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Performance improvement and optimization of 10,000 m^3/day SWRO desalination plant

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Abstract

Desalination of seawater has been considered as one of the most promising techniques for supplying fresh water in Libya. Reverse osmosis (RO) is one of the major technologies for mid and large size desalination plants because it offers a mean of producing high quantity and quality of fresh water from seawater with lower energy consumption than other processes such as evaporation processes. Due to the development of thin film composite membranes and spiral wound element configurations, the paper aims to improve the performance a 10,000 m^3/day Tajoura desalination plant in a manner of reverse osmosis, using three dissimilar software developed by several membrane manufactures. The performance improvement was achieved through high rejection and higher productivity which resulted in better water quality significantly lower energy consumption, and improved system operation (lower fouling, higher recovery with less number of membranes).

Keywords: Exergy analysis; reverse osmosis; membranes; pressure exchanger.

1. Introduction

Reverse osmosis technique were used as a water desalination choice in Libya about thirty years ago, this technique has seen a steady growth rate of almost constant during the last two decades, Figure 1.1 shows the cumulative capacities of reverse osmosis plants in Libya until the year 2004 [1]. Due to increased demand for water in Libya and the fast developments of a reverse osmosis technology, it has led to increased demand of this technology locally and broadly. Furthermore identifying the future needs for desalination technology development, as well as a research and development activities that will result in cost-effective, efficient desalination technologies that can meet the future needs. In this research the plant will be redesigned with low energy membranes for either lowering the operating cost or reducing the energy consumption. Consequently, decrease membrane replacement cost of the next membrane replacement with a result of higher productivity at lower operating fluxes, and energy consumption.

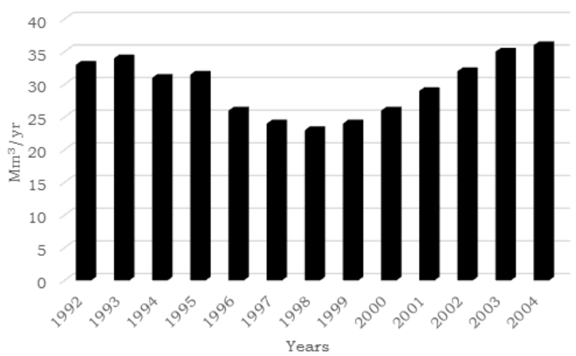

Figure 1.1: Installed capacities of reverse osmosis technology in Libya

2. Tajoura Reverse osmosis plant

Tajoura seawater desalination plant shown in Figure 2.1 is the biggest operating reverse osmosis plant in Libya. The plant is located at Tajoura on the Mediterranean coast about 30 kms east of Tripoli. The plant was designed to produce 10,000 m^3/day of potable water with a salinity of less than 500 milligram per liter (ppm) on continuous basis (365 days per year). The purpose of the plant is mainly to supply Nuclear Research Center (NRC) with industrial and drinking water and to supply Tajoura city with the surplus water in access to (NRC) needs. It utilized a double pass of spiral wound polyamide membranes. The first pass utilized polyamide membranes to desalt seawater and the second pass is used further to desalt the product of the first stage.

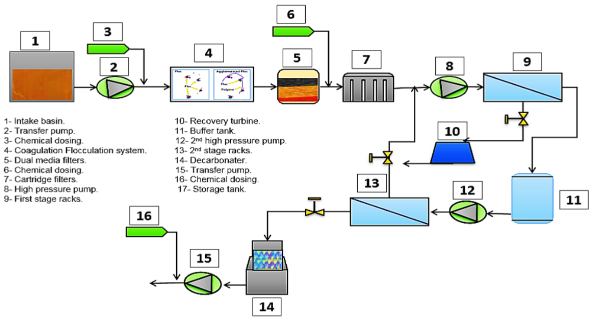

Figure 2.1: Schematic diagram of the SWRO desalination plant.

The Tajoura SWRO desalination plant with design parameters shown on Table 2.1, where seawater intake head is installed at a distance of 1,300 m into the sea 7 m below the sea level and 6 m above the sea bottom. From the intake head sea water by gravity through two 760 mm diameter plastic pipes to its destination into 5,580 m^3 basin at the seashore. From the basin 750 m^3/hr (1,500 m^3/hr for 100% operation) are pumped to the pretreatment section. The pretreatment consists of an online coagulation-flocculation, 8-media filters and 5 µm cartridge filters. Four chemicals are injected before the water enters the online coagulation. These are sulphuric acid for pH control, Copper sulphate for disinfection, sodium hydrogen sulphite for dechlorination and ferric chloride sulphate for flocculation.

The media filters are composed of three layers; sand in the lower part, gravel at the middle, and Anthracite at the top, before that the water is admitted to the 5 µm filters, sulphuric acid and antiscalant are injected to prevent scaling of the membranes by $CaCO_3$ and $CaSO_4$. From the pretreatment section, feed water is fed to the RO section. The RO system consists of two stages.

The first stage consists of four racks each having a high pressure pump. Seawater leaving the cartridge filters is fed to four first stage racks of RO system, by means of four high pressure pumps coupled to a recovery turbine to recover about 30% of its energy requirement from the high pressure concentrate stream. The system can be operated with either two racks 50% or four racks 100% of the total capacity with 35 % recovery of product water. Product of the first stage is collected in two interconnected buffer tanks. The water from the buffer tank is fed to two racks of a second stage by mean of two high-pressure pumps (for 50% operation one rack is operated).

