PROCUREMENT, CONSTRUCTION AND COMMISSIONING OF THE LARGEST SEAWATER RO PLANT IN SOUTH AMERICA

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Abstract

Minera Escondida limited (MEL or Escondida) copper mine is majority owned and operated by BHP. It is 170 km south-east of Antofagasta, Chile, at 3,100 meters above mean sea level. It is the largest copper mine the world. It is located in the Atacama desert, the driest place on the planet with average annual rainfall less than 0.6 inches. Currently the mine extracts water from local sources such as well fields, and a small desalination plant. However, to reduce its dependence on local sources and to meet increased demand due to planned expansion of the mining operations, a new seawater desalination plant is built in phases with ultimate capacity of 3200 lps (276,500 m3/day). It is referred to as the Escondida Water Supply (EWS) project. This paper discusses the design, procurement, construction and commissioning of the phase I of the project (2500 lps (216,000 m3/day). Even at its Phase I capacity of 2500 lps, it is the largest desalination plant in the Americas. In addition to the seawater reverse osmosis desalination plant, EWS includes intake and outfall systems and a water conveyance with storage system that moves treated water nearly 180 km to the mine located at an elevation of 3.2 km above sea level.

The project has several unique and sustainable design features. The execution of marine works incorporated special offshore and underground construction methods to greatly reduce the impact to the coastal zone which supports abundant marine life and a small fishing community. The plant incorporates energy efficient design features such as use of pressurized configuration from intake to the product water tank, use of positive displacement energy recovery devices, optimized RO train size configuration for cost, production flexibility and pump efficiencies, latest generation RO membrane elements with high permeability and variable frequency drives on all motors for operation at optimal conditions. The intake system is designed to abstract seawater of very high quality at a depth of 26 m to avoid influence of algal blooms and was constructed in environmentally friendly way using micro tunnels.

A Safety in Design program made this plant safer and easier to operate and maintain, by incorporating numerous operator safeguards to meet the highest safety guidelines followed by MEL and BHP. Given that the facility is located in the seismically most active region in the world, the design took into consideration appropriated code compliant measures to ensure the structural integrity.

The phase I was mechanically complete at the end of year 2016, and fully commissioned on the first half of year 2017.

I. INTRODUCTION

Located in the coast of Atacama Desert in Northern Chile (commonly known as the driest non-polar place in the world, Figure 1), the Escondida Water Supply (EWS) project supplies with fresh water, desalinated from the South Pacific, the operations of Minera Escondida, the world's largest copper producing mine, located East over the Andes at 3,100 meters above sea level.

The mine, currently one of the 10 deepest open-pit mines in the world, has been in operation since late 1990, with its ground water resources being limited from both a permitting and environmental standpoint, at the same time the operations are being expanded. Thus, Escondida's long term water sourcing strategy is primarily based on desalinated sea water. Indeed, for all Chilean copper producers, securing a sustainable water supply in the Atacama desert is a major priority to achieve a long-term strategy, so the completion of the EWS project has been a significant milestone for the business, minimizing the reliance on the region´s aquifers.

This paper discusses the design, procurement, construction and commissioning of the phase I of the project, sized to 2500 lps (216,000 m3/day), that became the South America largest desalination plant.

The discussion considers the project aims for operational simplicity and modularity, operational cost reduction, with special emphasis in energy consumption, and maximization of investment to add value for future growth decisions, besides the regular goals for safety, cost and schedule,

Figure 1 – Location of the desalination plant and the Escondida mine

II. MARINE WORKS

Pacific Ocean at the location of the plant is prone to periodic occurrence of algal blooms that may adversely affect the performance of the seawater desalination facility. To alleviate the impact of algal blooms, the intake is located at a depth of 26 m below sea level. At this depth, the impact of the algae blooms is expected to be minimal.

The intake consists of two tunnel pipes extending into the sea 540 meters, with an intake screen opening height of 1.6 m. The octagonal structure (in plan) of the intake velocity cap limits the screen velocity to a maximum of 0.1 m/s under maximum instantaneous flow to minimize entrainment of marine life. Coarse intake screens (150 mm center to center distance) are fixed around the perimeter walls of the intake structure to exclude large fish, mammals and floating debris from entering the intake system. The bars are made of cupronickel material to prevent marine growth. The screens are demountable to allow for removal/replacement but may be cleaned in-situ by wiping down. Spare screens should be held in stock for use to replace damaged screens or if screens are to be removed for cleaning.

