TETRA TECH

MEMORANDUM

TO:	Diane Gatza, West Bain Municipal Water District
FROM:	Mark Bush, P.E., Tetra Tech
JOB TITLE:	OWDDF Intake Biofouling and Corrosion Study
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INTRODUCTION

West Basin has been testing the feasibility of ocean water desalination since 2002 to reduce dependency on imported water. After six years of study and water quality tests conducted at the pilot facility in El Segundo, the District constructed the Ocean Water Desalination Demonstration Facility (OWDDF) at the SEA Lab in Redondo Beach. The purpose of the OWDDF is to conduct research and testing on full-scale equipment that also protects the environment. The OWDDF was dedicated in November 2010.

As part of the OWDDF, the District was testing the performance of a wedge wire intake screen. The District conducted an impingement and entrainment assessment to monitor the performance of the screen. The selected material of construction was a 90-10 copper-nickel alloy. The alloy is well known for is its seawater corrosion resistance and anti-biofouling properties. This material has been used successfully at other locations for intake screens. In October 2011, the District observed mussel growth on the screens. In 2012, the District replaced the screen due to the mussel growth. The District tried two different screen materials, the 90-10 copper-nickel alloy and a proprietary Z-alloy.

The OWDDF was successful in documenting the effectiveness of the screens for reducing impingement and entrainment. It has also shed light on the importance of material selection and proper installation of the screens and intake piping. The water quality and marine environment at the specific location must be assessed for corrosion and biological growth relative to material selection and operating practices. The Tetra Tech team performed literature research and conducted interviews to assess the different materials that have been installed in marine environments and their performance. The information obtained during this phase will be used to provide recommendations for the test materials in the study moving forward to simulate the test screen material and intake piping material.

APPROACH

The approach to the literature research is a two-fold approach: review of published documentation and interviews. A search for published documentation was conducted for materials used for structures and/or piping at the following: desalination facilities (study, design, and operation), intake screen manufacturers, Naval/Military applications, power plants, ports, and harbors. The material obtained and reviewed as part of this research is listed on the reference summary sheet in Appendix A. Particular focus was spent on research properties of seawater that impact marine installations, type of materials, corrosion, biofouling, and maintenance. Interviews were conducted with several industry experts and operators at wedge wire screen installations. The notes from the interviews conducted are contained within Appendix B. The research conducted is a broad based focus from publications and installations both locally and international.

CHARACTERISTICS OF LOCAL SITE CONDITIONS

The installation location of the intake screen and the make-up of the sea water at that location both in terms of aquatic life and water quality are important considerations for material selection. The following site factors were identified that impact material selection;

Seawater Corrosion Factors

Based on our review of the available literature, conditions that support corrosion are site specific. We identified the parameters that, in general, were noted as impacting corrosion rate and type and provided a general summary for the corrosion tendency of seawater towards metal alloys:

1. Concentration of chloride ion – Higher concentration of chloride ions promotes corrosion.
2. Concentration of oxygen – Conditions that result in low levels of oxygen can result in anaerobic conditions and may result in corrosion due to anaerobic micro-organisms. Environments rich in oxygen result in promoting oxidation reactions.
3. Flow velocity – Increase flow velocity leads to erosion-corrosion. Velocities depend on geometry of the structure and/or pipe. As velocities increase the potential for the protective oxide layer to be removed increases which will increase corrosion potential. The other result of velocity is that seawater contains a high amount of total dissolved solids and suspended solids such as sand and particulates that act as an abrasive.
4. Seawater temperature – Lower temperatures slows the formation of the protective outer oxide coating while warmer temperature increase the maturation of the oxide coating.
5. Seawater pH – The specific level of sea water acidity of alkalinity can promote aqueous corrosion, an electrochemical process. Most metals form a stable oxide or other film to inhibit the corrosion process. As the environment tends to become more acidic the corrosion potential increases.
6. Microbial corrosion – Iron-oxidizing bacteria can cause a breakdown of the outer protective oxide layer of a metal or shield the oxygen from the metal resulting in pitting.

Seawater Biological Growth Factors

Similar to the corrosion factor, biological growth factors are also site specific. We have made general conclusions regarding how biological activity is affected by seawater:

1. Dissolved oxygen concentration – higher dissolved oxygen concentration support marine life, however, lack of oxygen may also promote anaerobic bacterial growth.
2. Water temperature – warmer water temperatures promote biological growth
3. Water salinity – a stable salinity range is critical for micro-organisms to balance osmotic pressure.
4. Flow velocity – velocities that carry nutrients provide ideal feeding grounds for macro-organisms. Conversely, stagnant conditions result in decreased nutrients and oxygen replenishment and reduces macro-organism growth rate.
5. Local biological activity (nutrients and food source availability) – a higher concentration of nutrients result in increased micro and macro biological activity;
6. Seawater pH – micro- and macro-organisms are sensitive to pH changes.
7. Pollution – micro- and macro-organisms are sensitive to pollution in the water.

