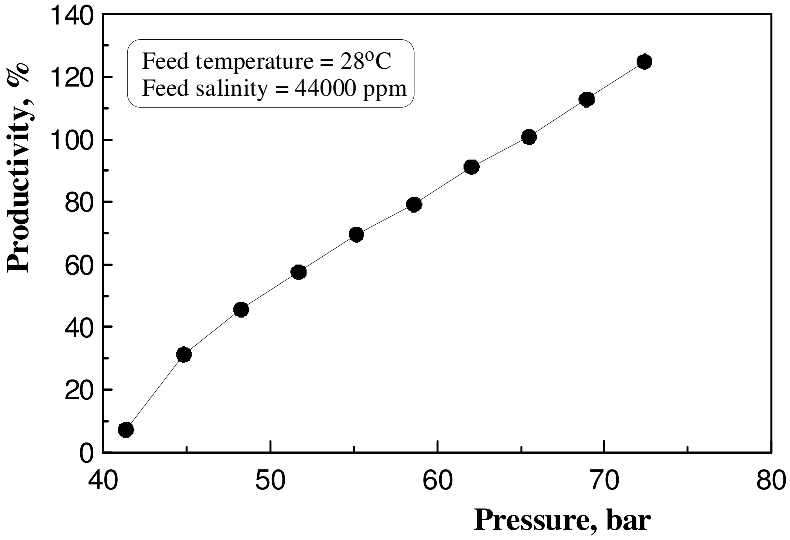


Figure 2. Effect of feed water pressure on the productivity

Figure 3 shows the effect of feed water temperature on the productivity of the RO plant. The results of this experiment are taken at different times of the year to obtain different values of feed water temperatures. It is clear from the figure that the productivity percent increases also linearly with increasing the feed water temperature. The productivity increases from 74.4 to 112.8% corresponding to an increase in the feed temperature from 10 to 32°C respectively, at a feed pressure of 63 bar. Therefore, in hot and arid zone, where water temperature is high, the RO productivity can be increased which resulted in low power consumption and cost.

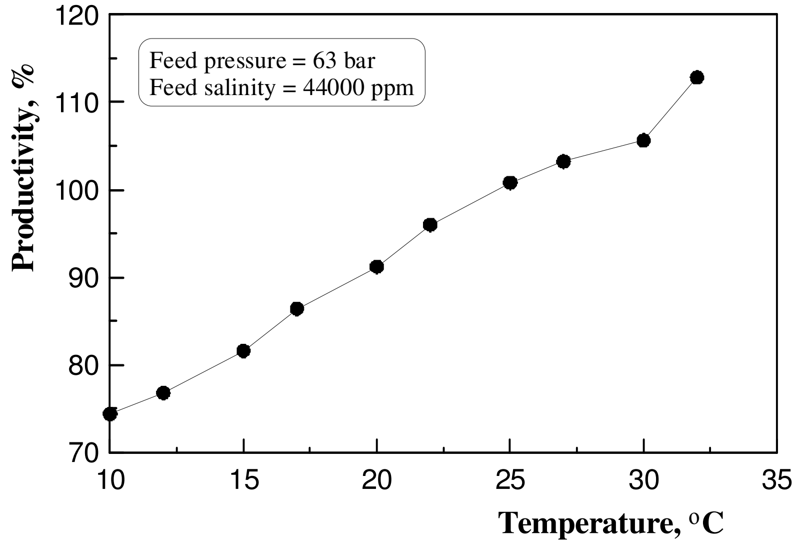


Figure 3. Effect of feed water temperature on the productivity

Increasing the feed water pressure reduces the product water salinity as shown in Fig. 4. The product salinity decreases from 1500 to 300 ppm corresponding to an increase in the feed pressure from 41.37 to 72.4 bar respectively, at a feed water temperature 28°C and an average feed water salinity of 44000 ppm. The decrease in the product salinity is seen to be rapid when the feed pressure decreases down to 50 bar. At larger feed pressures, the decrease in the product salinity is much slower.

