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First desalination plant in Cyprus — product water aggresivity and corrosion control

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Abstract

The first major desalination plant in Cyprus is the Dhekelia Desalination Plant, which utilises the reverse osmosis system. The Dhekelia Desalination Plant started its operation on 1st April 1997,with a capacity of 20,000m^3/d, and by the 18th May 1998 its capacity increased to 40,000m^3/d. The plant supplies potable water to the Famagusta, Larnaca and Nicosia Districts. During the summer of 1998 there was a change in the colour of the desalinated water 20–30km far from the plant, where the water appeared to be yellowish-brown, especially in areas where the distribution systems consisted of metal/iron pipelines. The tests results of water samples from the affected areas (Famagusta Area, whose water supply was solely from the Dhekelia Desalination Plant), undertaken from the State General Laboratory and Khirokitia WDD's Laboratory, showed high iron content in the water and the Langelier index was found negative. In order to solve the problem, it was agreed to change the range of pH from 7.0–8.0 to 6.5–9.5. The pH of the desalinated water was then increased by readjusting lime and carbon dioxide dosages. Trials to increase calcium hardness and alkalinity more caused high turbidity in water (3–4NTU). By the increase of pH to values more than 8.5 the Langelier index increased to 0.0–0.5 and the iron content decreased. Later, from September 1999 for the further increase of the hardness of the desalinated water, magnesium sulphate is added at the post-treatment stage in addition to the lime and carbon dioxide. Additional tests have been carried out by installing mild steel corrosion-coupons to the desalinated water from the Dhekelia Desalination Plant as well as at the drinking water reservoirs of different communities in order to examine the corrosive tendency of desalinated water.

Keywords: Langelier index; Precipitation index; AWWA index; Larson index; Corrosion coupons; Corrosion rate

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1. Introduction

1.1. History

Despite the development of the conventional surface water sources, Cyprus still faces an acute water shortage problem. Therefore in order to eliminate the dependency of the towns and tourism centres on annual rainfall and in the view of the increasing water demand, the Government has decided to proceed with the construction of seawater desalination plants.

The first major desalination plant in Cyprus is the Dhekelia Desalination Plant, which utilises the reverse osmosis system.

The Dhekelia Desalination Plant started its operation on 1st April 1997,with a capacity of 20,000 m^3/d, and by the 18th May 1998 its capacity increased to 40,000 m^3/d. The plant supplies potable water to the Famagusta, Larnaca and Nicosia Districts.

The project was implemented according to the BOOT system (Build, Own, Operate and Transfer), and it is owned and financed by the contractor. The contractor will operate the plant on his own expenses for ten years and sell potable water to the Government. After the ten years period the desalination unit will be owned by the Government, while it is possible that the Government can buy the unit before the end of the ten years period.

The Contractor is controlling the process and quality parameters and the Government, as the client is checking/monitoring the product water quality from the desalination plant to the consumers, according to the contract specifications and European Union (EU) recommendations.

Furthermore, the State General Laboratory monitors the desalinated water for toxic, microbiological and other specific parameters.

1.2. Scope of the study

Water Development Department (WDD), as the client, is monitoring the quality of the water produced by Dhekelia Desalination Plant from the beginning of its operation to ensure:

- the safety from chemical and microbiological point of view(compliance with the European Directives for drinking water quality and the parameters particularly defined in the contract)
- and the protection of the distribution system (from microorganisms and corrosivity against pipe materials).

All the tests and analyses regarding this monitoring were done at the Khirokitia and Tersephanou WDD's laboratories and refer to the three years operation of the plant April 1997–April 2000.

During the summer of 1998 there was a change in the colour of the desalinated water 20–30 km far from the plant, where the water appeared to be yellowish-brown, especially in areas where the distribution systems consisted of metal/iron pipelines.

The tests results of water samples from the affected areas (Famagusta Area, whose water supply was solely from the Dhekelia Desalination Plant), undertaken from the State General Laboratory and Khirokitia WDD's Laboratory, showed high iron content in the water and the Langelier index was found negative.