Marine fouling was studied by PK Abdul Azis, et al, 2002 to address the serious implications on performance of desalination and power plants. Micro and macro-biofouling is a serious problem to utility managers that operate intake structures in seawater. The composition and community of organisms have wide variations based on location. Microfouling is caused by bacteria and diatoms attached to a surface and rapidly divide and form a slime layer. Marine animals such as barnacles, mussels, byozoans, hydroid, tunicates, corals, etc result in macrofouling. Attachment of biofouling results in pipelines losing their carrying capacity and corrosion of materials.

Similar marine studies at the seawater reverse osmosis plant at Al-Birk located in the southern region of the Red Sea coast of Saudi Arabia faced operational problems that were thought to stem from biofouling. The study identified that biological activity is a result of site dependent factors including: temperature, nutrient load, pollution and the depth of the intake.

Site Characterization

The OWDDF is located off the Redondo Beach coast just offshore and north of the King Harbor breakwater, at the AES Power Plant. The north intake of the AES Power Plant was utilized by the OWDDF project with the intake piping installed through the approximately 1800 foot long, 10-foot diameter tunnel and the intake screen installed just above the outlet of the 14-foot diameter intake riser pipe. The AES intake tunnel pipe is no longer used to draw cooling water to the plant. As part of the Intake Barrier Structure Project performed by the District, this site was characterized per the Basis of Design Report prepared by Halcrow Inc, dated December 9, 2011. The water level, wind, currents, water temperature, salinity, and waves were analyzed. The data was derived from measurements performed by the National Oceanic and Atmospheric Administration (NOAA) at the nearby Santa Monica Pier. The site characterization from this report is summarized in Appendix C.

The tide range is in the order of 5 to 6 feet with the Mean Sea Level (MSL) is approximately 3 feet above the Mean Lower-Low Water Level. Winds in Santa Monica Bay are typically light and dominated by the northwesterly sea breeze that sets in around noon. Average wind speed is 5.6 knots and maximum wind speeds experienced during an El Nino event have been measured up to a maximum per hour average of 19.6 knots. Currents offshore of Santa Monica Bay are a combination of tidal and wave induced currents. The currents are relatively low in magnitude and the tidal current speed diminishes toward shore due to bottom friction. The water temperature seasonally varies between 57ºF and 74ºF. The average salinity is 33.5 parts per thousand (ppt). The waves are typically mild with wave heights about 3 feet for 88% of the time.

Water Chemistry

The District provided water chemistry from their monthly monitoring reports that were generated while the OWDDF was in operation. The information was provided by the District as part of their quarterly water quality sampling submittal to California Regional Water Quality Control Board dated October 31, 2011 for water samples taken at the AES Power Plant discharge pipe in July 2011, August 2011, and September 2011. These values will change throughout the course of a year and may even be different year to year. The data is a snap shop in time of the water quality and was used to gain a feel for the seawater chemistry:

pH	7.9
Temperature	70.4 F
Dissolved Oxygen	7.85 mg/l
BOD (composite)	3.52 mg/l
Ammonia (as N)	1 mg/l

General Observations of Local Conditions

The location off King Harbor is a thriving marine environment, with conditions that support marine life. Based on the published information, as well as the marine growth witnessed by the District at the OWDDF, the conditions and the nutrients are present to support aquatic organisms. In addition, the seawater is considered highly corrosive to metals.

INTAKE SCREEN MATERIAL SELECTION

Various publications and studies were reviewed relative to the performance of materials installed in a marine environment. The performance of the material is dictated by the specific installation site's properties such as salinity, temperature, currents, and nutrient availability. Publications from international sources as well as local (west coast) publications were reviewed. In addition, interviews were conducted with several industry experts and operators. The material obtained and reviewed as part of this research is listed on the reference summary sheet in Appendix A. The notes from the interviews conducted are contained within Appendix B. The materials assessed were those that can be used to construct a wedge wire screen. The materials need to be commercially available as well as be made into wire, bar, and plate shapes to construct intake screens. Based on the literature research and interviews, two material groups were found overwhelmingly used; copper alloys and steel alloys.

In a seawater installation, seawater has the following challenges:

1. Low resistivity promoting galvanic corrosion.
2. Microbial growth promoting a slime layer/biofilm which forms on surfaces and has a catalytic effect on the cathodic reaction in the corrosion process (i.e. oxygen reduction).
3. Erosion corrosion – the marine environment is an abrasive environment due to the suspended solids, flowing currents, and wave action. It should also be noted that per the publication by Detlef Gille for seawater intakes for desalination plants dated February 2003, screens such as stainless steel or copper nickel that become partially blocked by fibrous debris, the velocity through the remaining free area will increase the effect of erosion-corrosion.

