Innovative Designs of the UF&– SWRO Limassol Desalination Plant in Cyprus

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1. Introduction

MN Limassol Water Co Ltd is a consortium of Mekorot Development & Enterprise Ltd – subsidiary of Mekorot Water a company, providing international advance comprehensive water solutions and Netcom Ltd, Cyprus (a company owned by Logicom Public Ltd) and Demetra Investment Public Ltd, Cyprus. MN LW Co Ltd has been awarded by the Water Development Department of Cyprus, the Limassol Desalination Plant BOOT contract for 20 years. The contract requires the Plant to operate under the strict EU water Quality, Quantity and Energy standards.

Mekorot Water Company, the National Water Company of the State of Israel, is engaged in a wide range of activities in the management, operation and treatment of all types of water resources, whether surface water, underground water, brackish water, seawater or effluents. Mekorot is one of the worlds' most technologically advanced water companies and is a world leader in an efficient operation of water supply systems, management of municipal systems (24/7), wastewater and effluents reuse projects for agricultural and industrial proposes, sea water & brackish desalination projects, water treatment facilities, hydrology and wells.

Mekorot Development & Enterprise (MDE), is the international business subsidiary of Mekorot Water. MDE leverages the 70 years of experience accumulated in Israel to carry out long term water projects worldwide including the design, construction, operation and maintenance (BOT, DBOT, PPP) of various water facilities.

The Limassol Desalination plant (Figure:1, Aerial photograph) is to be commissioned in June 2012 with an initial daily production of 40,000 m^3/day. The Plant is located at the outfall of the (dry) Kourris river, near Episkopi village within the district of Limassol. The tender required that the design and construction of the Plant was such so that it takes into account expansion of the production from 40,000 to 60,000 m^3/day by installing from the beginning enlarged plants' infrastructure such as the following:

- Sea water supply pipe line,
- Brine discharge pipe line,
- The intake pit,
- The brine pit,
- Power supply connections from the national grid,
- Final product supply pipe line and
- Adequate space for future additional equipment and process units such as additional pumps, re-mineralization columns, Ion Exchange units, UF and RO Skits etc.

The tender for the Limassol Desalination Plant, stipulated the build-up of the total water cost and the criteria of selecting the winning bidder, according to the lowest water cost.

The produced water cost parameters were:

A. Unit rate per cubic meter of delivered water for the recovery of the capital, based upon the capital expenditure and the recovery interest rate for 20 years
B. Unit rate per cubic meter of delivered water for the recovery of the operation and the maintenance cost excluding cost of electricity: a. Operation and maintenance mode, b. Stand-by mode
C. Unit rate per cubic meter of delivered water to cover the cost of energy based upon selling cost by the Cyprus electricity authorities at 0.10 Euros/ Kwh

The criteria of selecting the winning bidder were:

- Total unit rate of desalinated water, production mode = A+ B(a) + C
- Total unit rate of desalinated water, stand-by mode = A+ B(b)

2. Design details and submitted Total Water Cost

The tender price of MN Consortium (MN Limassol Water Co Ltd) was 0.8725 €/m^3, a figure which includes all plant stages (Figure: 2) including pumping the product water to 170m elevation.

The tender stipulated the required water quality with main parameters: TDS less than 600 PPM, Boron less than 0.50 PPM, Turbidity less than 1.0 NTU and Alkalinity more than 30 PPM. Also a conspicuous value in the tender was the very high energy cost stipulated for the calculation of the energy cost component.

Two points became quite obvious:

- The unit power cost of 0.10 Euros/Kwh is very high. Taking into account that in addition to the desalination energy, an energy for the transportation of the water to the Ypsonas reservoir (8.5 Kilometers from the plant at a level of 170 meters above sea water level) shall be required. One can understand that the energy cost component was crucial to win the tender.
- The demand for less than 0.5 PPM Boron in the Product water is very severe, but the demand to supply TDS less than 600 PPM is far from severe.

3. Innovative Design Process stages and process optimization

The plant has 7 main process stages as shown in Figure:2:

Stage 1&2 – Intake

Sea water is gravity fed via a 1km pipe into a the intake pit where it undergoes initial filtration via rotary screens; all screenings greater than 2mm² are removed and the filtered water is then pumped to Stage 2. The intake pit consist of the brine pit / pipe outfall some 1.2 Km into the sea. Special purpose diffuser system has been design for the effcient dispersion of the brine into the sea currents.

Stage 3 – Pre-filtration and Ultra Filtration (UF)

Sea water is filtered through self-cleaning basket type filters which remove particulates above 300microns in size and then filtered through 'Ultra-Filtration' modules containing hollow fiber membranes that remove particulate and microbial contaminants greater than 0.3µm in size. Permeate from the UF is contained in a tank that then supplies the next stage. As the UF membranes become fouled they will require cleaning. Specific designed backwashing cycles are in place to deal with short, medium and long terms cleaning requirements of the UF membranes. Optimization of these backlashing g cycles will be performed during the initial stages of the plant operation.