The execution of marine works (Figure 2) incorporated special offshore and underground (72 ft deep) construction methods to greatly reduce the impact to the coastal zone which supports abundant marine life and a small fishing community. The littoral zone was completely untouched because state of the art slurry tunneling machines were used to mine beneath this zone from a shaft on shore straight to the intake and outfall locations deep beneath the ocean. The largest diameter offshore drill in the world was used to bore the shafts in the hard rock seafloor where the tunnel machines would exit, eliminating the need for more disruptive offshore construction techniques. With emphasis on safety, above nine hundred diving immersions were recorded without incidents, for the end of tunnels connections with underwater structures, such as the outfall diffusers and the intake screens.

Figure 2 – Left to right: Tunnel boring machine recovery; Tunnel internal aspect before flooding; Outfall diffusers connection

III. INTAKE AND SEAWATER PUMPING

Seawater is conveyed by means of two 2000 mm internal diameter pipelines from the onshore intake junction box to the screening structure transition box equipped with baffles for stilling and distribution of uniform flow to the travelling band fine screens. Three screen channels are designed with an approach velocity of 0.6 m/s. The channels are equipped travelling band screens for removal of fine particles and other materials from raw water. The screens are centre flow type (inside to outside pattern), and can be manually isolated with the slide gates. The screens consist of continuous band of mesh panels with 3 mm openings. The screened water is pumped by 9 vertical diffusion vane pumps through the pre-treatment system to the RO trains. There is no other intermediate pumping station taking advantage of the

slopped site conditions. Those vertical pumps operation were physically simulated at scale at different scenarios of flow patterns, resulting in the addition of anti-vortex cones and mesh bridge beneath the suction head, later on successfully proved to work in real scale conditions (Figure 3).
Provisions for biofouling control include shock chlorination at the velocity cap in the ocean. The addition of chlorine is interlocked with the operation of the seawater pumps. This is to prevent inadvertent addition of chlorine when the plant is not in operation, which may result in chlorine leakage into the ocean.

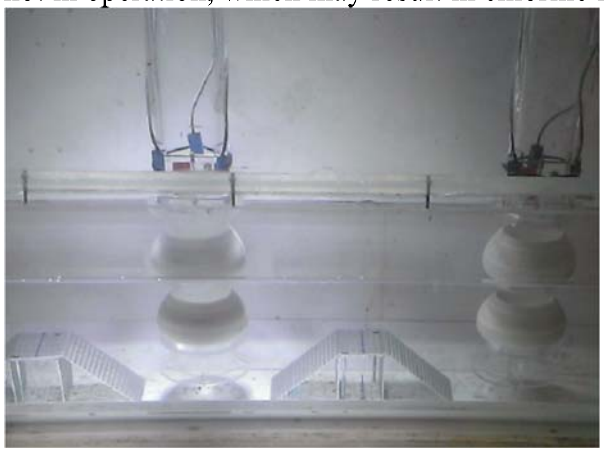

Figure 3 – Test with physical model (scale 1:6) of EWS seawater pumping

IV. PRETREATMENT

The pretreatment system is designed to produce high quality filtered water (RO feed water) to minimize the fouling of the RO membranes. It consists of the following processes:

- Acid, Coagulant and polymer (optional) addition and mixing
- In-pipe flocculation
- Two stages of dual media filtration (sand and anthracite) with pressure filters

Ferric chloride is used as coagulant. There are provisions for addition of polymer when the water quality deteriorates. However, it is expected to be used only under worst seawater quality conditions. The primary concern is the potential for excess polymer irreversibly fouling the RO membranes.

Two stages of pressure filters are selected to ensure high quality water to the RO system. The media consists of sand and anthracite. The first stage is designed with 40 pressure vessels and second stage with 20 pressure vessels, each with dual cells (Figure 4). The loading rate for 1st stage is 9.3 m/h for first stage and 13.8 m/h for second stage, with all vessels online. The media for second stage is smaller than first stage. The filters are designed to be backwashed with RO concentrate, to minimize the intake flow.