Any metallic material selection will be potentially affected by one or all of the above types of corrosion methods.

Copper Alloys

Information regarding the copper alloys were obtained from various sources including Copper-nickel Alloys, properties and applications published by the Copper Development Association and Uhlig's Corrosion Handbook, 2011.

Pure copper is a very soft and malleable metal. It is alloyed with small quantities of metals to modify the properties for particular applications while retaining many of the properties of the pure metal. Additions of zinc, selenium, and nickel are made to improve the mechanical properties of the metal and to retain its corrosion resistance properties. Iron (Fe) is added to improve the resistance of some copper alloys to erosion-corrosion (about 2%). Copper and its alloys display noble potentials in regards to corrosion resistance. They also form a cuprous oxide product fill that is responsible for their protection. There are several copper alloys suitable for marine service: coppers, copper-nickels, bronzes, brasses, and copper-beryllium.

The 90-10 copper-nickel alloy is the most commonly used wrought copper alloy for marine applications. Alloys with higher nickel content or highly alloyed with chromium, aluminum, and tin are used where greater resistance to flow conditions, sand abrasion, wear, and galling are required, as well as higher mechanical properties. The 70-30 copper-nickel alloy is stronger and can withstand higher flow velocities. Alloys modifying 70-30 are available when higher resistance to erosion corrosion is required due to suspended solids. Copper alloys are ductile and can be machined for shape fabrication. The 90-10 and 70-30 copper-nickel alloys can be joined by brazing and welding. While consumables are available that deposit weld metal similar in composition to the 90-10 copper-nickel alloy, welds made with them may not have adequate corrosion resistance for all applications. Consumables for the 70-30 alloy, on the other hand, offer superior deposition characteristics and the corrosion resistance of 70-30 weld metal is at least comparable to each of the base metal alloys. These consumables are therefore recommended for both types of alloy. The 90-10 copper nickel is often selected because it offers good resistance at lower costs.

Summarized herein are the properties of copper alloys used in marine service.

Typical Applications for Copper-Alloys

Alloy	Typical Applications
General Engineering Alloys	
– 90-10 Cu-Ni	Naval and commercial condenser and seawater piping, boat hulls, aquaculture cages
– 70-30 Cu-Ni	Naval and commercial seawater piping, heat-exchange equipment, military submarine service, boat hulls.
– Nu-Ni-Cr	Wrought condenser tubing, cast seawater pump and valve components
High Strength Copper-Nickels	
– Cu-Ni-Al	Shafts and bearing bushes, bolting, pump and valve trims, gears, fasteners
– Cu-Ni-Sn	Bearing, drill components, subsea connectors, valve actuator stems and lifting nuts, seawater pump components

Summarized herein are the copper alloys and their respective UNS reference:

Metal Alloy UNS (Unified Numbering System) designations for Copper-Nickel alloys		
Alloy	**UNS**	**ASTM**
– 90-10 Cu-Ni (wrought copper alloy)	C70600 C70620 (welding rod composition) C71581 (welding filler metal)	B111, B122, B151, B171, B359, B395, B432, B466, B467, B543, B552, B608
– 70-30 Cu-Ni (wrought copper alloy)	C71500 C71520 (welding rod composition) C71581 (welding filler metal)	B111, B122, B151, B171, B359, B395, B432, B466, B467, B543, B552, B608, F467, F468

B111 – Copper and Copper-Alloy Standard Specification for Seamless Condenser Tubes and Ferrule Stock
B122 – Copper-Nickel Standard Specification for Plate, Sheet, Strip and Rolled Bar
B151 – Standard Specification for Copper-Nickel-Zinc Alloy and Copper-Nickel Rod and Bar
B171 – Standard Specification for Copper-Alloy Plate and Sheet for Pressure Vessels, Condensers and Heat Exchangers
B359 – Standard Specification for Copper and Copper-Alloy Seamless Condenser and Heat Exchanger Tubes with Integral Fins
B395 – Standard Specification for U-Bend Seamless Copper and Copper Alloy Heat Exchanger and Condenser Tubes
B432 – Standard Specification for Copper and Copper Alloy Clad Plate
B466 – Standard Specification for Seamless Copper-Nickel Pipe and Tube
B467 – Standard Specification for Welded Copper-Nickel Pipe
B543 – Standard Specification for Welded Copper and Copper-Alloy Heat Exchanger Tube
B552 – Standard Specification for Seamless and Welded Copper-Nickel Tubes for Water Desalting Plants
B608 – Standard Specification for Welded Copper-Alloy Pipe
F467 Standard Specification for Nonferrous Nuts for General Use
F468 Standard Specification for Nonferrous Bolts, Hex Cap Screws, Socket Head Cap Screws and Studs for General Use.