In order to solve the problem, it was agreed to change the range of pH from 7.0–8.0 (contract specification) to 6.5–9.5 (EU recommendation). The pH of the desalinated water was then increased by readjusting lime and carbon dioxide dosages. Trials to increase calcium hardness and alkalinity more caused high turbidity in water (3–4 NTU). By the increase of pH to values more than 8.5 the Langelier Index increased to 0.0–0.5 and the iron content decreased. Later, from September 1999 for the further increase of the hardness of the desalinated water, magnesium sulphate is added at the post-treatment stage in addition to the lime and carbon dioxide.

Additional tests have been carried out by installing Mild steel corrosion-coupons to the desalinated water from the Dhekelia Desalination Plant as well as at the drinking water reservoirs of different communities in order to examine the corrosive tendency of desalinated water.

The study covers the following subjects:

- Product water quality parameters and their compliance with the European Directives for drinking water quality and the contract specifications.
- Corrosion examination:
  – Corrosivity–stability indexes
  – Corrosion coupons method.

2. Water quality parameters

2.1. Introduction

According to the contract for Dhekelia Desalination Plant, the water produced by the plant should be of high quality and should conform to the current EU drinking water standards. In particular the quality of the product water should meet the specifications listed in Table 1 [1].

Table 1
Contract specifications

Parameter*	Specification
pH	6.5–9.5
Turbidity, NTU	0.2 before and 2 after addition of lime
Alkalinity, ppm as HCO_3	Not less than 30
Total hardness, ppm as $CaCO_3$	100–150
Total dissolved solids (TDS), ppm	Less than 500
Boron (B), ppm	Less than 1
Langelier index (LSI)	positive
Nitrates (NO_3), ppm	Less than 50
Free residual chlorine, ppm	Not less than 0.2

* The particular parameters included in the contract list are more, but the above list includes only the parameters, which are more critical for this report

2.2. Data analysis and interpretation

Data analysis has been based on the European directives for drinking water quality and the examination of the parameters particularly defined in the contract. Figs. 1 and 2 presenting the results for a few critical parameters, for the three years operation of the plant.

More specifically:

- *pH values*: These values are found to be according to the agreed range. In an effort to have Langelier index positive most of the time pH is very high (8.6–9.3) and the pH values are very unstable.
- *Turbidity:* Even though turbidity values are found to be in the agreed range of values for the inlet water of WDD reservoir, deposition of lime in the reservoir causes turbidity of the outlet water higher than 2NTU, especially when the level of the water in the reservoir is low. Turbidity values are also found to be very unstable.
- *Alkalinity (as HCO_3):* Generally these values are found to comply with the specification.
- *Total hardness (as $CaCO_3$):* During 1997 these values were found to be close to 100. Since December 1997 up to the end of 1999, hardness was always below the range. From the beginning of the year 2000,values near 100 have been reached for a few times. Even after: a) changing pH range from 7.0–8.0 to 6.5–9.5 (October 1998), b) allowing turbidity to be less than 2NTU(instead of 1NTU), c) addition of $MgSO_4$-post-treatment stage, (September 1999), — total hardness of the desalinated water is below the range defined in the contract.
- *Calcium content:* Concentration of calcium in desalinated water was found to be low from the very beginning, even after allowing pH to be in the range of 6.5–9.5 and turbidity to be less than 2NTU.
- *Total dissolved solids, chlorides and boron:* These values are many times found to be

