PUMP MATERIALS FOR DESALINATION PLANTS

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Contents

Summary

Materials of construction play an important part in determining the reliability, efficiency and economics of desalination pumps. It is shown here how, by using well established corrosion data to guide the selection of materials, the needs of pump manufacturers and operators can be achieved.

1. Introduction

Pumps are essential to the operation of all desalination processes and their reliability often determines that of the entire plant. As the various fluids handled, such as seawater, brines and distillate, all present corrosion problems, stringent materials selection is required to ensure long life and reliable operation.

Pump materials may be exposed to a variety of corrosive conditions, including static, fast flow, cavitation, corrosion fatigue and wear. This section considers the effects of these conditions on various materials considered for pumps, such as copper-base alloys, stainless steels, nickel-base alloys and alloy cast irons, and indicates how these materials can be used effectively for different components in pumps.

A variety of materials often offers the optimum solution in a particular pump type, therefore galvanic corrosion has to be considered.

The specialist requirements of pumps and recovery turbines for reverse osmosis (RO) processes are also reviewed.

Service experience with various materials in pumps is described.

2. General Considerations

Centrifugal pumps are the type most commonly used in desalination processes. These consist of an impeller which transfers energy from a prime mover to the fluid, causing it to flow. By impeding this flow, an increase in pressure or head can be developed. This is done by surrounding the impeller with a casing in the form of a volute which takes the flow from the impeller to discharge by means of a cutwater. Some pumps use diffusers to control the flow from the impeller. Figure 1 is a simple impeller/casing arrangement from which it is clear that fluid velocities and turbulence in the way of the impeller are high and materials resistant to these conditions are necessary if a long life is to be achieved.

In reverse osmosis processes the high pressure brine effluent from the plant can be used to generate power in a recovery turbine, thus reducing the power requirements of the process.

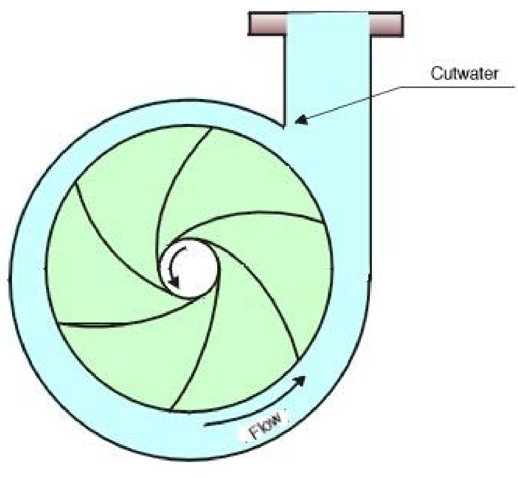

Figure 1. A simple impeller/casing arrangement.

3. Materials Behavior in Waters

3.1. Corrosion

Desalination processes handle waters of varying compositions such as seawater, concentrated seawater or brine, distillate and condensate. Some processes use brackish ground waters as feed and these can vary greatly in composition. Oldfield and Todd (1984) provided data on various brackish waters which showed wide variations in the various ions present. However, in terms of corrosion the situation is simplified by the fact that in most cases the pH of waters is in the range pH 6.0-8.0 - this is also true for most seawaters. This means that corrosion is mainly determined by the oxygen content of the water, as the pH is not low enough to release hydrogen. Below pH 4.5, corrosion of carbon steel is controlled by the hydrogen evolution under acid conditions and above pH 9.5 by an insoluble film of ferric hydroxide. In between these values, corrosion is controlled by the oxygen content of the water. In general, however, corrosion rates in this range depend upon many factors, such as the ability of the material to form protection films, the effect of dissolved salts in the water on these films, fluid velocity etc. In all cases, in the pH range normally found in waters, namely 5.0-8.5, the cathodic reaction is that for oxygen reduction, which can be written as:

$$O_2 + 2H_2O + 4c = 4OH^-$$

Fluid velocity is fundamental to all centrifugal pumps and different materials behave in different ways under flow conditions. Table 1 gives data on a range of possible pump materials in seawater. Using these data, it is possible to group these alloys into three types, as follows:

1. Gray cast iron and carbon steel: These corrode at appreciable rates at all velocities and are unsuitable (unless protected in some way) for long life application in pumps, apart from low speed occasional intermittent operation.
2. Copper-base alloys and austenitic cast irons: These alloys show good resistance at low and moderate velocities, but at high velocities suffer erosion-corrosion at about 1 mm per year.
3. Stainless steels and nickel-copper alloys: These show essentially zero general corrosion at low velocities, but with a tendency to pit. At velocities above about 1 m s^{-1}, further pitting ceases and corrosion is negligible up to at least 40 m s^{-1}.

Alloy	**Quiet seawater 0-0.6 m s^{-1}**		**Flowing**	**Seawater**
	Average corrosion rate (mm y^{-1})	**Maximum pitting (mm)**	**8.2 m s^{-1} Corrosion rate (mm y^{-1})**	**34-42 m s^{-1} Corrosion rate (mm y^{-1})**
Carbon steel	0.075[a]	2.0	-	4.5
Gray cast iron	0.55[a]	4.9	4.4	13.2
Admiralty gunmetal	0.027[b]	0.25	0.9	1.07
85/5/5/5 CuSnPbZn	0.017[b]	0.32	1.8	1.32
Ni-Resist cast iron: Type 1B	0.02[c]	Nil	0.2	0.97
NiAlBronze: (BS 1400 AB2-C)	0.055[d]	1.12	0.22	0.97

Alloy	**Quiet seawater 0-0.6 m s^{-1}**		**Flowing**	**Seawater**
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70/30 CuNi + iron	< 0.02[a]	0.25	0.12	1.47
Type 316 SS	0.02[a]	1.8	< 0.02	< 0.01
NiCu alloy 400	0.02[a]	1.3	< 0.01	0.01

[a] 3-year test at Harbor Island, North Carolina.
[b] 42-month test at Freeport, Texas.
[c] 6-year test at Kure Beach, North Carolina.
[d] 442-day test at Kure Beach, North Carolina. Alloy 10.6% aluminum, 2.5% iron, 5% nickel, 0.75% manganese.

Table 1. Effect of velocity on the corrosion of metals in seawater.

All the above data are taken from actual test results and are thus not exactly reproducible. This is particularly true of the maximum depth of pitting, which may vary widely from test to test.

3.2. Cavitation

In low pressure areas in pumps, e.g. at the pump suction, vapor cavities are likely to form. These can collapse in a higher pressure area, causing damage to the protective films on the material, allowing rapid corrosion to occur. In severe cases, the high pressures resulting from the vapor cavity collapse can cause mechanical damage to the material, so that it is possible for cavitation damage to occur in non-corrosive liquids. However, in waters the metal loss is normally a combination of both corrosion and mechanical attack.

The back faces (suction faces) of the impeller blades are another area where cavitation can occur, and the attack is usually confined to a small area on the back face, where the vapor cavities are collapsing. Other parts subject to cavitation are RO recovery turbines where the fast flow and release of high pressure can result in vapor cavities forming at nozzles and striking turbine blades.

Pump design, layout of piping or flow to the pump inlet largely control the occurrence or absence of cavitation, but it is desirable to use materials with good cavitation resistance as it is not always possible to avoid cavitation completely.

The usual way of testing cavitation resistance of materials is to subject a sample of the material to cavitating conditions in a medium similar to that in which it will be used. The most common type of test is the magnetostriction test, where a sample of material is mounted on a rod of nickel and immersed in a liquid. In a magnetic field, the nickel rod changes in length and, if caused to do so rapidly, then vapor cavities from on the sample. The damage caused in this type of test is largely mechanical and flow type tests are sometimes used to give a combined corrosion/mechanical attack. In these tests, the sample is exposed to fast flowing fluid and the flow is disturbed, e.g. by drilling a hole in a sample placed parallel to the flow, so generating cavitation damage downstream from the hole.

Table 2 gives data on some pump materials, in both parallel flow (in natural seawater) and magnetostriction tests (in 3 per cent salt solution).