Other UNS numbers for copper nickel alloys are available, however they were found to not be commonly used and their applications could not be confirmed, are no longer used but still listed or are used in the manufacturer of electrical components

Summarized below are copper-alloys properties in seawater:

Copper-Nickel Alloy Properties
Anti-biofouling properties (typically installed with no antifouling coatings but rather uncoated)
No cathodic protection of the alloy is also recommended
Copper alloys also have a high resistance to chloride pitting and crevice corrosion.
Copper alloys are also not susceptible to: • ammonia stress corrosion cracking • suphide stress cracking • hydrogen embrittlement.
The surface film (patina) is critical in corrosion resistance of the material. The surface film can take several weeks to develop and mature. During the initial exposure it is critical to establish this protective layer.
Erosion corrosion due to flow velocity or suspended material can result in the surface film to breakaway. The critical flow velocity and shear stress depend on the alloy and geometry. The maximum flow velocity for a 90-10 Cu-Ni piping greater than 4-inches is approximately 11 ft/sec. 70-30 Cu-Ni can be used at velocities around 13 ft/sec.

The anti-biofouling properties of copper-nickel alloys are attained by the formation of surface films and caused by a reaction with the seawater. In marine installations, a surface patina is developed. The eventual development of the light green patina can take years to develop. Copper alloys are intended to be allowed to corrode. The general corrosion rates for seawater vary on temperature, salinity, and pH but are expected to be between 0.02 and 0.002 mm/year, with higher rates of corrosion assumed at the initial installation and decreasing over time.

Steel Alloys

Different grades and types of steel are used in a variety of marine installations. Steel can be provided in numerous shapes and can be welded. Carbon steels can be used cost-effectively when corrosion is not an issue by providing a sufficient corrosion allowance. For this study, carbon steel is not being considered as the District is looking for a long term product.

The various types of stainless have differing corrosion resistance properties when in contact with seawater. Stainless steel does not have inherent anti-biofouling properties and most often needs to be coated in order to address potential biological growth. Coatings do not have a long life expectancy and vary widely due to erosion from the suspended solids in the marine environment. Certain types of stainless steel have been used in various marine applications. Grade 304 austenitic stainless steel is suitable for above the waterline applications that are frequently washed down with fresh water. Grade 316 austenitic stainless steel is suitable for above the water line installations of deck fittings and riggings. Stainless steel will corrode in seawater; however, the corrosion process is not an evenly distributed process and typically occurs through the result in pitting and crevice corrosion. Duplex stainless steel was developed to address this type of pitting and crevice corrosion. The three most common types of duplex stainless steel used in marine applications are:

1. UNS S32304 (commonly known as 2304)
2. UNS S31803 (commonly known as 2205)
3. UNS S32750 (commonly known as 2507)

In seawater applications, Duplex 2205 is the most widely used duplex stainless steel grades with good corrosion resistance and high strength. Super Duplex 2507 is used for demanding applications for increased strength and corrosion resistance properties. Super Duplex 2507 has resistance to pitting, crevice, and general corrosion. Stainless steel is also susceptible to corrosion by chlorine and sulfide attack.

Titanium

Titanium is not susceptible to corrosive attack by seawater. It is used in various submarine valves, pumps, and ship cooling piping systems. Titanium is resistant to general corrosion and crevice corrosion in all water temperatures, polluted waters, and microbiologically influenced corrosion. Titanium is also resistant to erosion corrosion. Titanium can be machined, cut, and welded.

Anti-Biofouling Coatings

Several anti-biofouling coatings were reviewed. Anti-biofouling coatings are used on numerous submerged applications to mitigate biological growth. Coatings studied to mitigate biological growth are divided into the following categories:

1. Foul Release Coatings
2. Antifouling Coatings
3. Fluorinated Powder Coatings
4. Epoxy and Metallic Coatings

The following summarizes the results from coatings that were tested in a mussel control program published by Dr Allen Skaja for the Bureau of reclamation, March 2012:

1. The Foul Release are silicone based. Bryozoans and algae did not foul the silicone coatings and if attached can easily be removed. Silicone foul release coatings are soft and susceptible to abrasion and/or gouging by debris. The life expectancy of this coating is about three (3) years.
2. Antifouling Coatings are copper metal filled polyester. Antifouling coatings try to mitigate biological growth by utilizing copper, an element that is toxic to biological growth. The antifouling coatings perform well in mitigating mussel attachment. The life expectancy of this type of coating is about two (2) years.
3. Fluorinated Powder Coating provides a slick surface that allows easy removal of growth. These coatings do not actually inhibit growth and continual maintenance is required.
4. Epoxy and Metallic Coatings fouled within one (1) year of service.

As discussed in P.K. Abdul Azis, et al, February 2002 paper on review of control technologies for marine macrofouling; the advantages of coatings are ease of manufacture, high speed and low-cost application. The disadvantages are limited life, the lack of ways to apply coating to submerged or wetted surfaces and toxicity of control agents.