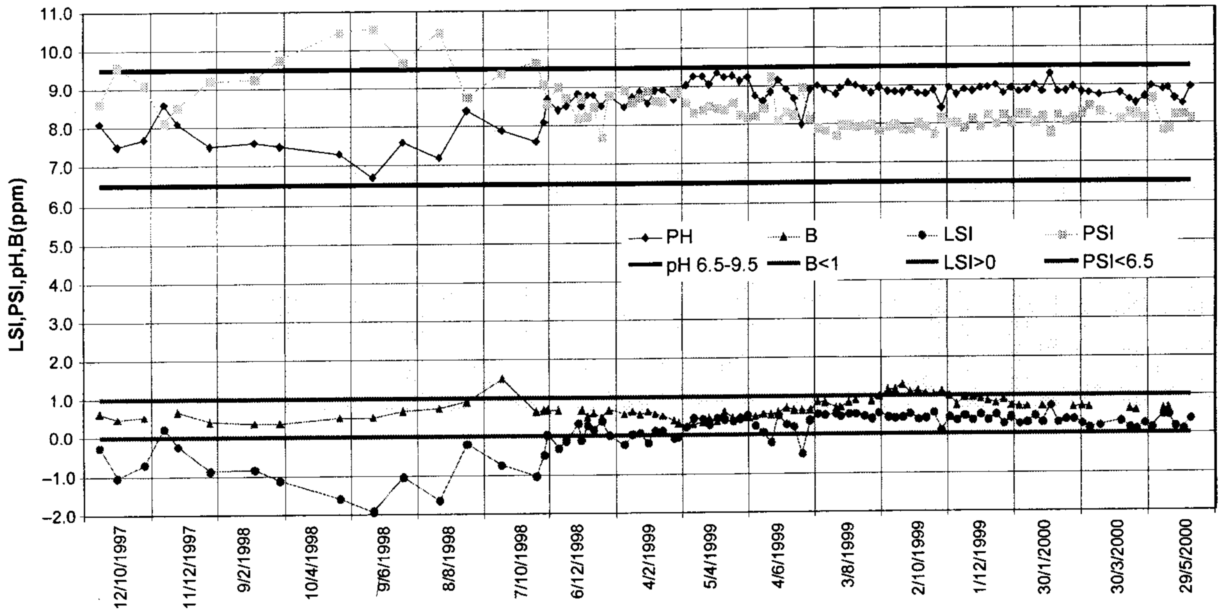

Fig. 1. Quality parameters – inlet WDD reservoir August 1997–April 2000.

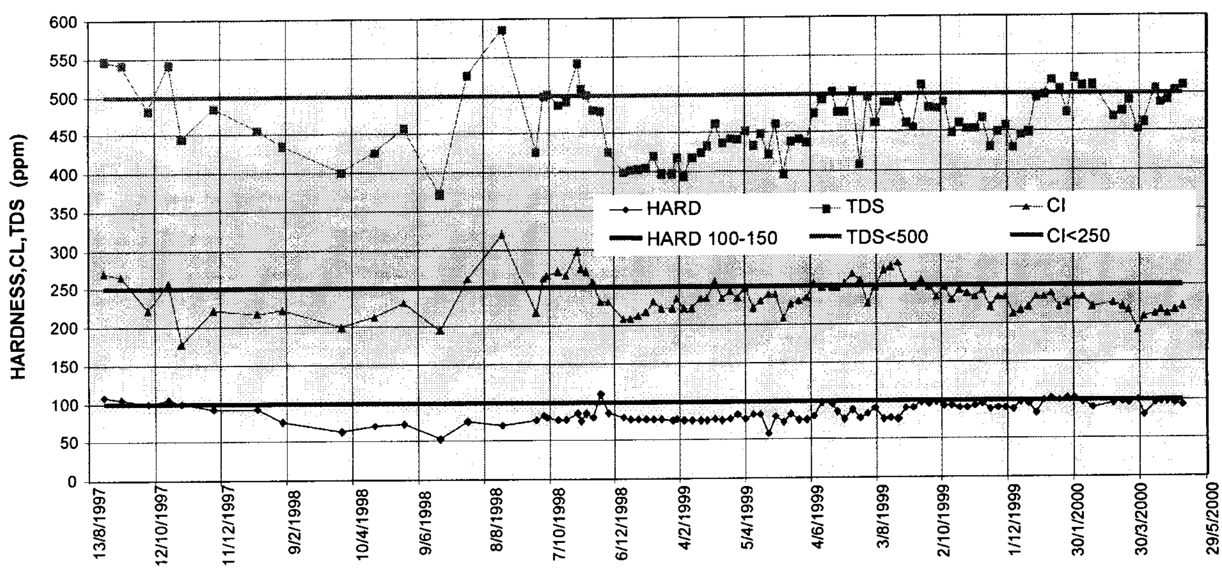

Fig. 2. Quality parameters – inlet WDD reservoir August 1997–April 2000.

higher than the maximum permissible levels defined in the contract.