These data indicate that stainless steels and nickel aluminum bronze have a high resistance to cavitation. The softer, less corrosion-resistant materials, such as gunmetals and gray cast iron, have poor cavitation resistances. The parallel flow test shows the effect of erosion-corrosion as well as cavitation - this is the situation normally experienced in practice.

Material	**Parallel flow test (37 m s^{-1})**		**Magnetostriction (20 Kc s^{-1})**
	General corrosion (mm y^{-1})	**Maximum cavitation (mm per 30 days)**	**Volume loss (mm^3 h^{-1})**
Gray cast iron	12	-	15
Admiralty gunmetal	0.9	-	7.2
Stainless steel type 304	0.025-0.10	0.05	2.7 (type 316)
Ni Al Bronze	0.33-0.50	0.25	1.1

Table 2. Cavitation tests in natural seawater and 3% salt solution.

3.3. Corrosion-Fatigue

Pump shafts operate under conditions of corrosion-fatigue, and cracking is a problem which must be considered. These shafts usually have features such as keyways, changes of section, etc., which accentuate fatigue stresses. Failures in service normally initiate at one of these points of stress concentration and can often be prevented by ensuring that generous fillet radii are provided at all changes of section, including keyways. It is surprising how often this simple design feature is omitted in practice. Even when cracks have initiated, if they can be found at an early stage and completely removed, leaving a well-radiused profile, subsequent cracking can be avoided.

Table 3 gives data on some shaft materials (Sedriks and Money 1978) in natural seawater. One of the most commonly used shaft materials for seawater and brine pumps is stainless steel. For waters low in chlorides, lower grades of stainless steel such as Type 304 or the ferritic grades such as Types 410 (12%Cr) and 430 (17%Cr) can be used. However, for seawater, where pitting and crevice corrosion can occur, the minimum grade advised is Type 316 and equivalents. In general, alloys with high strength and corrosion resistance have good corrosion fatigue strength.

Duplex stainless steels such as UNS S31803 and various proprietary grades, are attractive for pump shafts as they have much higher strength than the standard austenitic grades such as Type 316 and can be used at higher design stresses. This allows a reduction of diameter and cost. Also, these alloys often have improved pitting and crevice corrosion resistance than Type 316. Early problems with distortion of duplex stainless steel shafts after final machining, have been overcome by careful heat treatment and machining sequences, and these alloys are now frequently used for shafting.

All values in MPa at 100 megacycles (48 days)		
Alloy	**UTS**	**Corrosion fatigue at 100 megacycles**
Inconel[a] Alloy 625	1028	345
Monel[a] Alloy 500	1214	179
CF-4 Cast Type 304L stainless steel (with cathodic protection)	-	138
Type 316 stainless steel	586	96
Type 316L stainless steel	545	89
Nickel aluminum bronze (cast)	600	86
CF-4 Cast Type 304L stainless steel	-	62

[a] Trademark

Table 3. Rotating cantilever beam tests in natural seawater 1450 rpm.

