New Shuqaiq SWRO Desalination Plant with Advance BWRO Process

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Abstract

Mitsubishi Heavy Industries, Ltd. has received a full-turnkey order for the construction of a heavy crude oil-fired thermal power generation and desalination plant in Shuqaiq, Saudi Arabia. The order was placed by the Shuqaiq Water and Electricity Company (SqWEC). The construction work will get under way from coming June and commercial operation is scheduled to begin by the end of April 2010. In this project, seawater reverse osmosis (SWRO) process is adopted for desalination plant, which will have capacity to produce 212,000 m^3/d of desalinated drinking water. In this plant, chloride concentration has to be reduced to less than 18 mg/l for the prevention of the piping corrosion, and also the boron concentration to 0.5 mg/l maximum to follow the recent modifications in WHO guidelines for boron limits in treated water. These are challenging values for SWRO desalination plant.

To achieve these values, Mitsubishi Heavy Industries, Ltd., which is the EPC contractor of this group, proposed the advanced two-step RO process. In this process, part of the permeate of 2^{nd} step process (BWRO process) is circulated. This process has been demonstrated successfully in the small plant located at Dukhan, Qatar, and even in Shuqaiq plant, RO design calculator demonstrated the significant results. This calculation showed that chloride concentration could be reduced to less than 10 mg/l and boron concentration to less than 0.4 mg/l using this advanced process.

This paper will introduce this process and present the results of study for adopting the process to Shuqaiq desalination plant. Also, the economical advantage of the process will be explained.

I. INTRODUCTION

Mitsubishi Heavy Industries, Ltd. received a full-turnkey order for Shuqaiq Phase-Ⅱ Independent Water and Power Project (IWPP). The order was placed by the Shuqaiq Water and Electricity Company (SqWEC). SqWEC, the special-purpose company (SPC) composed of Public Investment Fund (PIF), Saudi Electricity Company (SEC) and the consortium established by ACWA power, Mitsubishi Corporation and Gulf Investment Corporation (GIC), will supply electricity and water to Water & Electricity LCC (WEC) of Saudi Arabia over an extended period of time. WEC is an equally owned joint venture between Saline Water Conversion Corporation (SWCC) of Saudi Arabia and SEC. The SPC and WEC signed Power and Water Purchase Agreement (PWPA) to supply water and power to WEC for 20 years, and based on it, the SPC will build the power generation and desalination plant in order to achieve the project goals. In this project, MHI will be in charge of plant engineering, manufacturing, construction, installation and commissioning.

Shuqaiq Phase-Ⅱ IWPP located on the southwestern coast of Saudi Arabia and will supply water and power to the cities of Abha, Jizan and surrounding area, which is a region that has been subject to recent water and power shortages. The 1,020 MW power plant will consist of three 340 MW steam turbines, heavy crude oil-fired boilers and generators. The seawater reverse osmosis (SWRO) plant will have capacity to produce 212,000 m^3/d of desalinated drinking water.

SWRO plant reduces dissolved salt content in seawater to drinking water level by filtering feed water through double pass of RO membrane. This paper will describe the specification of the seawater desalination plant and overall RO process adopted to this project. Especially, the advanced process BWRO (Brackish Water Reverse Osmosis) will be present in detail.

Ⅱ. SPECIFICATIONS

The tender specification of Shuqaiq Phase-Ⅱ IWPP requested the 850 MW crude oil-fired power plant and 212,000 m^3/d seawater desalination plant with all facilities such as fuel oil unloading & storage facilities and intake & discharge systems. This plant will be constructed adjacent to Shuqaiq Phase-Ⅰ, which also has power and desalination plant, as you can see Figure 1. In phase-Ⅰ, desalination plant adopts multi-stage flash (MSF) technology [1].
In this project, seawater desalination plant is requested to supply 212,000 m^3/d of drinking. The seawater is shown in Table 1. And the requested water quality is presented in Table 2.