The first stage desalted water is recovered by 85% using the second pass and collected in an intermediate tank for further post treatment. The concentrate from the second stage is recycled back and mixed with the feed to the first stage after cartridge filter. The product water will go through a decarbonator to remove carbon dioxide, and before delivery to the storage tank water is treated for pH adjustment by sodium hydroxide and chlorination by calcium hypochlorite.

Since 1999 the installed membranes in the four first stages racks can convert sea water directly to potable water in the range of 500 ppm. The second pass is operated only when high purity industrial water with 170 ppm is needed [2].

3. A proposed alternative design

Three different membranes of low energy consumption were tested to validate high rejection and low energy consumption for Tajoura SWRO plant, the membranes and the suppliers related to are listed below:

- DOW Filmtec (SW30HRLE-440i) ;
- Toray and (TM820L-400);
- Hydranautics (SWC5).

Using different design programs developed by the membrane manufacturers for redesigning Tajoura SWRO plant, a permeate salinity goal of less than 500 mg/L was achieved for all the suggested membranes. Table 3.1 presents a comparison between the three different membranes recommended.

Table 2.1: The major design parameters of Tajoura desalination plant

Item	First stage	Second stage
Number of RO racks	4	2
Pressure vessels configuration	1 stage	3 stages (24-12-6)
Number of pressure vessels	396	84
Number of membranes	2376	504
Number of membranes per pressure vessel	6	6
Nominal diameter, inch	8	8
Membrane model	TFC 1501 PA	TFC 8600 PA
Design pressure, bar	69	41
Working pressure, bar	54	31
pH	5–6	5–6
Maximum temperature,°C	45	45
Feed flow, m^3/h	1,576	552
Permeate flow, m^3/h	552	426
Concentrate flow, m^3/h	1,024	84
Design salt rejection, %	98.6	98
Recovery, %	35	85
Permeate salinity, mg/L	1,940	170
Feed salinity, mg/L	36,204	1,940

Table 3.1: Comparison between modern membranes and the installed one

Company Name	Koch	DOW Filmtec	Toray	Hydranautics
Design software used		ROSA	TorayDS	IMS design
Pressure vessels configuration	1 stage	1 stage	1 stage	1 stage
Number of pressure vessels	369	284	284	284
Number of membranes	2,376	1,704	1,704	1,704
Number of membranes per pressure vessel	6	6	6	6
Nominal diameter, inch	8	8	8	8
Membrane model	TFC 1501 PA	SW30HRLE-440i	TM820L-400	SWC5
Max. operating pressure, bar	69	83	83	83
Working pressure, bar	55	44.49	43.4	47.3
pH	8	8	8	8
Maximum temperature,°C	45	45	45	45
Feed flow, m^3/h	15,76	1,577.14	1,577.14	1,577.3
Permeate flow, m^3/h	552	552	552	552.1
Concentrate flow, m^3/h	1,024	1,025.14	1,025.14	1,025.3
Design salt rejection, %	98.6	99.7	99.8	99.8
Recovery, %	35	35	35	35
Permeate salinity, mg/L	1,940	160.06	310.7	289.8
Feed salinity, mg/L	36,204	36,225.84	36,203.9	36,213.3

4. Results and discussions

DOW Filmtec (SW30HRLE-440i) was selected as candidate membrane for the next membrane replacement for the following reasons:

- The permeate salinity is 160.06 ppm which was half of the produced by the other membrane types at the same time the need for the second pass can be eliminated because the permeate produced by the second pass with salinity of 170 ppm.
- The number of the membrane elements of the first stage were decreased from 396 to 284, which will decrease the cost of the next membrane replacement as well.
- The area of the first stage racks will be decreased which can be used for other purposes such as plant extension for the extra pressure vessels and increase the ventilated area for the workers and the other equipment's such as pumps and electrical valves assuming the plant working 24 hours per day, and the gases emitted from the chemicals used as well.
- Decreasing the number of throwing away membranes at the end of the recommended life period, as far as the problem of disposing still point of research for the water desalination centres.
- Where the feed pressure for high pressure pump was 54 bar and the recommended 44.49 bar according to that the product capacity can be increased from 552 m^3/hr to 1,399.99 m^3/hr with feed pressure 54.13 bar and specific energy consumption without energy recovery device is 5.96 kW/m^3 by installing the membrane elements to the remaining 112 pressure vessels.

5. Conclusion

The suggested development design for Tajoura SW-RO desalination plant will result in a significant decrease in the number of pressure vessels used which means less number of membrane elements and lower membrane replacement cost can be achieved. Moreover, important reduction in the energy consumption and feed pressure. Thus, less size of high pressure pump HPP could be suggested. The second pass of the plant can be used for increasing the production capacity of the plant with a minor changing in the piping system with no power is needed to operate the alternative design and no need for changing the HPP as well. Furthermore, the proposed plan for the next membrane replacement has shown that an annual savings of about 178,438.87 Libyan Dinar/yr can be achieved, it seems to be no doubt that the proposed design will improve the performance of the plant. The most important reason is the current used membranes have not been replaced with developed membranes with high rejection rate and lower energy consumption.

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