3.4. Effect of Deaeration

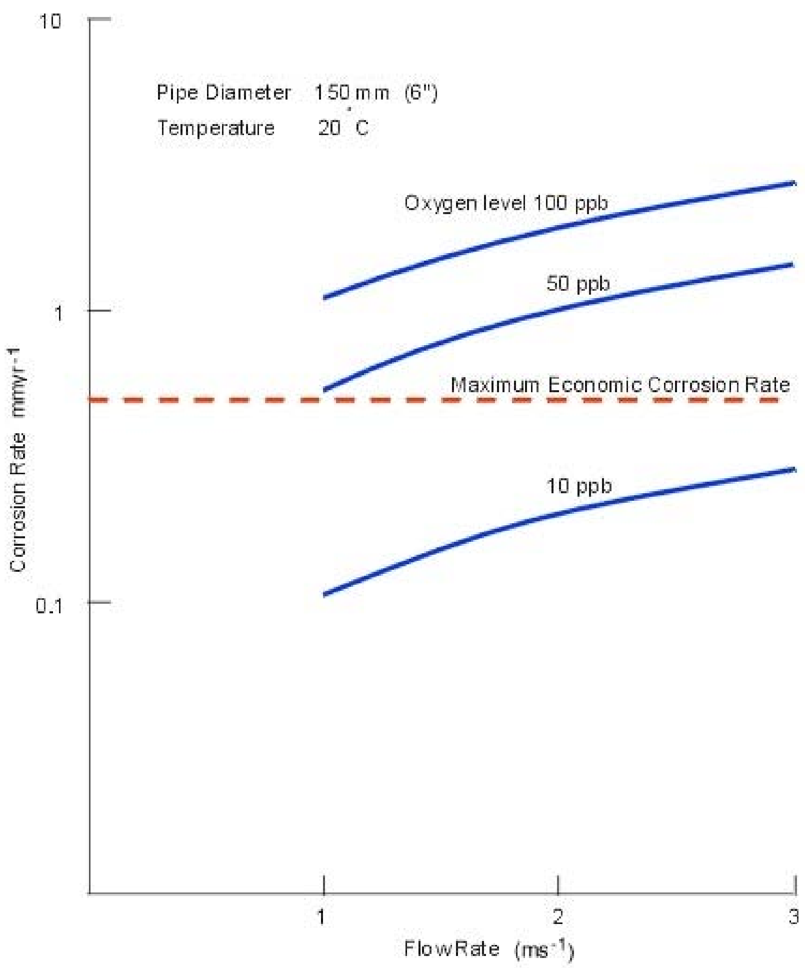

Figure 2. Estimates of corrosion of carbon steel in sea water as a function of flow rate at various oxygen concentrations.

Multistage flash distillation involves deaeration and the brine recycle and blowdown pumps are exposed to deaerated brine. In this environment, the oxygen is reduced from 5 to 10 ppm in natural seawater, to about 10 ppb in well-deaerated systems. As the pH is usually maintained in the slightly alkaline range (pH 7-8.5) the low oxygen level inhibits cathodic reaction rates and the environment is much less corrosive than natural seawater, even though the temperature may be raised. However, it is still necessary to use alloy materials as the high flow rates in pumps provide a high mass flow of oxygen to a corroding surface, even though the oxygen concentration is low. Figure 2 (Oldfield 1979) illustrates the high corrosion rates which can be experienced in carbon steel with deaerated brine. Thus, carbon steel and cast iron cannot be considered for deaerated brine pumps.

In the case of stainless steels, the resistance to pitting and crevice corrosion is much improved, as these reactions depend upon the establishment of a difference in oxygen concentration between the inside and outside of the pit or crevice. Clearly, at very low oxygen concentrations any difference will be extremely small and insufficient to set up an appreciable galvanic cell. Table 4 provides data on stainless steels in aerated and deaerated seawater.

Improved behavior in deaerated conditions can also be expected for copper-base and nickel-base alloys.

Alloy localized	**Environment**	**Velocity ($m\ s^{-1}$)**	**Maximum depth of corrosion (mm)**
Type 316 stainless steel	North Atlantic Ocean	0	2.4 P (486 days)
Type 316 stainless steel	Deaerated seawater 100°C 25 ppb O_2	0	0.17 P (547 days)
Type 304 stainless steel	Deaerated seawater 100°C 25 ppb O_2	0	0.60 P (547 days)
Type 316 stainless steel	130,000 ppm chloride pH 7.8 25 ppb O_2	40	0.027 G (/yr)[a]
13%Cr4%Ni stainless steel	130,000 ppm chloride pH 7.8 25 ppb O_2	40	0.18 G (/yr)[a]

P = Pitting
G = General corrosion.
[a] (Pini and Weber 1975)

Table 4. Materials in aerated and deaerated seawater and brine.

3.5. Galvanic Effects

Pumps are often made from several alloys in order to optimize technical and economic considerations. Specific cases involving galvanic considerations - such as the use of Ni Resist cast irons with stainless steels - are discussed later. General considerations can be dealt with using a galvanic series - see Figure 3. In using galvanic series, the following guidelines should be observed:

- Wherever possible, use materials as close together in the series as possible.