The pre-treatment is based upon six ultra-filtration modules, the units are supplied by Dow chemicals. This UF pre-treatment process stage, incorporated several substantial advantages in comparison to the traditional dual media filtration deign: The construction period is rather shorter: i.e. about 4 month, where as with the conventional multi media filters it was estimated to take at least 9 month (taking into account the curing of the very large concrete works). Also the UF pre-treatment can handle high turbidity sea water derived from rough / stormy sea conditions. Sea water feed to the UF with turbidity of 100 NTU comprises no problem to the UF, and subsequently the shut down time is reduced substantially.

Stage 4 – Reverse Osmosis (RO)

UF Permeate is fed through a series of increasing pressure pump systems at high pressure, via Lwo and High pressure feed pumps followed by the High pressure pumps before entering into the RO stage. Low pressure UF permeate water is fed into the energy recovery systmes of the RO stage before boosting their pressure to the RO feed water pressure, before entering the RO skids. Permeate from the RO modules is separated into two parts based on Boron levels. 'Front Permeate' which is fed to the front permeate tank and 'Back Permeate' is sent to the back permeate tank and then onto the Ion Exchange system for Boron removal.

Stage 5 – Ion Exchange (IX)

Back permeate is fed through columns which contain Ion Exchange resin beads. These resins are designed specifically to remove Boron, as the permeate passes up through the column the charged ions on the resin beads remove the Boron ions. The IX system contains a water softening stage which prevents scaling of the columns and as the resin beads become 'loaded' they require a regeneration stage, explained later. All permeate from the IX system is fed to the front permeate tank which feeds both the final product tank and the Re mineralization columns.

For the removal of the Boron from the desalinated water an Ion exchanging resin process stage was used rather than the conventional second RO pass was utilized. The Ion exchanging resin is manufactured by Rohm and Haas, affiliated of Dow Chemicals. The advantages of Ion exchanging Resin in comparison to the conventional "Second pass" are: Lower energy consumption as the pressure drop over the resin bed is about 0.5 Bar, compared to pressure of about 12 Bar in the conventional "Second pass", the recovery of the resin is about 100% compared to 90-95% in the "second pass" design, the guaranteed replacement rate is 10 years compared to 5-7 years in the "second pass" design, and the danger of the precipitation of Calcite and Brurite in the second pass does not exist in the IX unit

Stage 6- Re-mineralization (Remi)

A proportion of the front permeate is fed through the Remi columns, these contain locally produced Limestone gravel which is used to return hardness and increase the alkalinity of the permeate, this makes the water palatable and less corrosive. The re-mineralized water pH is adjusted before is then fed to the Product Supply tank.

Stage 7 - Product Supply

Permeate directly from the front permeate tank is bottom fed into the 5000m3. Product Tank, permeate from the Remi filters is fed into the top of the product tank. From the product tank the product water is pumped into the final product pipeline that supplies the Cleint's 5000m3 reservoir at 170m elevation. .

4. Membrane Selection Model

In addition to the above, a comprehensive model was developed in order to find the best performing membranes from well known manufacturers and the type among the commercially available membranes (approved by the tender) which shall provide the lowest Total water desalination cost.
This was done in accordance with the prevailing economical parameters of the tender namely: electricity cost, cost of the utilized chemicals, capital expenditure of the various components, discount interest rate, cost for the replacement of the first pass and second pass membranes (if needed) and subsequent cost for the replacement of the IX resin in order to maintain the low boron levels (< 0.5 ppm), and other cost parameters.

It should be stressed that the evaluation of each and every commercial membrane was based upon the comparative parameters such as the energy consumption, where as other parameters common to all the membranes such as intake and sea water supply, the pre-treatment, the transmittal of the final product etc. were not taken into account.

The simplified procedure was as follows:

- The model was run for all the potentially preferred RO membranes per chosen supplier, for sea water temperature range of 16 to 30 degrees centigrade
- Based upon the availability of each sea water temperature (percent of the yearly time namely 365 days per year) find the average energy consumption per the investigated RO membrane (example shown in Table:1)
- Each investigated first pass RO membrane is possessing properties which define the split between the front permeate and the back permeate as required to conform with the demands in the contract with the water authorities. The TDS and the boron concentration of these streams are known; The capital expenditure and operating expenditure were defined of the second pass (if required) and that of the ion exchanging resin.
- The capital expenditure is defined according to the "worst case" namely the maximum size units required to remove maximum Boron and maximum TDS. The maximum shall be generally at the highest sea water temperature.
- The operating expenditure includes the energy consumption of the second pass (if needed) and the Ion exchanging columns, their chemicals consumption and rate of replacement of membranes and resins.

As a result of the model one can find which is the most economical membrane pertaining and subjected to the economical parameters of the project.

In this particular project, second pass for the reduction of the TDS was not required as a result of the high value of 600 PPM in the final product as stipulated in the tender.