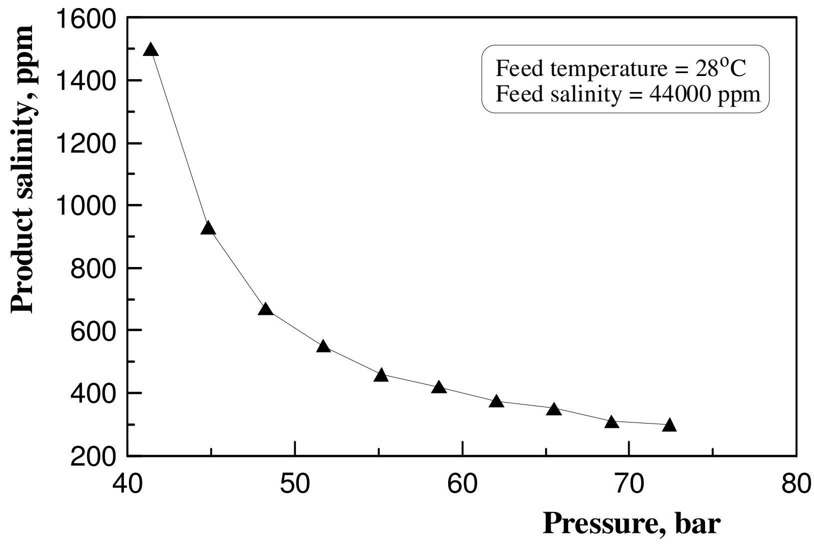


Figure 4. Effect of feed water pressure on product water salinity

The salinity of feed water has a significant influence on the productivity of the RO plant. As the feed water salinity increases, the productivity of the plant decreases as shown in Fig. 5. The plant productivity decreases from 120 to 100.8% as the feed water salinity increases from 15000 to 45000 ppm respectively.

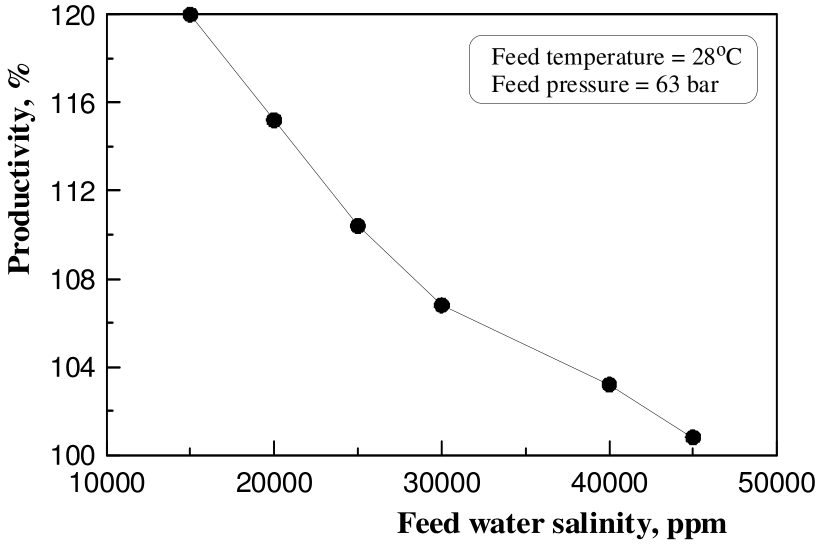


Figure 5. Effect of feed water salinity on the productivity

The salinity of feed water affects also the salinity of the product water as shown in Fig. 6. The salinity of product water increases by increasing the salinity of the feed water. The salinity of feed water increases from 67 to 350 ppm corresponding to an increase in the feed water salinity from 15000 to 45000 ppm respectively. This experiment is carried out at a feed pressure 63 bar and feed water temperature of 28°C.

The above readings are taken during 24 hours with one hour interval on the first day of each month. The daily average values of the measured data are calculated for testing the performance of each component and detect any changes of the plant performance. The recorded data during the years 2002 and 2005 are shown in Appendix A. The measured data are recorded from the attached instruments to the plant. Therefore, the pressure is recorded as psi.