- Make the "key" components, i.e. components whose failure would cause greatest concern, from the more noble (cathodic) materials, so that these will receive cathodic protection from adjacent less noble (anodic) materials.
- Try to ensure that the less noble materials are present in much greater area than the more noble ones. In this context, it is sometimes advantageous to coat a noble material to improve the anode/cathode area ratio, so reducing galvanic effects on the less noble material.

In general, copper alloy pumps tend to be made entirely from copper-base alloys, and more than one alloy may be used. This is also the case with all stainless steel pumps. Here galvanic considerations are not a problem, as within these alloy groups the potentials of the alloys are similar. These comments refer only to galvanic effects, as corrosion can arise for other reasons.

The position of graphite in the galvanic series should be noted. It is cathodic to most metals and can give rise to galvanic corrosion problems when used in gaskets, packings and bearings.

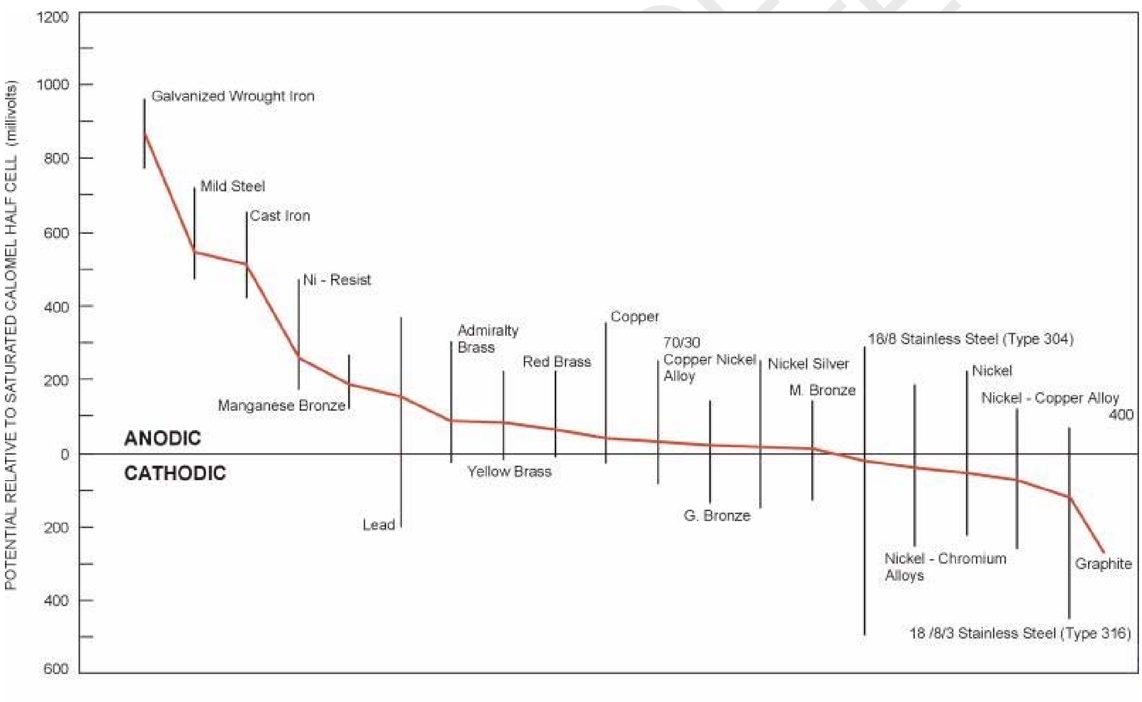

Figure 3. Galvanic Series.

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Bibliography and Suggestions for further study

A. Múñoz Elguera, S.O. Pérez Báez (2005),Development of the most adequate pre-treatment for high capacity seawater desalination plants with open intake ,Desalination, Volume 184, Issues 1-3, Pages 173-183

A.M.Shams El Din(1993),Copper alloys for desalination plants ,Desalination Volume 93, Issues 1-3, Pages 499-516

Anees U Malik and P.C. Mayan Kutty(1992), *Corrosion And Material Selection In Desalination Plants*,SWCC 0 & M Seminar, Al Jubail.