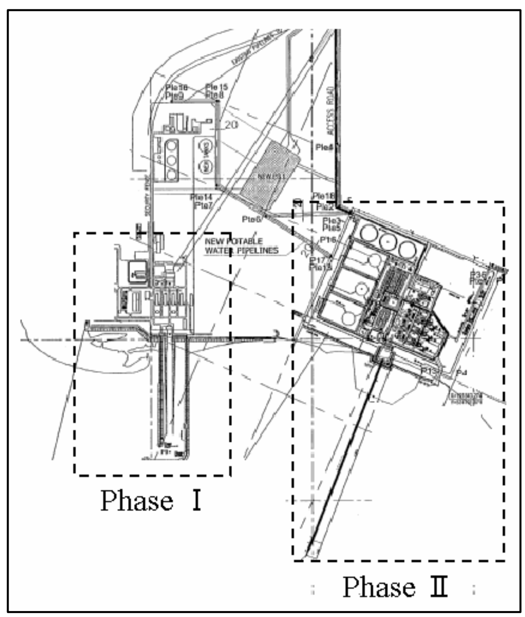

Figure.1 General layout of Shuqaiq Phase-Ⅰ and Phase-Ⅱ

Table 1 Seawater characteristics

Item	Unit	Value
Temperature	℃	23 - 35
Conductivity	μS/cm	58,000
Turbidity	NTU	1
pH	-	8.3
Alkalinity	mg/l as $CaCO_3$	122

Table 2 Requirements for water quality

(1) Production quality after desalination process		
Temperature	℃	Max.40
Chloride	mg/l	Max.14
Conductivity	μS/cm	Max.50
(2) Production quality after potable water tank		
Temperature	℃	20 - 40
Chloride	mg/l	Max.18
Calcium	mg/l	14 - 20
Total Dissolved Solid	mg/l	Max.110
Boron	mg/l	Max.0.5
pH	-	8.3 - 8.6
Langelier Saturation Index (LSI)	-	+0.1 - +0.3

When financial bids were announced in July of 2006, three desalination technologies - reverse osmosis (RO), multi-stage flash (MSF) and multiple effect distillation (MED) – competed to this offer. Despite a tight target of 14 mg/l chlorides and 0.5 mg/l boron, the RO-based bid from the consortium composed of ACWA Power Projects, Mitsubishi Corporation and Gulf Investment Corporation (GIC) came up as the first ranked bidder with the lowest price. And the adoption of RO process was decided formally in March of 2007. The top process of the bid using RO will be introduced in following section.

III. RO DESALINATION PROCESS

RO desalination plant in Shuqaiq IWPP consists of the following sections:

- Seawater intake process
- Pretreatment process
- Reverse Osmosis (RO) process
  1. Seawater reverse osmosis (SWRO) process
  2. Brackish water reverse osmosis (BWRO) process
- Potabilisation process

The flow diagram is demonstrated in Figure 1. This process is designed to produce 212,000 m^3/d of drinking water from 600,000 m^3/d over the period of 20 years' operational life after PAC of the plant.