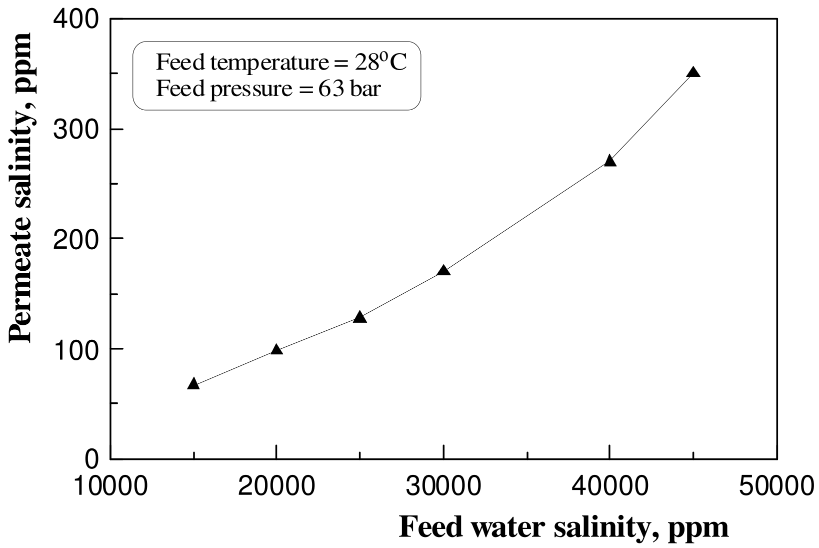


Figure 6. Effect of feed water salinity on the product salinity

Economical Analysis

In order to evaluate precisely the RO process, an economical analysis is important. The analysis is made for one unit (1000 m^3/day). In addition to the capital cost, the major factors that influence the cost are the power consumption, running and maintenance costs.

A- Power consumption cost

Using power from local power network (Price of one kWh is 0.22 LE); the following individual power consumption for each component of the plant is recorded and illustrated in Table 1.

Table 1 Energy requirements

Pump	Power (kW)	kWh/m^3
Sea water pump	18	0.432
Filter pump	18	0.432
Additive pumps	1	0.024
Product pump	3	0.072
RO HP pump	285	6.84
Total	325	7.80

Power cost for one m^3 product water = 7.8 x 0.22 = 1.716 LE/m^3

B- Chemical requirements

Table 2 shows the costs of chemical treatment as an average during the operation period.

Table 2 Chemical cost per m^3 product water

Item	gr/m^3	Cost, LE/m^3
Ca O Cl (Pre + Post)	20	0.03
H Cl (30%)	100	0.08
Anti Scalant	10	0.25
Na O H	80	0.04
Others	-----	0.12
Total	-----	0.52

C- Maintenance and repair

The average cost values of maintenance and repair during the normal operation of the plant are shown in Table 3.

Table 3 Maintenance and repair costs per m^3 product water

Operation Name	Cost, LE/m^3
Cartridge filter	0.03
Pumps and motors	0.08
Controls and electrical, etc.	0.05
Instrument, etc.	0.03
Miscellaneous	0.05
Total	0.24

D- Labor and administration

Labor and administration costs are estimated by 0.50 LE per m^3 product water as an average value.

E- Capital cost

For one unit, the capital cost is estimated by 5,500,000 LE.
Working days = 335 per year
Expected life time = 10 years

$$\text{Capital cost per 1 m}^3 \text{ product water } = \frac{5500000}{10 \times 335 \times 1000} = 1.642 \text{ LE/m}^3$$

F- Cost of wells and plant civil work

Civil work cost per 1 m^3 product water = 0.274 LE/m^3

Total cost per 1 m^3 = 1.716 + 0.520 + 0.240 + 0.500 + 1.642 + 0.274 = 4.892 LE/m^3

From the above cost analysis, it appears that the major factors affecting the product water cost are the capital and power costs as shown in Fig. 7. Surprisingly, the chemical treatment cost is one of the lowest in percentage. This is may be due to the fact that the plant membranes are new and in a good condition.