All coatings were found to require maintenance and had short life expectancies that require recoating.

Some coatings are NSF 61 certified for drinking water system components.

Summary from Interviews

Screens of various materials (Cu-Ni, Z-Alloy, and Stainless Steel) have been used throughout the world. In general, wedge wire screens composed of copper alloys had lower bio-growth than super duplex stainless steel. Stainless steel in general had higher corrosion resistance, especially at higher temperatures. Welds were also found susceptible to corrosion. Biogrowth and corrosion was found to occur at almost all locations and the degree of effectiveness varied widely for both copper and steel alloys. Those interviewed recommend a maintenance program. The type of maintenance varied and included manual cleaning performed by divers and utilizing compressed air to try to dislodge debris and attachments.

A summary of wedge screens seawater installations was extracted from a database provided by Johnson Screens Company from their US and European office. The majority of installations listed are outside US (about 90%).

Summary of Seawater Installations Provided by Johnson Screens	
Period of equipment order dates	1994 - 2012
Number of seawater installations reported	78
Material of construction	316L SS – 15% Duplex steel – 32% Cu/Ni – 52%
Capacity, m3/hr (gpm)	22 – 7250 (100 – 32,000)
Slot size, mm (inch)	1 – 9 (0.04 – 0.35)

The intake screens were used for various ocean water applications including: power plants, liquefied natural gas, desalination, thalassotherapy, etc.

Conclusions for Intake Material

Copper alloys, duplex, and super duplex stainless steels are commonly used in marine installations. The 90-10 and 70-30 are two of the most common copper alloys and the duplex 2205 is the most common stainless steel alloy. During our research we found no reference to screens that were constructed with titanium. We recommend that the following materials be considered for the study:

1. 90-10 CuNi (UNS C70600)
2. Johnson Screen Z Alloy
3. 70-30 CuNi (UNS C71500)
4. 2205 Duplex stainless steel
5. 2205 Duplex stainless steel (coated with Sherwin Williams Foul Release System)

Super duplex stainless steel was not deemed warranted as neither the duplex nor super duplex have anti-biofouling properties, and the duplex stainless steel is suitable for the offshore water temperature. The additional cost for the super duplex does not appear to be warranted for the addition anti-corrosion properties.

Based on our review of different foul release coatings and our discussions with the District, we researched the coating system that has been utilized for multiple years and that also had NSF 61 certification. This Sherwin Williams Foul Release System has a well documented product history in the United States and is NSF 61 compliant. The system consists of the following:

A. 1st coat - Sherwin Williams Macropoxy 646 PW immersion grade epoxy primer @ 6 mils dft

B. 2nd coat - Sherwin Williams Macropoxy 646 PW immersion grade epoxy primer @ 6 mils dft

C. 3rd coat - Sherwin Williams Seaguard Sher-Release beige silicone Tie Coat @ 6 mils dft

D. 4th coat - Sherwin Williams Seaguard Sher-Release white silicone Surface Coat @ 6 mils dft

It should be noted that all coatings require maintenance and recoating. The life of a coating is site specific to the conditions it must perform in.

INTAKE PIPING SELECTION

Various types of piping are used in marine installations. The selection of pipe material is based on the resistance to corrosion, availability, and ease of installation. Common pipe materials used in submerged ocean water service include: concrete, duplex stainless steel, high density polyethylene (HDPE), polyvinyl chloride (PVC), and glass reinforced plastic (GRP) pipe.

Installations in Saudi Arabia, Fort Lauderdale, Cyprus, and Israel were contacted to ask about the performance and maintenance of their various intake pipelines.

Corrosion

Due to seawater's high potential for corrosion, non-metallic pipes are often the preferred option. Pipes, just like the intake screen material selection, are susceptible to same corrosion mechanisms and biological growth challenges. Metallic pipes will be subject to galvanic corrosion, microbial growth slime layer/biofilm corrosion process (i.e. oxygen reduction), and erosion corrosion. Pipe systems that utilize carbon steel, ductile iron, or 316 stainless steel are not being considered as they corrode quickly in a seawater environment and would result in a limited service life. Duplex stainless steel pipe is used commonly in desalination, naval, port, and harbor installations; Duplex stainless steel is corrosion resistant up to a point and is still susceptible to pitting and crevice corrosion in seawater with similar water temperatures. It is susceptible to chloride attack and if chlorination is being considered to mitigate biological growth, it is not a preferred material.

Concrete pipes are subject to sulfide corrosion attack due to sulfur-reducing bacteria. The bacteria produces an acid that attacks the lime in the pipe resulting in softening of the concrete. Concrete has to be coated with a protective coating to mitigate this deterioration. The coating has to be maintained as its effectiveness is diminished over time and due to erosion corrosion.

A non-metallic pipe such as HDPE, PVC and GRP are not impacted by any of the corrosion processes above.