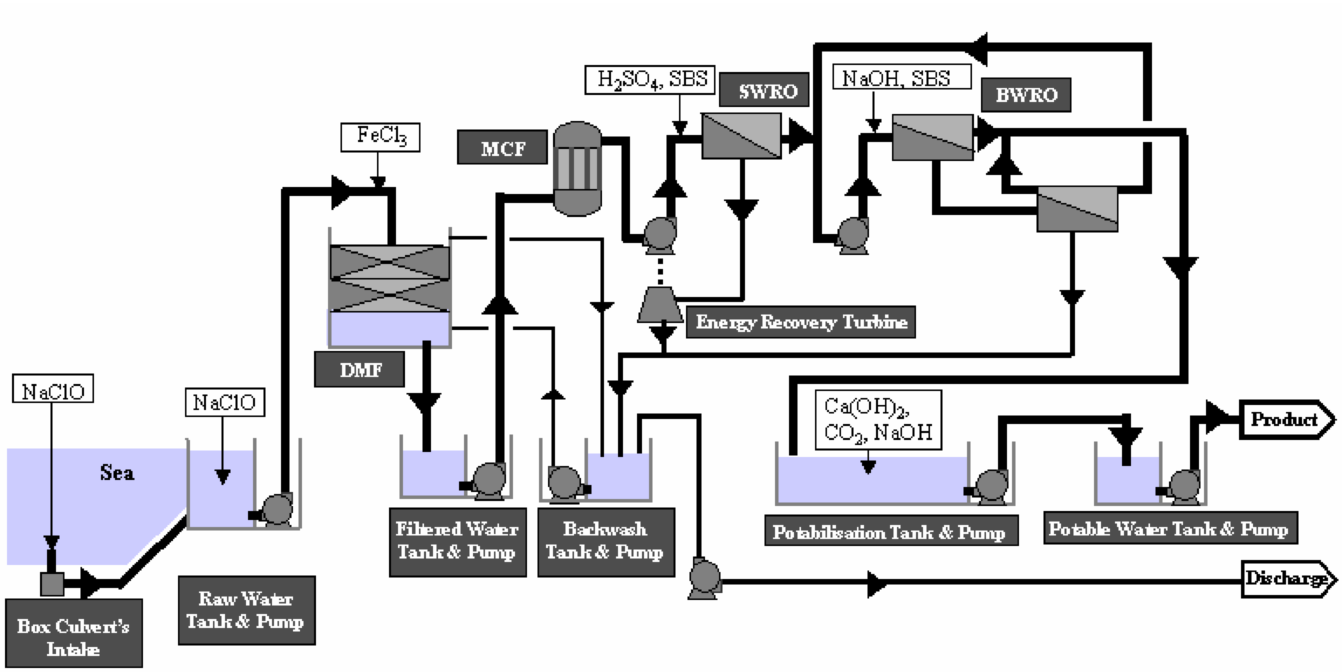

Figure 1 Process flow of the RO desalination plant in Shuqaiq IWPP

3.1 Seawater intake System

In this plant, seawater of 600,000 m^3/d is taken at the point of approximate 5 m depth and around 1 km offshore and led to raw seawater tank. The seawater will be chlorinated at two points, at the head of intake channel and at the suction of the seawater pump. The dosing rate will be decided to achieve suitable residual chlorine level at the outlet of dual media filter.

3.2 Pretreatment Process

Pretreatment process will be needed to remove silts, suspended solids and organic materials and achieve the requirement of RO elements. The pretreatment unit of this desalination plant is conventional gravity type of filtration. Dual media filter (DMF) with in-line coagulation is provided to ensure the pretreatment performance. The coagulant is injected at the upstream of a static mixer to achieve effective removal. As the coagulant, ferric chloride is injected with 40% concentration. DMF consists of sand and anthracite media with gravel support layer. The media will be backwashed with the brine from RO process.

Shuqaiq has very severe sand storm frequently in summer, so the turbidity of seawater becomes high, which means summer is difficult season for pretreatment process. Therefore, the specification, such as size and height of each media and filtration velocity, needs to be optimized. It will be decided finally after the pilot test at the site in Shuqaiq.

For further protection of high pressure pumps and RO elements, filtered water from DMF will be passed through an array of micro cartridge filters (MCFs) with 10 μm mesh. The replacement of MCF will be possible during operation without any loss of production.

3.3 Reverse Osmosis (RO) Process

The reverse osmosis process is the crucial part of desalination plant. It removes dissolved solids in seawater. The process of Shuqaiq plant will be two-pass process, which means two staged desalting by SWRO and BWRO. In this project, desalination process is required to achieve 14 mg/l chloride ion and 0.5 mg/l boron. For this requirement, full two-pass, which means all of permeate from SWRO is desalted by BWRO, will be provided. The designed total recovery of this process will be 36%.

3.3.1 Seawater Reverse osmosis (SWRO) Process

The pretreated feed seawater will be dechlorinated by sodium bisulfite (SBS) and adjusted to pH 6.5 by sulfuric acid and pressurized to around 7 MPa and sent to SWRO modules. The elements for SWRO will be the cellulose triacetate SWRO membranes of hollow fiber type. This type of SWRO membrane has unique chlorine tolerance. Therefore, intermittent chlorine injection (ICI) method will be adopted to eliminate bio-fouling of the membranes[2]. Chlorine will be injected for 3 hours per day by the operation without SBS injection. The designed recovery will be set to 40 %. The 98 - 99 % of dissolved materials will be removed through this process. The brine of SWRO will have much energy, so this energy will be recovered by Pelton Wheel. After that, the brine will be sent to the backwash tank.

3.3.2 Brackish Reverse Water Osmosis (BWRO) Process

All the permeate of SWRO process will be dechlorinated by SBS and adjusted to pH approximate 10 by caustic soda. High pH feed water is needed for effective boron removal[3,4]. After that, it will be supplied to BWRO process. The permeate circulation process will be adopted to this process. This process is effective when high rejection of dissolved substance is required. This will be explained in the following section in more detail. The elements for BWRO will be the polyamide BWRO membrane of spiral wound type. The chloride and boron content in the permeate will be less than 14 mg/l (Cl) and less than 0.5 mg/l (B). The designed recovery will be set to 90 %. The brine will sent to backwash tank similar to SWRO process.

3.4 Potabilisation Process

The aim of this process is to potabilise the permeate of RO process into required water quality. The process will include 3 stages mainly; hydrate lime dosing, carbon dioxide dosing and caustic soda dosing. Hydrate lime and carbon dioxide will be injected to increase hardness and alkalinity respectively. And caustic soda will be injected to adjust pH to the range from 8.3 to 8.6 and Langelier saturation index (LSI) to the range from +0.1 to +0.3, which are the requested values for potable water of this project. The adjusted potable water will be stored in the potable water tank and delivered to the end-users by SWCC (Saline Water Conversion Corporation).