5. **The Design Parameters Selected**

The result of the above membrane selection model and design optimizations was as follows:

- Six UF Pre Treatment skids using DOW UF membranes
- Five SWRO Skids, with 120 pressure vessels , each vessel containing 8 RO membrane (fro 40,000m3/d)
- The pressure is supplied according to a power pressure principle, namely: Low pressure feed pumps followed by High pressure feed pumps and then High pressure pumps batteries feeding the RO skids at 60 bar
- The Energy Recovery is individual per skid, and supplied by ERI which are fed by the LP Feed pumps
- The economical membrane pertaining to the prevailing economical date were a combinations of DOW membranes: SW30X HR & SW30 HRLE-440i
- The front permeate is about 80% of the total permeate during the winter month. The balance permeate is feed to the ion exchanging columns. During the summer month the front permeate is reduced to 60% and the balance 40% flow as feed to the ion exchanging resin.
- The UF recovery is 97% and that of the SWRO 45%
- Second pass is not required. The rejection of the first pass membranes is adequate for the supply of TDS as required in the tender (re-mineralization is taken into account

6. Conclusion

The tough competition and tender requirements of the Limassol Desalination Plant has imposed innovative and refined process design and optimization in order to drive the Total water cost down to winning levels and in particular the low boron requirements of 0.5 ppm. The Design and Engineering of the SWRO Limassol Plant by MN Consortium has successfully combined innovative UF per treatment with advanced boron removal process of Ion Exchange and together with an optimized pumping systems has resulted in a Desalination Plant to be commissioned in June 2012 capable of meeting all the contractual requirements of water Quality, Quantity and specific Energy consumption

FIGURE: 1 AERAIL PHOTOGRAPH OF LIMASSOL DESALINATION PLANT

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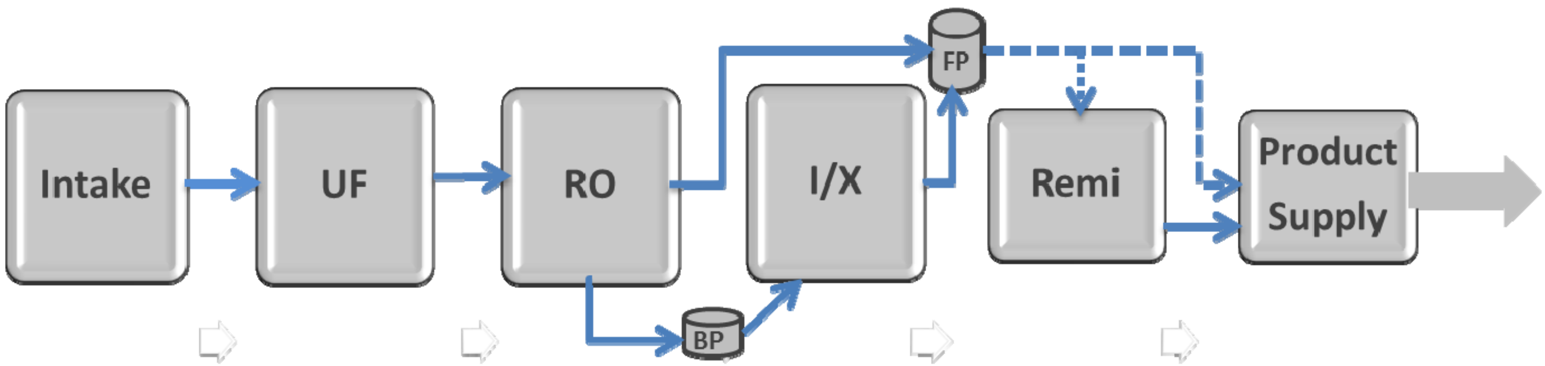
FIGURE: 2

Limassol Desalination Plant – General Process Overview



Stage 1&2

- Sea Water Feed Pipe
- Brine Out Pipe
- Intake Pit
- Intake Pumps
- Vacuum Priming pumps
- Stop Logs
- Rotary Screens

Stage 3

- Amiad Self Cleaning Filters 300#
- UF Units 6x2 skids
- Backwash System
- CIP System
- CEB System
- Chemical dosing system
- Powder addition
- Air System
- UF Pumps

Stage 4

- L.P. Feed pumps
- Amiad Filters 100#
- H.P Feed pumps
- HP pumps
- ERD's
- Booster pumps
- Pressure Vessels
- Membranes
- CIP Tank
- CIP Pump
- Chemicals

Stage 5

- Back Permeate Tank 800m3
- Feed Pumps
- 4 x IX Units
- Chemical Clean
- Softener Unit
- Chemical Waste Tank
- Chem. Dosing System

Stage 6

- Front Permeate Tank 1200m3
- Feed Pumps
- 6 x Vessels
- Limestone Storage
- B /wash System
- Chemical Dosing System

Stage 7

- Product Tank 5000m3
- Product Pumps
- Water Analysis Station
- Surge Tanks
- 13km pipe to Ypsonas
- Flow Meters