Biological Growth and Maintenance

Concrete pipes have rougher interior surfaces and require continual maintenance due to slime layer development as well as attachment by mussels, barnacles, and other sea life. Concrete pipes require continual maintenance either by divers or by pigging (pulling/dragging a mandrel) to remove the attachments.

All the non-metallic piping that has been placed into service has experienced attachment by biological growth at different time intervals. Based on the interviews and studies, the time interval has less to do with the material than it has to do with the marine environment and how aggressive/nutrient and animal rich it is. All non-metallic piping has to be maintained.

Maintenance strategies for intake systems to mitigate biological growth varied and are summarized herein:

1. Heat Treatment

Biofouling control methods based on temperature changes are used in power plant cooling systems (Kamala Kanta Satpathy et al., 2010). This method is routinely used at some plants in the USA, England, Italy, Netherland, and Russia. Heated effluent from the condenser of the power plant is diverted through the intake tunnel which when passed through the condenser picks up more heat. In general, heating the water to a temperature of 40º C (104º F) for approximately one hour is enough to eliminate mussel and other fouling organisms. Heat treatment was only found to be used at power plants; we did not find any desalination facilities utilizing this control strategy.

2. Scouring velocities (velocities kept at or higher than 10 fps)

In Italy at Vado Ligure, the cooling water intake of a power plant (1320 MW (e), four 2.2 m diameter culverts of 1400-1500 m long) was kept free of biofouling for l4 years by maintaining a velocity of 11 ft/sec (Kamala Kanta Satpathy et al., 2010)

3. Addition of chemicals
    a. Constant addition
    b. Shock chlorination

Chlorination is a common method used to control biofouling. Intermittent chlorination can be used to compact micro-fouling, such as a bacterial slime layer (Boehmer et al, 1985). Continuous chlorination is needed to address macro organisms such as mussels; mussels will close up during intermittent periods of chlorination (Boehmer et al, 1985). Chlorination is effective in killing marine organisms; shells from barnacles, mussels, etc remain in the system. (Boehmer et al, 1985).

Continuous and shock chlorination is used Al-Jubail Power/MSF Plant. The residual chlorine target was 0.2 to 0.50 ppm.

The seawater reverse osmosis plant at Al-Birk located in the southern region of the Red Sea coast of Saudi Arabia utilized continuous chlorination and then added sodium metabisulfite (SBS) to neutralize the chlorine residual before the reverse osmosis membranes. The free chlorine residual was a maximum of 1 mg/l. This resulted in the surviving bacteria feeding on the nutrients caused by the degradation of larger molecules and the bacteria entered into a cycled of tremendous growth. This resulted in a significant increase in biomass developing of the surfaces of the piping and RO membranes (Mohamed Saeed, January 2000).

4. Manual maintenance (typically pigging)

The operators the Ashkelon Desalination Plant in Israel pig the line one to two times a year to remove macro-organism growth. The pigging is done in combination with chlorination.

5. Combination of chemical and manual maintenance techniques

Based on our research and discussion with industry experts, all piping systems will require a maintenance program whether it is chemical, manual (pigging, divers), or both. Chlorination was the chemical of choice being used to control biofouling. We did not find publications that documented the use of another disinfectant such as chloramines, ozone or any acids to control biological growth. It is our understanding that the District’s proposed full scale facility has a rated capacity of 40 mgd of seawater drawn through a 54-inch diameter pipe. This results in an average velocity through the pipe just less than 4 fps based on the District’s Ocean Water Desalination Program Master Plan. To mitigate biological growth solely through scour, velocities within the pipe will need to be about 10 feet per second or higher per the research found. Non-metallic pipes being considered are appropriate for this control strategy. Stainless steels are susceptible to corrosion attach by chlorine.

The conclusions from the interviews was that maintenance requirements are site specific; at some locations the pipe has been relatively clean requiring very little maintenance and at other locations the inlet pipe has required extensive cleaning.

Conclusions for Intake Piping Material

The intake pipe should be non-metallic to mitigate the corrosion issues that are present in a submerged seawater application. For the test, HDPE and/or PVC could be used. GRP type pipe does not provide the connection types to readily assemble a testing pipe rack. The interior surfaces of all three of these non-metallic materials are also very similar in how they are formed. HDPE pipe is being recommended for the following reasons:

1. It has been used at the demonstration facility and known results of its performance during and can be used as part of the study
2. It is readily available
3. Its interior surface is similar to that of PVC and GRP as all three are formed with a smooth interior
4. Cost effective