Figure 4: Dual media pressure filters (3D Model and installed filters)

V. RO SYSTEM

Five micron cartridge filters are provided upstream of the RO system for protection of the RO membranes. Water pressurized by the sea water pumps passes through pretreatment and cartridge filters and is supplied to the RO system high pressure pumps and energy recovery devices. The pressurized stream is split, with half of the flow going to the high pressure pumps (one dedicated for each of 9 RO units) and the other half to the energy recovery devices (one dedicated for each RO unit). Flow entering the energy recovery device is pressurized by hydraulic energy recovered from the concentrate and by a booster pump (as needed to supply the incremental pressure required) to combine with the remaining half of the flow entering the RO modules. High pressure RO feed pumps and ERD booster pumps are equipped with AFDs. Each SWRO train has a permeate capacity of 269 lps (nominal) and 280 lps (maximum). Two types of RO membranes are used. Each pressure vessel has three SWC5-LD membranes and four SWC6-LD membranes. The RO system operates at a recovery of 50% and maximum flux of 13.2 lmh. A positive displacement type device, Dual Work Exchange Energy Recovery (DWEER) system is used. Product water remaining pressure displaces the fluid to product water concrete tanks placed on the foudations of pretreatment uphill.

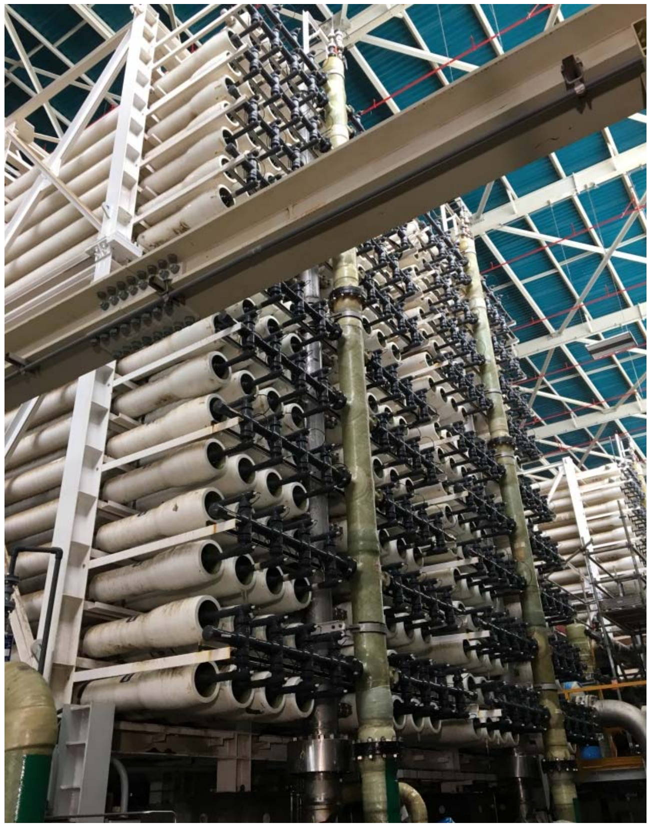

Figure 5: EWS Reverse Osmosis train

VI. POST TREATMENT

Without post-membrane stabilization, SWRO permeate tends to be aggressive towards downstream equipment, pumps and transmission piping as a result of its low pH, alkalinity (to buffer the treated water) and elevated chloride. Post-treatment stabilization includes both the addition of alkalinity in the form of carbonates as well as pH. Zinc orthophosphate, sodium carbonate, and carbon dioxide are used to achieve the target finished water quality values.

Figure 6: Soda ash silos

VI. CONSTRUCTION

The construction schedule was aggressive (approximately 30 months) and the space is limited. The project execution utilized a 4D model which utilized a 3D model, with detailed construction schedule superimposed, to build the project virtually before actual works begin. This aided in the coordination, engineering, scheduling and construction elements of the project. As a result, procurement overseas were directed by the site erection sequence to prioritize elements in fabrication.

Figure 7a: 4D model used for design and construction

Figure 7b: Plant layout

Figure 7c

Figure 7d

Figure 7e

Figure 7f

Figure 7g

Figures 7c-g: Construction sequence satellite images

VII. CONVEYANCE SYSTEM

The water conveyance system of the EWS project is able to transport desalinated water from the sea level up to the mine site at an elevation of 3.200 meters and 180km distance, with an ultimate flow of 4,000 lps (although this phase I investment is for 2,500 lps), through two 42" diameter pipelines and four high pressure pump stations. This Project package, for the 2,500 lps condition, consumes approximately 88 MW.

