

Sustainable seawater intake solutions

How can they be designed in terms of: optimized life cycle costs, optional fish protection, dealing with corrosive environments / jellyfish and red tides?

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How seawater intakes have technically evolved coping with the global demand to reduce total life cycle costs of desalination plants as well as to preserve aquatic life?

The Middle East and the US currently represent the largest consumers of desalinated water in the world and, regardless of the desalination method employed (whether SWRO, BWRO, MSF, MED or a combination of these methods), planning/building a desalination plant should properly take into account CAPEX, OPEX as well as total life-cycle costs for the various stakeholders of each project. One of the most critical parts of the desalination process is the provision of source water to a plant. Even when dealing with relatively clean debris-free seawater, the screening plant at the intake has to remove a considerable amount of material potentially harmful to downstream processes (such as DAF and multimedia-filtration).

In this study we will analyze the various civil and mechanical design solutions associated with seawater intakes from a CAPEX, OPEX as well as from an environmental point of view: e.g. principally open-channel type, tunneled type structure, onshore as well as offshore-submerged designs for intakes / fine filtration.

There are several possibilities to conduct the necessary mechanical screening and fine filtration of the water prior to the actual desalination process. As a function of the expected debris type and (sometimes seasonal) quantities as well as of flow rates, TSS, salinity and temperature, the most appropriate solution can be engineered to measure matching the specific site conditions. Additionally, long-term reliable corrosion protection, selection of stainless steel grade as well as state-of-the art measures to comply with local regulations, e.g. regarding protection of maritime life, are to be taken into account.

This article shall give an overview on the current challenges for seawater intakes as well as to present case studies and experience gained over the last 50 years on available technologies, larger as well as smaller projects worldwide to cope with specific environmental conditions.

1. Introduction and objective

A comprehensive system raises and falls with its input quality and quantity. For a desalination plant right at its front-end will be located the salt-water feed by the intake facility. It is typically not viewed as a plant's core, but nonetheless the intake fine filtration plays an essential role in terms of a sustainable function and low life cycle costs of a plant. Before using seawater as feed for a desalination plant or also as cooling medium along with thermal and nuclear power plants, the feed water will have to be mechanically cleaned from debris to protect the downstream pumps, membranes, condensers and other sensitive downstream equipment from clogging and other damage. Depending on the water quality, amount of debris and fauna situation, screening of the

incoming water can be performed by an off-shore system such as passive screens (JOIS) or could need a more accessible multi-stage screening and filtration solution realized with one or more redundant intake channels and an active screening, extracting debris, jellyfish or plastics from the sea. What was formerly just withdrawal of water from an open water source is today a strictly controlled philosophy of balance between low costs for machines, civil structure as well as operation, corrosion protection, and compliance with numerous partly even site-specific regulations (such as fish protection, fish retraction from the traveling water screens associated with fish-friendly return buckets), restrictions and standards, especially in respect of corrosion or marine life protection.