Ⅳ. ADVANCED BWRO PROCESS

The target of 14 mg/l chloride and 0.5 mg/l boron are tight values for RO seawater desalination plant. To achieve these values, the advanced BWRO process will be provided, which is called permeate circulation process (PCP). The schematic diagram is shown in Figure2. This process has two BWRO stage and has the line for part of the permeate from 2^{nd} stage to circulate into the inlet of the pump. In the 2^{nd} stage, the permeate for desalinated water will be led from the permeate port at the front end of the modules and that for circulation will be led from at the rear end. This can make process performance improved more. Chloride of 97 % and boron of 85 % in the SWRO permeate will be able to be removed with 90% recovery in the designed BWRO process for Shuqaiq plant. The principle and feature of the PCP can be founded in the different paper[5,6].

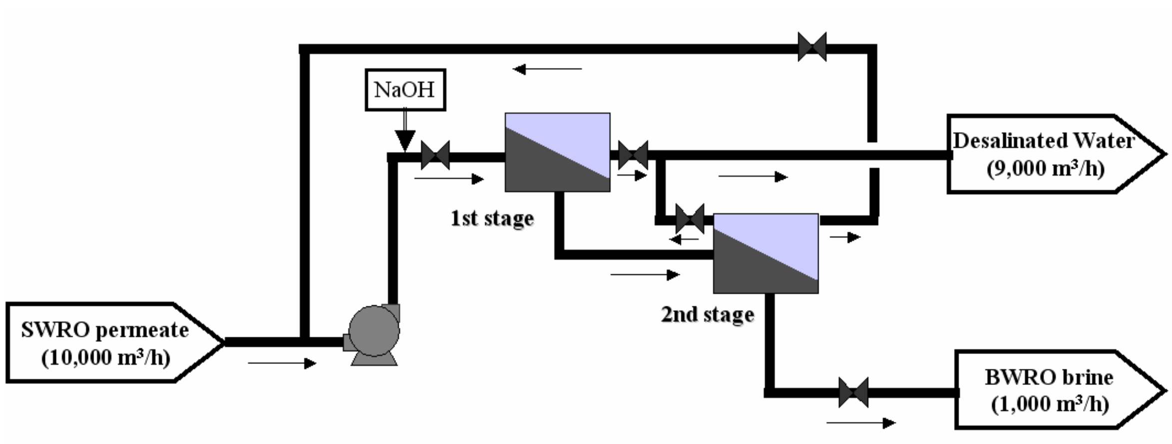

Figure 2 Schematic diagram of BWRO process in Shuqaiq IWPP

To confirm the merit of the process, two types of process are compared by RO process design calculator; one is the PCP and the other is conventional process. They are shown in Figure 3. The calculation condition was set to 35 degree C in 8 years' time after the start of operation, which is the most difficult condition to remove dissolved materials in Shuqaiq plant, which will be operated with membrane replacement of 12.5 % per year in the temperature of the range from 23 degree C to 35 degree C. The quality of the feed in the processes will be set to predicted values of the permeate of SWRO in this condition. The membrane type was set to the same in each process and membrane number was decided so that the average permeate flux would be 34 lmh. The feed pH was set so that the boron concentration of the desalinated water would be 0.45 mg/l. The total recovery was 90 % in both processes. In the PCP, 30 % of the permeate was circulated to the feed, which is the designed value in Shuqaiq plant.