- *Sulphates and magnesium:* The values are within the specifications. No remarkable change has been found for these values from the time that magnesium sulphate is added to the desalinated water at the post-treatment stage (September 1999).
- *Langelier index:* Langelier index became positive from November 1999 with the increase of pH to values between 8.5–9.3. Whenever pH is less than 8.5 Langelier index is found to be negative because of the low concentrations of bicarbonate and calcium of the product water.
- *Nitrates and microbiological parameters:* They always comply.

3. Corrosion

3.1. Corrosivity and stability indexes

3.1.1. Theory

- *Langelier saturation index [2,3,4]*

Langelier proposed a “saturation pH” (pHs), at which the total alkalinity and the calcium hardness would be at equilibrium with each other and with calcium carbonate. Langelier saturation index is the difference between the measured pH and the pHs.

LSI = pH – pHs

Where pHs=*f* [TDS, temperature, calcium hardness and total alkalinity].

When:

LSI<0 solution undersaturated with $CaCO_3$ (will dissolve $CaCO_3$)(corrosive water)

LSI=0 solution at equilibrium with $CaCO_3$

LSI>0 solution supersaturated with $CaCO_3$ (will precipitate $CaCO_3$ which preserves the water distribution pipes) (non-corrosive water)

- *Precipitation index [3]*

PSI = 2pHs – pH

Precipitation index should be less than 6.5 otherwise the water is corrosive.

- *Ryznar stability index [5]*

This technique calculates an ideal pH, pHi. Comparison of pHi with the actual pH shows whether the water will cause scaling or corrosion.

pHi=*f*[TDS, temperature, calcium hardness and total alkalinity]

The numerical indication of the scaling or corrosive tendency of water is given in Table 2:

Table 2
Ryznar index

Actual pH – pHi	Water quality
0–0.5	Little or no scaling
0.5–1.0	Little or light scaling
1.0–2.0	Light to significant scaling
>2	Significant to heavy scaling
0–0.5	Little or no corrosion
–0.5– –1.0	Little to light corrosion
–1.0– –2.0	Light to significant corrosion
<–2.0	Significant to heavy corrosion

- *AWWA aggressiveness index [6]*

AWWA Index = pH – pHsat

Where pHsat=*f*[TDS, temperature, calcium hardness and total alkalinity]

A slight positive index is frequently associated with noncorrosive conditions, whereas a negative index indicates the possibility of corrosion.

- *Larson and scold index (for iron and steel pipes) [4]*

Larson's ratio is developed from the relatively corrosive behavior of chloride and sulfate, and the protective properties of bicarbonate.

Recommendation:

$$\{[Cl] + [SO_4]\}/[HCO_3] < 1 \text{ (pref. 0.2)}$$

- *Corrosion of copper pipes [4]*

Corrosion is associated with low hydrogen-carbonate concentration and low pH.

Recommendation:

To prevent pitting: $pH > 7$ $HCO_3 > 2$ mmol/l

To prevent copper release: $pH > 0.38\,[HCO_3] + 1.5\,[SO_4] + 5.3$

- *Caldwell-Lawrence water conditioning diagrams [7]*

Caldwell-Lawrence (C-L) diagrams are lines of constant pH, alkalinity and calcium (in solution) plotted on coordinates so chosen that neither coordinate changes when $CaCO_3$ precipitates.

Any water can be represented by an envelope of pH, alkalinity and calcium.

Envelopes may be:
Very large-very unstable water
Small-nearly stable
or a "point"—completely stable water

3.1.2. Analysis and interpretation of the results

Based on the above, the stability and corrosivity indexes for Dhekelia Desalination plant product water have been calculated. The results are presented in Fig. 3 for the inlet water of WDD reservoir.