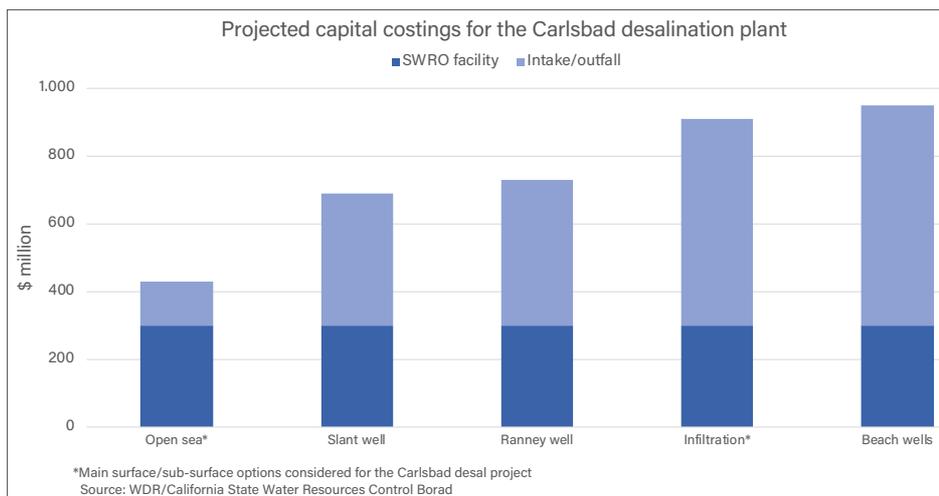


Figure 1: Cost comparison of different intake types at the example of Carlsbad Desalination Plant in USA "Among industrialized countries, the USA is one of the most important users of desalinated water, especially in California and parts of Florida. The cost of desalination has kept desalination from being used more often. This graphic shows how amendments to California's extensive desalination regulations (...) have threatened to bump up the costs of desalination just as the state looks to the sea to address its rampant drought."[4]

This article investigates common challenges and solutions such as the protection of the seawater screening equipment from corrosion, possibilities of a fish-friendly water intake, coping with large debris quantities as well as optimization and cost-saving solutions like reduction of pump stations' footprint or head loss. What is the current state-of-the-art and which solution should be prioritized by the contractor?

2. Opportunities and innovations on seawater intakes

2.1. Main design options for seawater extraction

Depending on the requirements to pursue a most efficient pretreatment of the water used for a desalination plant, there are mainly the following water intake types appropriate for water screening.

2.1.1. Open intake channels and tunnelled intakes

An open-channel seawater intake can either be located directly on the seashore as the wide-spread and renown open-channel intakes or slightly inland fed through tunnelled intakes. Many of the plants in the Middle East use tunnelled intakes to benefit from deeper intakes where cooler water is required (e.g. as source water for power and desalination plants).

Open intake systems are best suited to cope with very high capacities and flow rates. Those plants typically consist of one or multiple concrete intake channels in which the screening system, such as coarse and fine screening, isolating equipment and accessories like water level controllers are fixed into. Combined intakes providing feed water often handle up to several hundred thousands of cubic meters per hour. Plain open intakes using redundant MultiDisc® traveling water screens or large rotating drum screens can cover highest flow-rates. The water should ideally be screened in two or three steps, starting with a coarse bar rack of 50 mm-200 mm and finishing with a fine band screen mesh

with opening of some mm (dependent on the downstream process) to achieve best screening results and highest lifetime (typically 40+ years) reliability. The debris accumulating at the rack or mesh-kind of filtration will be actively removed and thus will improve sea-cleaning from debris. This can be done automatically or manually, whereby manual handling or divers regular cleaning has become outdated due to HSEQ risks implied, among other reasons. Highest efficiency can be achieved by state-of-the-art automatic cleaning of the racks by means of a mechanical rake and backwash cleaning of the traveling band screens, triggered by level sensors and cleaned by a pressurized spray water system.

2.1.2. Offshore or passive intakes

The typical range of intake capacities for passive intake screens offshore are smaller up to medium flow rates (sized up to 4,000 m³/h of feed water total flow rate of a plant). In contrast to the open intake solutions, the passive screens (vee-wire typically) remain submerged meaning at the same time that debris cannot be removed from the water. Access in case of maintenance has to be achieved by means of divers usually. The right material selection is typically more difficult on offshore passive intakes and remains a more difficult kind of choice (Cu Ni to minimize microbial corrosion, Duplex or Super Duplex to minimize galvanic corrosion risks). However, as passive screens usually do not have any moving parts below the water, they should be maintenance-friendly. The best way to remove the debris from the screening surface is being achieved by regular back-flushing with compressed air (hydroburst type air backwash systems).

2.1.3. Seabed filtration

Another possibility to collect water is by seabed filtration, meaning by an embedded screen. The water can

be withdrawn directly at a higher purity. As the flow through the sand and through the small screen openings remains very limited, for higher intake capacities the screening area would be accordingly higher. Special care has to be taken of the collapsing soil risk and often increased costs, higher than expected due to unforeseen soil conditions.