During design phases, the project determined a configuration for the water conveyance system, which does not include variable frequency drivers (VFDs) for the water flow control in any of the four high pressure pump stations (Figure 8). This was based on technical and economical trade off analysis, confirming that the sole use of VFDs to control the hydraulic system is not technically feasible and, with the use of other suitable flow control devices, VFDs give little energy savings and does increase capital expenditure significantly, with a payoff period superior to 25 years.

While VFD is a speed control method for electric motors, used in applications ranging from small appliances, to the largest of mine mill drives, the analyses shows that the reduction in power consumption is limited as the speed of the hydraulic pumps should not be reduced more than 5% due to the pump shaft critical speed concerns. Therefore, the sole use of VFDs is not a technically feasible option. However, without any control system, the pumps would operate beyond their maximum design flow (110% of the rated flow), and potentially beyond the maximum flow capabilities of the pump. For that reason, the use of flow control valves (FCVs) was required in all cases and in all flow conditions.

Nevertheless, the project had implemented further measures on this system in order to optimize the use of energy; the most significant are listed below:

- Pumps designed for the ultimate flow of 4,000 l/s were supplied in this phase I for 2,500 lps with impellers trimmed for best efficiency (different at each pump station), and then will be changed for the second investment for a common impeller at full size. This measure saved power consumption by 3.8% (equivalent to 4.2MW) compared to not changing them
- The main pipelines were installed with internal coating (fusion bonded epoxy) for a smoother surface which represents less resistance to flow, therefore requiring less input of pumping energy. The internal coating compared to bare steel pipeline, will be increasing energy savings with the years of use

and when the pipeline is used at higher flows. The energy saving range starts with 1.8% when pumping 2,500lps with brand new pipes, and can achieve 18.8% when pumping 4,000lps with ten years old pipe, again, compared to bare steel

- Main pump skids were supplied with high efficiency drivers (electric motor tested with 94.6% efficiency), seeking the more efficient pump model (quotes ranged from 82.1% to 86.5%). This has reduce power consumption from 3.7MW to 3.0MW at each skid
- Booster pumps, for providing head pressure on main pumps, were eliminated from initial design. The main pump was designed to have double suction concept. This further reduced 7 MW of energy input.
- The use of reservoir cells will buffer the water supply versus the water consumption in the mine, in addition with the implementation of modular trains of 278lps each, the water supply system keeps to a minimum the start and stop events of such trains (energy levels increases for a short period up to seven times nominal current), only for planned conditions influenced by seasonal fluctuations, and not by day to day events. The same reservoir is fully covered, by a floating HDPE cover, reducing water production losses; the cover material will have a payoff period of 5 years (Figure 9)

Even so, adding VFDs on a system with FCVs and trimmed impellers will save energy only by 0.7%, but adding capital cost in the flow control system by 440% that will not have a payoff period within the expected life of the equipment. The sole purpose of VFD would be soft start, since FCV will control operating range. The capital cost of soft starters is 38% less than VFDs, and was not recommended for the project due to same reasons.

As noted in the previous sections, on the other hand, the desalination portion of the plants being operated with VFDs to enable a continuous product water flow per train, the control system is used to adjust variations of salinity, temperature, membrane aging, among others.

Figure 8: Inside of the high pressure pump stations 1 to 4

Figure 9: Covered 0,5Mm3 reservoir at the mine

VII. CONCLUSIONS

Escondida Water Supply system is the largest desalination facility in the Americas (Figure 10). The project incorporates energy efficient design features such as use of pressurized configuration from intake to the product water tank, use of positive displacement energy recovery devices, optimized RO train size configuration for cost, production flexibility and pump efficiencies, latest generation RO membrane elements with high permeability and variable frequency drives on all motors for operation at optimal conditions. The intake system is designed to abstract seawater of very high quality at a depth of 26 m to avoid influence of algal blooms and was constructed in environmentally friendly way using micro tunnels. A modular design was implemented to facilitate maintenance and to reduce the number of spare parts that need to be procured to maintain the facility. A Safety in Design program made this plant safer and easier to operate and maintain, by incorporating numerous operator safeguards to meet the highest safety guidelines followed by Escondida and BHP. Given that the facility is located in the seismically most active region in the world, the design took into consideration appropriate code compliant measures to ensure the structural integrity.

Figure 10: Overview of the desalination plant