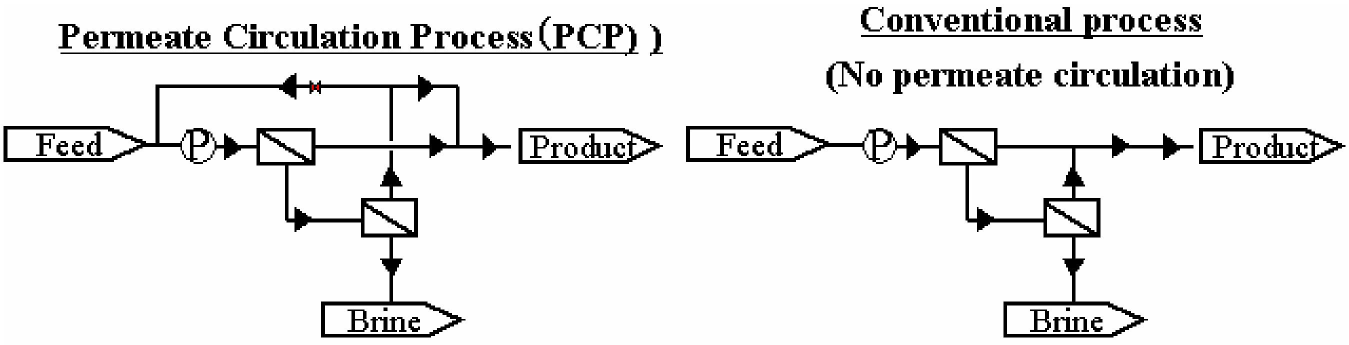

Figure 3 Processes for calculation

The calculation result is summarized in Table 4. It can be seen that chloride concentration in product is much lower in PCP (10 mg/l) than in conventional process (34 mg/l). The required chloride concentration in Shuqaiq IWPP is 14 mg/l and this can be achieved with PCP but not with conventional one. Moreover, the values of the feed pH are largely different; PCP is 10.0 and the other one is 10.7. Higher feed pH causes higher risk of membrane scaling and degradation and needs more chemical consumption. In this point of view, PCP is superior to the conventional one.

Table 4 Calculation results using two processes

	PCP	Conventional Process
Total Recovery	90 %	90 %
Boron conc. in product	0.45 mg/l	0.45 mg/l
Cl^- conc. in product	10 mg/l	34 mg/l
Feed pH	10.0	10.7
Feed flow rate ratio	1.27	1
Feed pressure	13.3 bar	13.5 bar
Membrane number ratio	1.3	1

The cost of water production was compared in the case of PCP and conventional process. This cost includes only BWRO process not pretreatment process and SWRO process and so on. The elements of cost was divided into 4 parts; amortization, chemical consumption, power consumption and membrane replacement. The unit costs were set to the predicted values in Shuqaiq IWPP. Figure 4 shows the calculated relative costs of water production when total cost of PCP is assumed to 1.

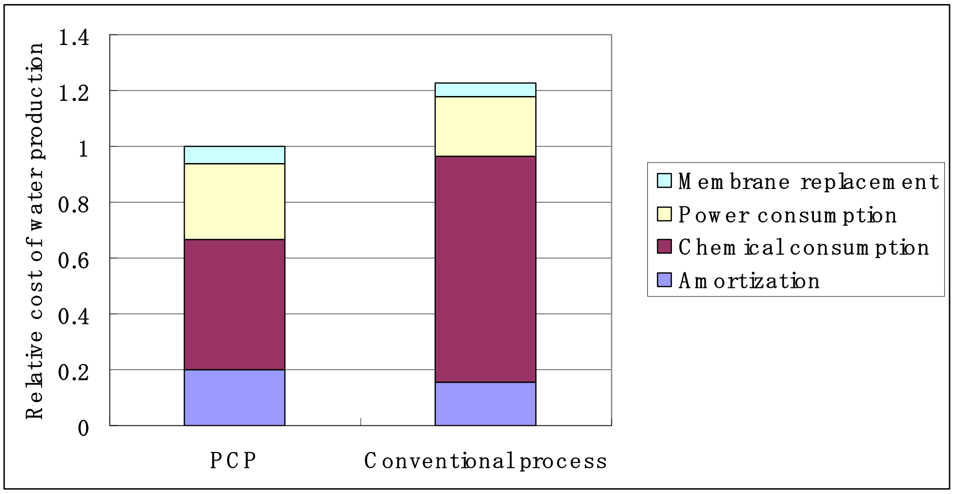

Figure 4 Calculation results of cost analysis.

As you can see, the cost of PCP is 20 % lower than that of conventional. And, the chloride in production water is much lower in the case of PCP as we showed in Table 4. Furthermore, in the case of PCP, we can operate it in lower pH relatively, which is superior from the standpoint of membrane scaling and degradation. From these analyses, PCP was decided to adopt in BWRO process in Shuqaiq IWPP.

Ⅴ. SUMMARY AND CONCLUSION

The RO desalination plant was designed to produce potable water of 212,000 m^3/d, which is composed of seawater intake process, pretreatment process, reverse osmosis process and potabilisation process. This will be completed in 2010 and will have been operated for 20 years.

In this project, the advanced BWRO process, permeate circulation process (PCP), will be provided in the BWRO process to achieve 14 mg/l chloride and 0.5 mg/l boron. In this paper, the desalination performance and cost of production water of PCP was compared to conventional process using a design calculator. This demonstration showed that the requested water quality in Shuqaiq IWPP would be able to be achieved by PCP, and PCP has a number of merits compared to conventional process.

Ⅵ. REFERENCE

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