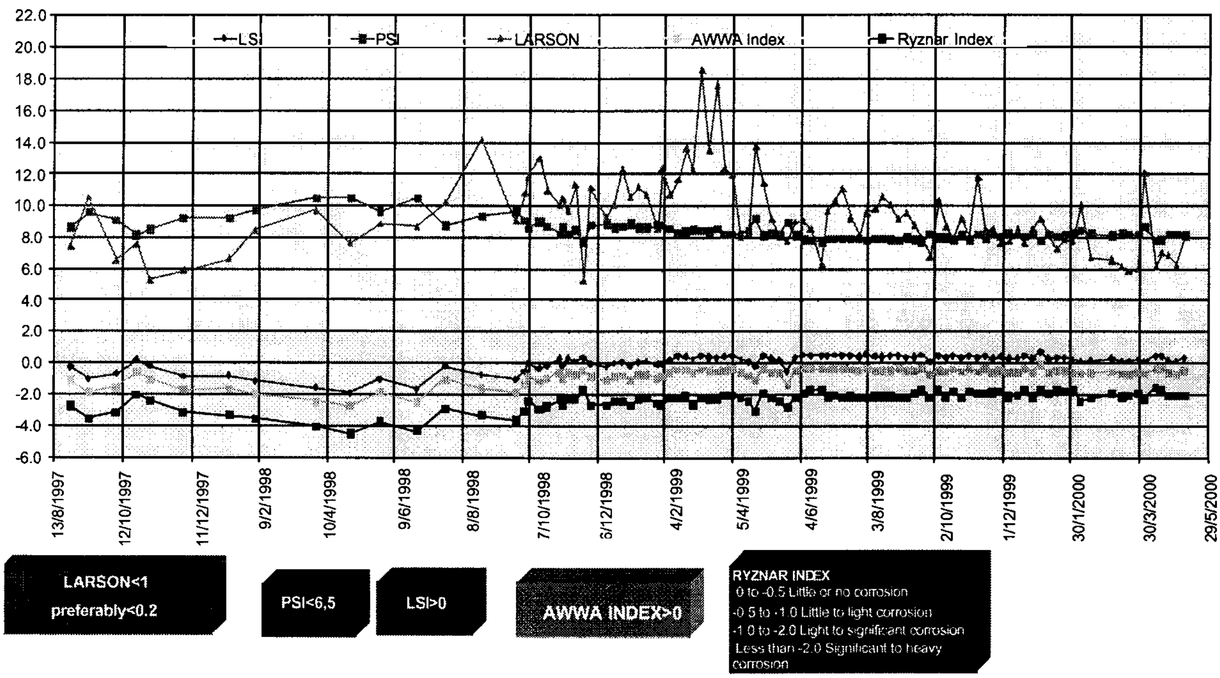

Fig. 3. Corrosivity and stability indexes — inlet WDD reservoir August 1997–April 2000.

More specifically:

- *Langelier index:* (as analyzed before)
- *Precipitation index:* Always more than 6.5 so the water is corrosive.
- *Ryznar index:* Although Ryznar index has been improved from November 1998 with the increase of pH, results indicate that the water can cause heavy to significant corrosion.
- *AWWA aggressiveness index:* Always less than zero which shows the corrosiveness tendency of the desalinated water.
- *Larson index:* Always much higher than the recommended value so the water is corrosive.
- *Corrosion of copper pipes:* According to the results, the water can cause copper pitting but not copper release.
- *Caldwell-Lawrence water conditioning diagrams:* The water is found to be unstable and is therefore corrosive.

3.2. Corrosion coupon method (weight loss method)

3.2.1. Theory [8,9]

This method covers the determination of corrosivity of water by evaluating pitting and by measuring the weight loss of metal specimens. The rate of corrosion of a metal immersed in water is a function of the tendency for the metal to corrode and is also a function of the tendency for water and the materials it contains to promote (or inhibit) corrosion.

The preweighed metal coupons are installed in contact with flowing cooling water for a measured length time. After removal the coupons are examined, cleaned and reweighed. The corrosivity and fouling characteristics of the water are determined from the difference in weight, the depth and distribution of pits.

Calculation of corrosion rate:

Corrosion rates are normally calculated as an average penetration in mils per year or millimeters per year.

For general corrosion: To calculate the corrosion in mils per year for each coupon:

Corrosion rate (mpy) = 22.3 $W/d.a.t$)

Where W, weight loss, mg; d, density of the metal, g/cm^3; a, exposed area of coupon, in^2; and t, time, days.

3.2.2. Application of the method and interpretation of results

Three series of tests have been carried out applying the above method:

In December 1998 twelve corrosion coupons were installed by Caramondani Desalination Plants for a period of four weeks to the desalinated water at Dhekelia, as well as in the water distribution system downstream from the Dhekelia Desalination Plant (Famagusta Area) [10].