2.2. Key challenge: corrosion

The galvanic corrosion of metal surfaces, especially of steel, in water is of electro-chemical origin. Due to the surrounding electrolyte (water), electrical circuits in varying dimensions are situated between the metallic components. At the respective exit point of current at the anode, the metal is being removed according to the Faraday's laws of electrolysis. The process can be understood as a reversal of the galvanic production of metallic deposits. The driving voltage of these corrosion currents comes either from a varying composition of the metal surface itself (formation of local elements) or the combined action with another metal surface, if galvanic elements are formed between the different metals together with the electrolyte according to the electro-chemical series of metals.

In contrast to the galvanic corrosion, which is more or less predictable based on water composition, temperature and material, also the microbiologically influenced corrosion (MIC) can cause severe damage. It is more complicated as the influence factors are biofouling, water quality and presence of bacteria. Therefore, it is difficult to foresee and to avoid and there are no 100% success promising measures but proven measures to minimize risks.

2.2.1. Methods to minimize the corrosion risk

The corrosion current and consequently the galvanic corrosion itself can be reduced or eliminated by insulation or by a protective direct current of reversed polarity (active cathodic protection). It is obvious that the corrosion-inhibiting effect of a coat of paint will last only so far and as long as the coat isolates substantially especially in a moist condition. Practically it is hardly possible to obtain a coat of paint that isolates well under water for prolonged periods of time.

The protective current method has not only the purpose of protection against corrosion of the bare spots where metal slides on metal, but at the same time also to protect the defective spots in the coating and /or unpainted parts. Even so-called high corrosion-resistant Duplex or Super Duplex materials can be subject to galvanic or sulphate-derived corrosion due to the hydrogen embrittlement effect on heat-affected zones for example. Here too, the protective current with active cathodic protection based on the impressed current method can much better protect the bare metallic surfaces against corrosion in combination with Duplex materials.

Whereas, there are different solutions to cope with galvanic corrosion, a possibility to reduce the MIC risk can be as well to apply a cathodic corrosion protection system (for example the Geiger ICCP) based on impressed current. Many of those references in 316 SS combined with ICCP have proven long term positive track records, due to repelling type of effect. These devices can typically have a lifetime of about 30+ years. Most plants installed by Aqseptence during the last 50 years in the Middle East have been combining 316/316L stainless steel with a so called Geiger-ICCP to minimize the risk of galvanic corrosion as well as to minimize the risk of microbial corrosion. Therefore, it is very questionable to apply Duplex or SuperDuplex screens without a proper automated impressed current cathodic protection system.

2.2.2. Cathodic protection: sacrificial anodes or impressed current

Sacrificial anodes rely on the galvanic corrosion of a more reactive metal (more negative electrode potential in the galvanic series), such as aluminum, zinc or magnesium, whereby aluminum has proven to be one of the most cost-effective materials in seawater applications. The advantage of the relatively low material and installation costs for sacrificial anodes is opposed to the disadvantages to be only suitable for a short service life, thus high operation expenses (typical lifetime of 2-5 years) and no possibility for control of the protection current leading to a risk of insufficient protection of rotating and moving parts.

Impressed current active corrosion protection by an ICCP therefore remains the most efficient way to provide an active protection against corrosion in conductive media albeit for 316L or Duplex screens. In case of an "impressed current"-type system the objects to be protected are connected by means of a cable to the negative terminal of an electronically controlled power supply unit. The submerged anodes are connected to the positive terminals of the power supply unit. According to the rules of current spreading the protective current flows to all surfaces which are in contact with the conductive sea water.

2.2.3. Super Duplex material

Super Duplex stainless steel has a high corrosion resistance and is therefore often considered self-protective against high saline water. The material itself has a considerably higher price level on the market than 316L stainless steel for instance.