The RO system is reliable for operation; it does not require any skill operator and simple to install. The only inconvenient is its high operating cost. In this case the high operation cost comes from two items; power cost 35% and capital cost 33.6%. Maintenance and repairs present only 5% and chemical treatment 10%. The high capital cost is due to the well system. Desalination is a high energy consumption process. The energy sharing amounts to 30-50% of total production cost. Due to the rapid progress in sea water reverse osmosis technology, the cost has decreased.

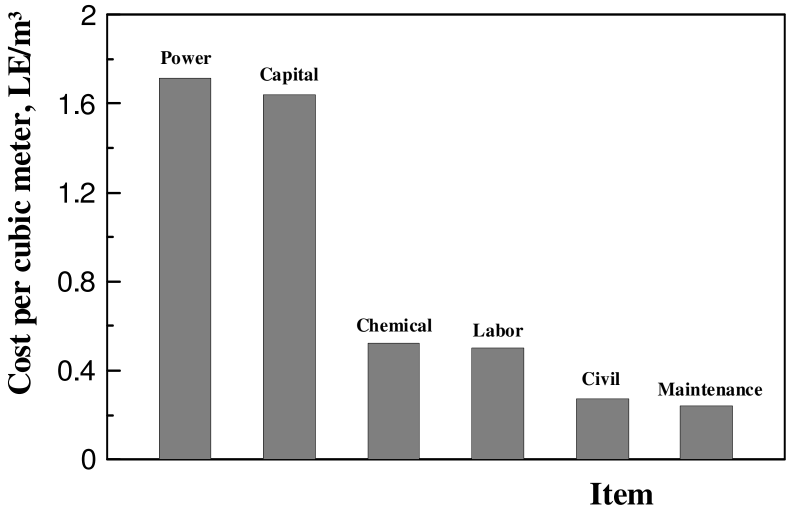


Figure 7. The capital and operation cost of the RO plant

Since all the components are new and satisfy the design conditions, the performance of the new RO desalination plant is very good. The performance of the plant should be kept at the same level during its operation period. The maintenance schedule is known to be very responsible about this issue. A part of this case study is to evaluate the maintenance schedule of the RO plant. Therefore, the maintenance processes are recorded during the operation of the RO plant as shown in Appendix B. This maintenance schedule is strictly applied. Therefore, there is no noticeable change of the plant readings during the period of operation as seen in appendix A.

CONCLUSIONS

Reverse osmosis desalination plant in Nuweiba City in Sinai, Egypt (5000 m^3/day) is taken as a case study. Experimental tests are carried out in site to evaluate the plant performance. The following conclusions are obtained based on 5 years of operation period from 2001 of the RO desalination plant:

1- The RO system is found to be sensitive to the variation in the feed water temperature, pressure and salinity;
   a) Higher feed water temperature increases the plant productivity.
   b) Increasing the feed water pressure increases the plant productivity, but decreases the permeate salinity.
   c) Higher feed water salinity reports lower productivity and higher product water salinity.

2- The used maintenance schedule (for 5 years operation) is seen to be suitable for the plant, since the change in plant performance during the operation period is not noticeable.

3- The cost analysis of the RO plant reveals that the major factors affecting the product water cost are the power consumption cost (35%) and capital cost (33.6%) while the chemical treatment represents 10% of the total cost.

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APPENDIX A

Normal readings of Nuweiba RO plant for years 2002 and 2005

Table 4 Measured data for year 2002

DATE	Sand Filter Pressure (psi)			Cartridge Filter Pressure (psi)			HPP Pr. Out (psi)	Turbo Pr. In (psi)	Membrane Pressure (psi)		Product Water Flow Rate (m^3/h)	Reject Water Flow Rate (m^3/h)	Product Water Conductivity (µ S/cm)
	In	Out	Diff	In	Out	Diff			In	Out			
1/1/2002	7	1	6	38	29	9	700	630	975	935	47	103	764
2/1/2002	11	1	10	38	28	10	700	630	980	940	48	102	765
3/1/2002	11	1	10	38	26	12	700	630	975	935	48	102	770
4/1/2002	11	1	10	38	25	13	700	630	980	940	47	103	771
5/1/2002	7	1	6	38	21	17	690	625	970	930	48	102	775
6/1/2002	11	1	10	38	19	19	690	625	975	940	47	103	779
7/1/2002	7	1	6	38	18	20	690	625	970	930	45	105	780
8/1/2002	7	1	6	38	19	19	695	625	970	930	45	105	785
9/1/2002	12	1	11	38	19	19	690	625	980	935	45	105	790
10/1/2002	12	1	11	38	18	20	690	625	975	935	46	104	798
11/1/2002	11	0	10	38	14	24	690	620	975	935	45	105	810
12/1/2002	12	1	11	38	32	6	705	620	970	930	45	105	770