Conclusions for Intake Piping Control Strategies

Based on our review and interviews, chlorination was the most widely used form of chemical control strategy. The District, as part of the OWDDF, utilized chloramination. The District preferred chloramines over free chlorine in order to protect the RO membranes from being damaged due to their sensitivity to free chlorine. Shock chlorination was used at some locations to kill the micro-organisms such as the bacterial slime layer. It also may result in killing macro-organisms; however this did not result in the attachments (e.g. shells and other encrustations) from detaching from the interior of the pipe. It has also been reported that several macro-organisms can survive several hours (more than 8 hours) of high concentrations of chlorine. The time duration was found to be dependent on type of species and site location. We also did not find publications that documented the use of other disinfectants such as chloramines, ozone or any acids to control biological growth. Another possible control strategy is creating a low oxygen (anoxic) environment. If the pipeline can be taken out of service and allowed go stagnant, resulting in depleted oxygen and nutrient levels, the macro-organism growth can be slowed. However, this will not mitigate the micro-organism slime layer growth or anaerobic bacteria. While this may result in slowed or even eventual macro-organism death, this process also may not result in detachment of the encrustations.

Based on our research we submit the following control strategies for this study to be considered by the District:

1. Continuous chloramination
2. Shock chlorination

The dosing and rate of the chemical will be discussed in the test plans.

Anoxic control will not be further studied as this control strategy only hinders or slows growth but does not prevent it. While the pipe is in operation, growth of micro- and macro-organisms is occurring. This method may slow or delay growth but will ultimately require maintenance in order to remove the growth that does occur. This also means that the pipeline will need to remain out of service long enough for the dissolved oxygen in the water to be depleted. This does not ultimately achieve the District's goal of utilizing a control strategy that mitigate biological growth and minimizes future maintenance. This also results in potential long interruptions in service.

High velocities to control biological growth were only found to be used at one location. High velocities results in higher headloss through the intake piping and the need for higher lift at the pump station and increased energy costs. The increased head and energy costs will be estimated as part of the intake piping test plan. At this time, control by high velocities is not being considered a viable alternative.

Similar to the intake screens material recommendation, an anti-fouling coating is not being considered. The required maintenance and continual recoating required is not desirous.

MWB/mah

Attachments

APPENDIX A

Reference List

Reference List

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APPENDIX B

Interviews

Interview with industry experts

Thomas M. Missimer, PhD
Visiting Professor
King Abdullah University of Science and Technology, Saudi Arabia
Author of Handbook: Water supply development, aquifer storage, and concentrate disposal for membrane water treatment facilities, Schlumberger (2009).
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Comments regarding application of wedge screens as intake inlet structure in seawater environment.

1. Johnson Screens utilize Cu-SS alloy (Z- Alloy) for manufacturing of wedge wires that have lower affinity for bio growth then wedge screen made of super duplex material. It has however, lower corrosion resistant then super duplex alloy, especially at high seawater temperatures.
2. The intake head (wedge screes) are cleaned by compressed air or manually (divers). The compressed air is effective for intake lines shorter than 300 m (~1,000 ft). For longer distance from shore, the air compressor has to be located closer to the intake inlet (on a floating platform)
3. Recommends shock chlorination as solution to prevent bio growth in the intake pipe.

David Keever
Director of operation
Aqua Chem
Ft. Lauderdale, Fl
Phone: (954) 524 5129

Comments regarding performance of Jonson screens in Aqua Chem RO seawater desalination plants

1. Largest installation applying Johnson screens in seawater has feed water flow of 1,200 gpm.
2. 70 – 80 smaller installations in the Caribbean
3. The oldest installation with Johnson screen intake started operation in 2004.
4. Preferred material of Johnson screens utilized by Aqua Chem is 316 L SS. Screens made of copper – nickel alloy experiencing some degree of corrosion at elevated seawater temperatures (Caribbean locations)
5. Frequent problem: mussels grow on the intake screens . Divers has to mechanically clean every 6 months. Some mussels grow at the pipe entrance. Very small grow inside raw water piping.
6. Aqua Chem intakes do not utilize air burst backwash of the wedge wire screens.
7. Very satisfied with product and responsiveness Johnson Screens company.

Nikolay Voutchkov,
President
Water Globe Consulting
Phone: (203)504-8343
e-mail: nvoutchkov@water-g.com

Comments regarding application of wedge screens as intake inlet structure in seawater environment.

1. General suitability of wedge screens for seawater intakes – they are very suitable for intakes of all sizes.

2. Convenience of operation – if installed in underwater currents with velocity of 0.3 m/s sec or more they are maintenance free.
3. Effectiveness of air burst to unplug screens from sediments and biological debris – varies with manufacturer – I would recommend a combination of air and water burst offered by all suppliers.
4. Relative advantage of Cu-Ni alloy vs 316L SS as screen material: corrosion resistance and biofouling. – 316L SS will not last more than 6 months in seawater – most existing screens for seawater applications are Cu-Ni. In one case of seawater application of in SWRO system in Indonesia of capacity of 4.5 MGD the intake wedge wire screens were made of 316 L alloy. The screens had high rate of corrosion after operation for 6 months.