For equipments which have only few piece parts, i.e. where only few contact spots to other components are necessary, Super Duplex is usually the simplest and most appropriate solution, which is the case for passive screens, for example. As a state-of-the art, the entire screen is made of one piece, completely pre-welded with just the connection of two flanges for



Figure 2: KPONE Independent Thermal Power Station, a 340 MW CCGT thermal power plant, was constructed to improve the distribution of electricity throughout Ghana. Cable-operated bar screening machines and zero-carryover through flow MultiDisc machines (both by Aqseptence Group) were selected to screen the cooling water through four channels, each with 15,000 m³/h; material of construction is 316L with impressed current cathodic protection. Due to the use of the state-of-the-art maintenance-friendly water-based cooling instead of air cooling in this climate region, a 3-5% higher energy efficiency rate of the power plant could be achieved [3] (p. 11 et seqq.)

water outlet and flush air inlet. However, for machines which are made of several moving parts like mesh panels, bolts, chains, guides, rollers etc. it is difficult and very cost intensive to realize the entire system completely made of Super Duplex as otherwise galvanic corrosion will still and even more intensively occur due to the different electrochemical potential of Super Duplex and other stainless steels at their direct contact connection spots (local elements, hydrogen embrittlement risk as per chapter 2.2.1).

In a nutshell, for large intakes with open intake structures the most reliable and most efficient long-term proven solution remains 316L stainless steel in combination with a well-performing cathodic protection system, especially of the impressed current.

2.3. Key challenge: fish protection

As might be expected, there are no perfect fish protection system available. However, according to EPA 316B as well as Central European Fish Protection Guidelines, proven solutions do exist. Effective fish protection is only possible using an intelligent combination of individual measures, such as fish barriers, tailor-made to meet the specific local requirements. Generally, fish barriers can be categorized into behavioral and mechanical barriers. Behavioral barriers can often be installed relatively easily and inexpensively into existing water intake structures to avoid bigger fish swimming into. At center-flow traveling band screens as well as at multi-disc traveling screens highest fish survival has been registered due to optimized fish buckets and gentle pouring of the fish/eel into back-flow channels (80-90% juvenile fish survival rates typically). As long as a proper combination of barriers is set up correctly, loss of fish can

be almost completely avoided no matter what type and size of fish involved.

2.4. Key challenge: seasonal large debris quantities (e.g. jelly fish, algae)

Depending on the amount and sizes of debris as well as on the water flow, required fine screening size and hydraulic conditions, the system can be adapted in order to match the regulations and special project design requirements. Subsequently number and type of screening machines are chosen.

Most intake designs consist of multiple-channel and redundant coarse screens (with typically proven cable-operated front-end screens to cope with large-format debris 50-200 mm bar spacing) and a second cleaning stage filtration (traveling water screens 0.5-8 mm mesh/perforated panels) to avoid smallest debris carry-over. It can however make sense to install an additional revolving chain screen type of fine bar screen (10-20 mm) in between the front-end screen and the band screening machines, which would additionally be able to cope with abnormal seasonal large quantities of medium-sized debris.

Recently, massive jelly fish swarms throughout the Middle East and South America have drawn attention to the importance of a well-designed intake that can cope with large quantities of unusual debris. Huge plants mean huge investments, and the respective intake facility is often not in the main focus during the design phase. A fully-functioning and 100% reliable seawater intake that provides screened seawater even in adverse and difficult conditions however will be essential to sustainably protect the important downstream equipment (condensers and membranes) and to achieve full operational reliability. For this task, high-capacity mechanical



Figure 3: Power and MSF-Desalination Plant - Qurrayah, Kingdom of Saudi Arabia. Upgrading with 20 revolving chain screens (by Aqseptence Group), thus removing up to 60 t/h jellyfish per machine out of sea at a total flowrate of 700,000 m³/h; material of construction of submerged parts is 316L with impressed current cathodic protection

screens such as Geiger high-capacity KUR revolving chain screens remain widely proven since they can upgrade existing channels and remove huge amounts of debris thanks to the high cleaning frequency of the racks by means of multiple robust cleaning rakes when it comes to a pollution peak.