Table 5 Measured data for year 2005

DATE	Sand Filter Pressure (psi)			Cartridge Filter Pressure (psi)			HPP Pr. Out (psi)	Turbo Pr. In (psi)	Membrane Pressure (psi)		Product Water Flow Rate (m^3/h)	Reject Water Flow Rate (m^3/h)	Product Water Conductivity (µ S/cm)
	In	Out	Diff	In	Out	Diff			In	Out			
1/1/2005	12	0	12	38	33	5	705	615	970	945	47	103	786
2/1/2005	12	1	11	38	33	5	705	625	970	930	48	102	780
3/1/2005	12	1	11	38	33	5	705	620	970	930	48	102	789
4/1/2005	12	0	12	38	33	5	700	620	970	930	49	101	785
5/1/2005	7	0	7	38	32	6	700	625	980	940	48	102	792
6/1/2005	11	0	11	38	32	6	700	630	970	935	47	103	799
7/1/2005	11	1	10	38	32	6	695	625	970	935	46	104	793
8/1/2005	12	1	11	38	31	7	700	625	980	935	46	104	806
9/1/2005	8	1	7	38	30	8	700	620	980	940	46	104	819
10/1/2005	8	0	8	38	29	9	700	625	970	940	46	104	785
11/1/2005	12	0	12	38	27	11	700	625	970	930	45	105	780
12/1/2005	12	1	11	38	25	13	690	620	970	930	45	105	784

APPENDIX B

The maintenance procedure of Nuweiba RO plant

Periodical maintenance for sand filters

No.	Maintenance steps	Daily	Weekly	Monthly	Yearly¼	Yearly½	Yearly
1	Filter body & filter cleaning	x					
2	Checking for leakage	x					
3	Tightening flanges and valves	x					
4	Checking valves	x					
5	Discharging water from sump	x					
6	Checking dosing connections	x					
7	Recording pressure gauges readings	x					
8	Manual back wash		x				
9	Checking leakage in air lines		x				
10	Checking the control panel			x			
11	Checking the auto valves sequence			x			
12	Calibration of pressure transmitters				x		
13	Checking filter media					x	

Periodical maintenance for feed pumps

No.	Maintenance steps	Daily	Weekly	Monthly	Yearly¼	Yearly½	Yearly
1	Dry cleaning for pump body	x					
2	Checking oil & lubrication level	x					
3	Checking (heat-noise-vibration)	x					
4	Checking for leakage	x					
5	Tightening flanges and valves	x					
6	Checking valves	x					
7	Recording motor current	x					
8	Recording pressure gauges readings	x					
9	Checking the control panel		x				
10	Checking the circuit breakers		x				
11	Checking the contactors		x				
12	Checking the motor cable		x				
13	Checking pump parts			x			
14	Checking the motor				x		

Periodical maintenance for cartridge filters area

No.	Maintenance steps	Daily	Weekly	Monthly	Yearly¼	Yearly½	Yearly
1	Dry cleaning pump body	x					
2	Checking the oil and lubrications level	x					
3	Checking for (heat - noise - vibration)	x					
4	Checking for leakage	x					
5	Tightening flanges and valves	x					
6	Checking valves	x					
7	Recording motor current	x					
8	Recording pressure gauges readings	x					
9	Checking the control panel		x				
10	Checking the circuit breakers		x				
11	Checking the contactors		x				
12	Checking the motor cable		x				
13	Checking pump parts			x			
14	Checking the motor				x		