Water Development Department proceeded with the installation of two series of ten corrosion coupons, for a period of three months (June–September 1999 and February–May 2000), including locations not only with desalinated water but also treated water from water treatment plants (WTP) and mixed water (desalinated plus water from WTP or and underground). All coupons installed in reservoirs, in an effort to keep most of the factors affecting results the same for every location, and to compare the results according to the type of the water. Fig. 4 is presenting the results (corrosion rates) for the three time periods and the kind of water for every different location.

4. Conclusions/Suggestions

All results and tests showing that there was improvement regarding the quality of the

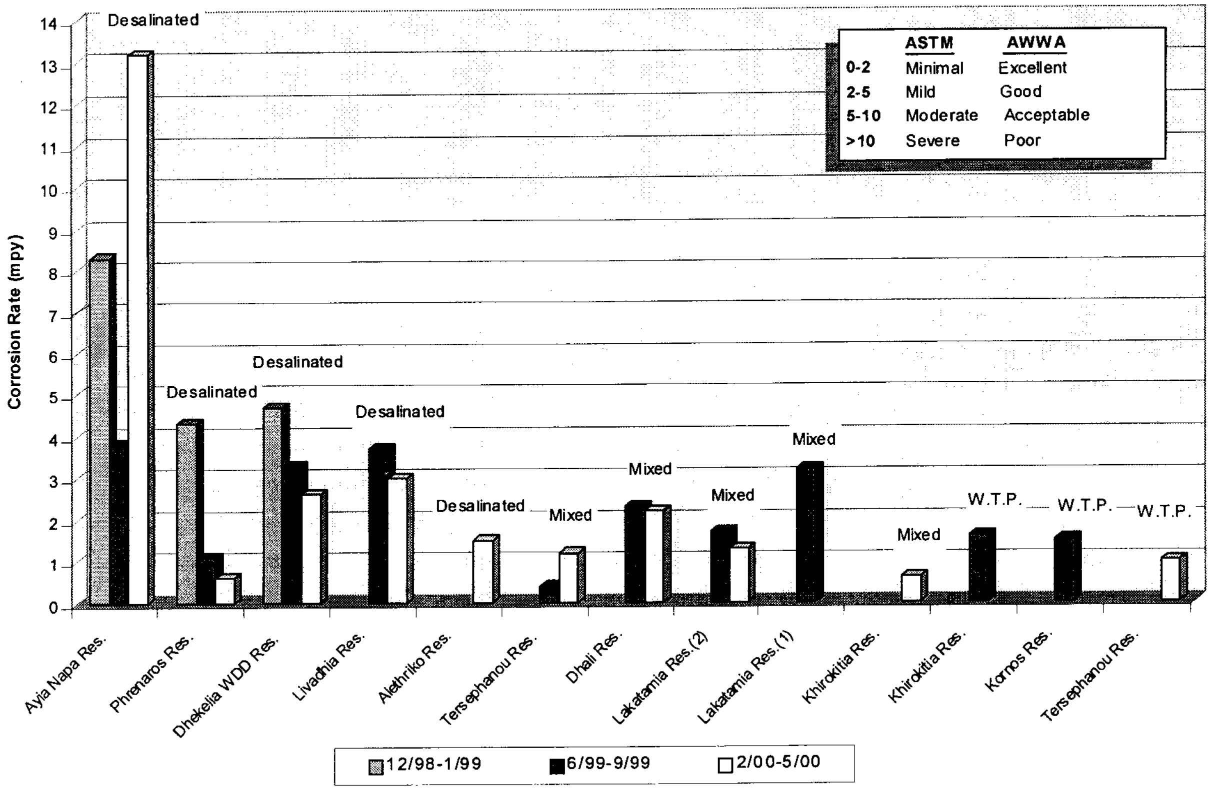

Fig. 4. Corrosion rates.

desalinated water and that mixing of the water can help in reduction of corrosivity. The application of other chemicals in the post-treatment stage should be considered also. Using corrosion inhibitors may protect distribution system.

The checking of the parameters and the studying of the results will be continued to ensure the optimization of the process and stabilization of the product water, supplied for human consumption by the Dhekelia Desalination Plant.

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