2.5. Further opportunities in respect of civil structure cost savings, head loss and carry-over

In contrast to the passive intake systems or temporary seabed filtration, open intake solutions typically do provide a higher redundancy (N+1 or N+X) potential. Upgrading, efficiency improvements and individual adjustments can be customized. The probably most important and significant saving potential can be achieved along with the often massive civil structure. Such savings can be achieved by designing a straight-flow channel, with no back-walls, no flow deviation and thus lesser head loss accompanied by lesser turbulences and a more even flow characteristic. With lesser dead-zones the larvae/mussel-growth risk, which could occur downstream of screens in front of the pumps, is reduced and straight flow channels have proven significant benefit for the utility operators. Another benefit compared to center- or dual flow of traveling band screens is the smaller footprint for the intake equipment as well as the reduction of the pump chamber size. Other significant improvements in terms of hydraulics will be the reduction of head loss, mussel growth and the minimization of carry-over-risks.

Less pressure loss across an intake filtration machine will lead to a lower demand of pressure head serving the downstream arranged pumps, demanding reduced power requirements for the entire system. Hence, it will

be advantageous to invest into hydraulically optimized water intake screening machines that enable the water, for instance, to pass a band screen filtration machine only once instead of twice.

Reduction of the footprint of an intake can be achieved by designing solutions and equipment providing low turbulences on the downstream side. Such design will result into shorter required distances between the screens/prefiltration outlet and the cooling water pumps. One-pass through-flow machines with low head loss, such as for example the multi-disc screen [1], allow to significantly reduce the concrete inlet chamber length (between the mesh-screen/filtration and the pump) by up to 50% or 7-8 m, especially when multiple redundant pump bay chambers are being applied.

Years ago, the so-called carry-over effect of debris regularly could cause severe harm at downstream equipment such as pumps, membranes, heat exchangers or other apparatus. It has been a widespread problem of conventional through-flow traveling band screens; the transport of debris from the raw to the clean water side in case of spray water system inefficiency and especially in case brushes had been used in the past. The selection nowadays available and proven zero-carry-over intake traveling water screens (of through-flow type) do however allow to avoid such risks and can therefore assure a sustainable long-term screening operation.

Case Studies

As an example of how important the right selection of the water intake system from a total life-cycle point of view remains, two case studies are shortly presented in **Figure 2** and **Figure 3**.

In Ghana (see **Figure 2**), the cooling water feed for a new multi-fuel-fired independent power plant (IPP) has been installed along the difficult West African coastline in 2016. Since the energy-efficiency of water cooling in contrast to air cooling is remarkably higher [3], the installation of large cooling towers along the coast could be avoided. The decision regarding the fine screening was made in favor of a technology that caters for zero carry-over of debris to the process. Through-flow traveling water screens with one passage through the screen, reduced pressure loss and easy-installation due to a self-supporting pre-mounted frame made in Germany could provide highest reliability and efficiency.

Conclusion

Numerous studies have evaluated the most cost-effective and efficient method of feeding seawater to desalination plants, and most conclude that an open seawater intake significantly saves on capital and life-cycle costs (CAPEX). Cathodic corrosion protection is the most efficient method of protecting steel installed in conductive media against natural corrosion. This technology is firmly associated in the water field for example with the name of Geiger® (Aqseptence Group) as for more than 30 years the brand Geiger® has been developing its own cathodic protection systems design for the protection of water intake screens. These systems are patented and are installed in over 100 large-scale desalination plants operating since decades. The question of how to design the perfect fish friendly water intake cannot be answered comprehensively. Different factors such as the existing flow conditions, type of marine life and intake type have to be considered and should typically lead to a combination of mechanical and behavioral barriers.

To resume the question of lower costs versus higher benefit, it is important to put into consideration that in general for a high quality and efficiency equipment, the investment costs are higher, while the OPEX costs can be remarkably reduced. The exact amortization time is different from site to site, of course, but especially for large desalination plants where a malfunction of the intake would be disastrous, it is definitively recommendable to rely on sustainable and maintenance friendly solutions.

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