Antunes F F, Cornman R E and Hartkopf R J (1981) *International Congress on Desalination and Water Re-use*, Bahrain, pp. 109-122.

B. Todd (1967),The corrosion of materials in desalination plants Desalination, Volume 3, Issue 1, Pages 106-117

Bog S (1975) The resistance of copper alloys to different types of corrosion in seawater. (Seventh Scandinavian Corrosion Congress, Trondheim, Norway) pp. 356-370.

D. Bailey. (1982)"The Economics of Materials Usage in Seawater Systems." Project No. G30 .

Dawson J V and Todd B (1987) *Influence of carbide content on the stress corrosion cracking of Ni-Resist cast irons in warm seawater*; Nickel development institute publication 10018 and *BCIRA Journal*, November.

E. A. Tice and C. P. Venizelos (1963) *Corrosion Behavior of Condenser-tube Alloy Materials*. Power Nov. 1963.

Ghiazza E. and Peluffo P.(2003), A new design approach to reduce to reduce water cost in MSF evaporators. Proc. IDA world congress on desalination and water reuse, Bahamas .

J. W. Oldfield and B. Todd (1979), "Corrosion Considerations in Selecting Materials for Flash Chambers." Desalination, 31 .

J. W. Oldfield and B. Todd(1987), "Vapour Side Corrosion in MSF Plants." Desalination, 66 , pp. 171-184.

K. Habib, A. Fakhral-Deen (2001),Risk assessment and evaluation of materials commonly used in desalination plants subjected to pollution impact of the oil spill and oil fires in marine environment ,Desalination, Volume 139, Issues 1-3, Pages 249-253

Lee T S and Tuthill A H (1982) Guidelines for the use of carbon steel to mitigate crevice corrosion of stainless steels in seawater. *NACE Corrosion 82*, paper 63.

Miyasaka M and Ogure N (1986) Stress corrosion cracking of austenitic cast irons in seawater and brine, and its prevention. *NACE Corrosion 86*, paper 324, Houston.

Oldfield J W and Kain R (1994) *Crevice Corrosion Engineering Guide*, Nickel Development Institute, disk publication D-0003.

Oldfield J W and Todd B (1979) Corrosion considerations in selecting metals for flash chambers. *Desalination* 31, 365-383.

Oldfield J W and Todd B (1984) The use of stainless steels and related alloys in desalination plants (Proceedings of International Maritime Engineering Conference, Bahrain) pp. 139-147.

Olsson J. and Falkland ML.(2000), The Versatility of Duplex. Proc. Stainless Steel America 2000, Stainless Steel World, Houston 2000.

Olsson J. and Liljas M.(1994), 60 years of duplex stainless steel applications. Proc. NACE Corrosion ’94, Baltimore .

Olsson J. and Minnich K.(1999), Solid stainless steel for MSF once through plants. Proc. Desalination and water reuse, EDS, Las Palmas.

Pini G and Weber J (1975) Materials for pumping seawater and media with chloride content. *Sulzer*

Technical Review, 158.

S. Sato, K. Nagata and S. Yamuchi. "Evaluation for Various Preventive Measures Against Corrosion of Copper Alloy Condenser Tubes by Seawater." Paper No. 195. Corrosion 81. Toronto Apl 1981.

Sedriks A J and Money K L (1978) *Corrosion Fatigue Properties of Nickel Containing Materials in Seawater*. New York: International Nickel Co. Inc.

Sommariva C., Pinciroli D., Tolle E. and Adinolfi R.(1999), Optimization of materialselection for evaporative desalination plants in order to achieve the highest cost-benefit ratio. Proc. Desalination and water reuse, EDS, Las Palma.

W. F. Ridgway and D. J. Heath. "Lining Mild Steel Components with 90-10 Copper-alloy Sheet." Welding and Metal Fabrication. Oct 1969.

Zaharani S, Todd B and Oldfield J W (1986) Bimetallic corrosion in MSF desalination plants. (ASTM Symposium on Galvanic Corrosion, November, Phoenix, Arizona, USA).