Periodical maintenance for high pressure pumps

No.	Maintenance steps	Daily	Weekly	Monthly	Yearly¼	Yearly½	Yearly
1	Dry cleaning for pump body	x					
2	Greasing the moving parts and bolts	x					
3	Checking for (heat - noise - vibration)	x					
4	Checking for leakage	x					
5	Tightening flanges and valves	x					
6	Checking valves	x					
7	Recording motor current	x					
8	Recording operating hours and stop hours	x					
9	Recording flow and pressure	x					
10	Checking oil level		x				
11	Checking the soft starter			x			
12	Checking the control panel			x			
13	Checking the circuit breakers			x			
14	Checking the contactors			x			
15	Checking the motor cable			x			
16	Checking pump alignment					x	
17	Checking pump parts						x
18	Checking the motor						x

Periodical maintenance for RO units

No.	Maintenance steps	Daily	Weekly	Monthly	Yearly¼	Yearly½	Yearly
1	Cleaning unit area	x					
2	Recording flow, pressure and TDS	x					
3	Recording TDS for each pressure vessel	x					
4	Tightening flanges and valves	x					
5	Checking for leakage	x					
6	Checking for leakage in air lines	x					
7	Checking the auto valves sequence	x					
8	Flushing unit after stop	x					
9	Checking turbine operation	x					
10	Checking turbine parts			x			
11	Calibration of pressure transmitters				x		
12	Calibration of flow transmitters				x		
13	Calibration of conductivity meter				x		
14	Calibration of feed valve				x		
15	Chemical cleaning for units					x	

Periodical maintenance for product tanks

No.	Maintenance steps	Daily	Weekly	Monthly	Yearly¼	Yearly½	Yearly
1	Checking Chlorine and pH + dosing	x					
2	Flushing tanks			x			
3	Cleaning inlet sleeves			x			
4	Taking samples for analysis			x			
5	Chemical cleaning of tanks				x		
6	Calibration of level switches				x		

Periodical maintenance for power panels (MMC)

No.	Maintenance steps	Daily	Weekly	Monthly	Yearly¼	Yearly½	Yearly
1	Dry cleaning for panels	x					
2	Cleaning internal components with air		x				
3	Changing burned led		x				
4	Checking fuses		x				
5	Tightening cables fixation			x			

Periodical maintenance for brine and back wash pumps

No.	Maintenance steps	Daily	Weekly	Monthly	Yearly¼	Yearly½	Yearly
1	Dry cleaning for pump body	x					
2	Checking the oil and lubrications level	x					
3	Checking for (heat - noise - vibration)	x					
4	Checking for leakage	x					
5	Tightening flanges and valves	x					
6	Checking valves	x					
7	Recording motor current	x					
8	Recording operation hours	x					
9	Checking water levels in tanks	x					
10	Discharging water from sump	x					
11	Checking the control panel			x			
12	Checking the circuit breakers			x			
13	Checking the contactors			x			
14	Checking the motor cable			x			
15	Checking pump parts				x		
16	Checking the motor				x		

Periodical maintenance for dosing pumps and tanks

No.	Maintenance steps	Daily	Weekly	Monthly	Yearly¼	Yearly½	Yearly
1	Dry cleaning for pump body	x					
2	Checking tanks levels	x					
3	Checking pumps flow	x					
4	Checking for leakage	x					
5	Checking level switches		x				
6	Cleaning tanks and lines			x			

Periodical maintenance for pumping station

No.	Maintenance steps	Daily	Weekly	Monthly	Yearly¼	Yearly½	Yearly
1	Dry cleaning for pump body	x					
2	Checking the oil and lubrications level	x					
3	Checking for (heat - noise - vibration)	x					
4	Checking for leakage	x					
5	Tightening flanges and valves	x					
6	Checking valves	x					
7	Recording motor current	x					
8	Recording pressure gauges readings	x					
9	Checking city tanks levels	x					
10	Checking storage tanks levels	x					
11	Discharging water from sump	x					
12	Checking the operation of ventilation system	x					
13	Checking the control panel		x				
14	Checking the circuit breakers			x			
15	Checking the contactors			x			
16	Checking the motor cable			x			
17	Checking pump alignment			x			
18	Checking pump parts				x		