Erineos Koutsakos
Limassol Water Co., Cyprus
General Manager
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Comments on operation of seawater intake in the RO seawater desalination plants in Cyprus

1. Use of GRP piping resulted in high degree of bio growth in the pipe due to rough surface. Use of HDPE reduced attachment rate of barnacles to the intake pipe walls. No chlorination of intake pipe has been applied.
2. The seawater inlet section of the of the immersed intake tower is cleaned manually by divers utilizing strong water jet. Intake cleaning is conducted every 2 -3 years.
3. Common problems at the intake inlet tower are barnacle grow and plugging by sea weeds. The solution, that has been applied at Larnaca plant, Cyprus, is to allow passage of the sea weeds through the intake head and collect them on the traveling screens at the intake clear well.
4. Metal parts immersed in seawater require cathodic protection (sacrificial zinc anode) to reduce corrosion rate.

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VP Technology
Israeli Desalination Engineering (IDE), Israel
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IDE built and operates number of large RO seawater desalination plants at various locations.
The largest IDE plant of permeate capacity of 105 MGD has been completed last year.

Comments regarding biofouling experienced by IDE in seawater intakes.

1. The major problem is with barnacle larva. It is small size, less than 1 mm. It colonizes wall of the intake pipes and grows. Periodic shock chlorination, at the level of 5 ppm is not effective to prevent grow in the pipe. Dead barnacle serves as new rough surface for new barnacle to attach and grow. The only partially successful measure is high flow velocity in the intake pipe. Should be above 1.5 m/sec (~ 5ft/sec).
2. Cleaning of intake pipe by pigging, 1 -2 times per year. The intake head is cleaned manually.
3. Use of Cu-Ni alloy in intake not effective in prevention of bio growth.

E-mail from Mark Watson,
Bilfinger Water Technologies
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mark.watson@bilfinger.com

Response from Mark Watson on questions regarding suitability of material used in manufacturing of wedge wire screens for seawater applications. (Bilfinger is a subsidiary of Johnson Screens)

Ci-Ni and Z-Alloy are essentially one in the same. Z-Alloy is a copper-nickel alloy specifically developed by Johnson Screens for zebra mussel prevention. The make-up is confidential but it is closest to 90/10 cooper/nickel. This alloy was developed in the 1990's as an answer to the zebra mussel infestation in the Great Lakes. (see attached papers) It has since been shown to be very effective at anti-bio-growth in general including for seawater. Several years ago, Electric Boat called us and wanted to mount a T-18HC Screen out of z-alloy on the side of a trainer Trident Submarine in SC (that is all the ones you see on the installation list). Due to the trainer sub's lack of movement – the normal (9) intakes were an on-going problem. So after the first one was operated for a few months – we were going to remove it and dice it up and analyze the corrosion etc.. Since there was nearly no visible corrosion, they put it back on the sub and ordered a bunch more to complete the sub. We then started putting Z-Alloy in the Mediterranean area and found a little problem., Z-Alloy was at great corrosion risk in tropical warm water, in the presence of nitrates (wastewater outfall). We also have used duplex and our European group has used Super Duplex. These are great for corrosion but do not have any anti-bio attachment properties.

What we would recommend is us getting you a piece of screen (coupon) of each material considered and placing them in the area of the proposed intake for a while for corrosion study later.

APPENDIX C

Site Characterization

Site Characterization Table

Description	Measurement	Level
Highest Water Level Measured	Feet	8.5
Highest Astronomical Tide	Feet	7.27
Mean Higher-High Water	Feet	5.43
Mean Sea Level	Feet	2.79
North America Vertical Datum	Feet	0.19
Mean Lower-Low Water	Feet	0.00
Lowest Astronomical Tide	Feet	-1.97
Lowest Water Level Measured	Feet	-2.84
Wind	Avg Speed (knots)	5.6
	El Nino 1997 (knots)	19.6
Currents	Type	Combination tidal and wave induced
	Direction	Parallel to shore in a northwestward direction on the flood tide and southeastward on an ebb tide.
	Avg Velocity (cm/sec)	40 to 70
	Max Velocity (cm/sec)	45
Water Temperature	Ave Temp (C/(F))	18 (64.4F)
	Summer Temp (C/(F))	23 (73.4 F)
	Winter Temp (C/(F))	14 (57.2 F)
Salinity	Max (during 1998 El Nino) ppt	34.34
	Min ppt (1993 winter floods) ppt	31.02
	Winter to Summer Variation (%)	10
	Long Term Average ppt	33.5
Waves	Typical Height	Approx. 3 feet for 88% of the time
	Wave Period	12 to 18 seconds
	Max Storm Height (1983 storm event)	18.2 feet

The data was derived from measurements performed by the National Oceanic and Atmospheric Administration (NOAA) at the nearby Santa Monica Pier.