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Larnaca desalination plant, Cyprus — from an efficient to an effective plant operation

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Abstract

Larnaca desalination plant is currently within the 10 largest SWRO plants in Europe. It has an installed capacity of 54,000 m^3/d with product water conforming to WHO and EU drinking standards with innovative features such as 8 elements per pressure vessel and fully automated plant operation control.

The plant is now in its 6th year of successful operation meeting all its contractual requirements on energy consumption, water quality and water quantity. The plant operation strategy was to initially make the plant efficient, thus improving the plant processes to reach optimum operational conditions, and subsequently operate the plant effectively i.e. sustain a stable and efficient plant operation, achieving continuously the targeted plant performance.

The consecutive steps carried out in order to achieve the above were:

- Optimizations of process plant units
- Standardization of plant activities, and
- Stable plant operations

This paper describes: (a) the process units and the main optimization that was carried out; and (b) the results of the stable plant operation achieved and the general plant performance over the last 6 years. The paper also describes the time schedule for the implementation of the above consecutive steps which was the basis for the sustained plant performance.

Finally the paper concludes with generic steps of how to achieve efficiency followed by effectiveness in desalination plants.

Keywords:

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1. Plant operational strategy

The Larnaca Sea Water Desalination project was awarded to IDE Technologies Ltd with the following contractual requirements:

- 10 year BOOT project, starting in June 2001
- Installed capacity of 54,000 m^3/d with product water conforming to WHO and EU drinking standards
- Fully automated desalination plant
- Six units, 120 PV each, 8 membranes per PV
- Seawater feed from 1000-m pipeline from the sea
- Recovery of 50%
- Product delivery to 12 km with 90 m elevation
- Total energy consumption ≤ 4.52 kW h/m^3

Following the plant commissioning in June 2001, a plant operation strategy was formulated in order to achieve the strict plant performance defined by the contractual specifications, and subsequently maintain the achieved performance until the end of the project. The main steps are:

(1) Optimization of individual process units separately to reach the best/optimized operational conditions and achieve the best practically achievable plant performance as a whole.
(2) Having achieved the optimum conditions, review and standardize plant operational and maintenance procedures.
(3) Through careful, detail and proactive monitoring of all operational parameters maintain a stable monthly, quarterly and annual plant performance, meeting the best practicable achievable plant performance, consistently.
(4) As technology advances e.g. improved membranes, energy recovery, chemicals and dosing systems, and based on the experience gained, introduce innovations that can further improve the plant performance without affecting the financial viability of the project i.e. 10 year BOOT project time limit.

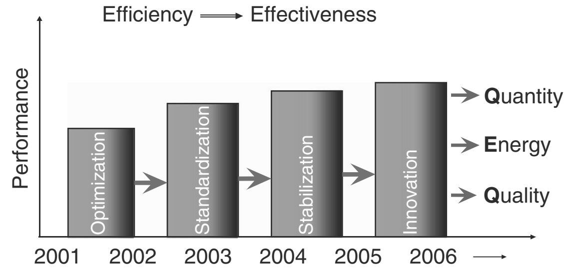


Fig. 1. Plant operational strategy (2001–2011).

Such a stepwise strategy is shown in Fig. 1, indicating that the steps 1 and 2 make the plant operation more efficient while step 3 achieves an effective plant operation, while step 4, assist to sustain an effective plant operation, in the long term.

2. Efficient plant operation

There are five main process stages of the plant as shown in Fig. 2. For each process unit of each

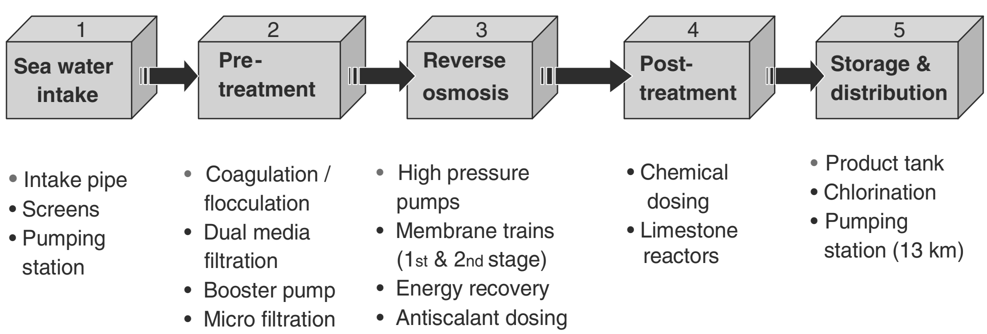


Fig. 2. Larnaca desalination process stages.

stage, operational problems and low efficiency areas were recorded and operational parameters that needed further investigation identified. Tests were set up to measure the existing efficiency of each process units and further trials were contacted to determine the best operational parameter values for improving the plant performance and achieving the best, optimum operational conditions. The main process units of each plant stage that have undergone optimization are listed in Table 1.

The improvements were done firstly for the individual process units and then as a whole plant, taking into consideration the seasonal variations which affect the plant operation.

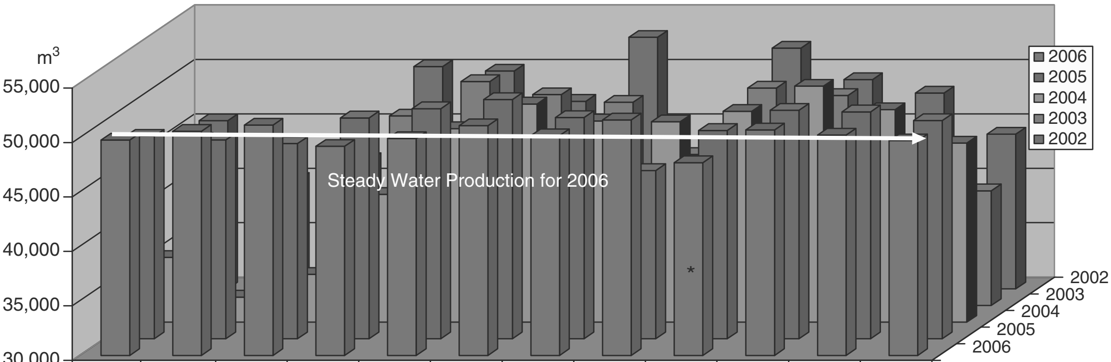
Once the initial process optimization was carried out, the efficiency of each unit and as a whole plant was monitored to determine that the achieved performance can be sustained. Subsequently as shown in Fig. 1, operational procedures were reviewed standardized and repeated.

3. Effective plant operation

A main objective of any production plant is to reach and sustain high performance. To achieve the best plant efficiency (optimum conditions) is a first target. A second target is to be able to sustain the achieved efficiency for the long term i.e. effective plant operation. For the Larnaca desalination

Table 1
Main optimized units of individual process stages

Process stages				
Sea water intake	Pre treatment	Main SWRO plant	Post treatment	Storage & pumping
Main process units optimized				
Sea intake screen/cleaning	Dosing of coagulant	Energy recovery system improvements	Improve quality of limestone (reactors)	Laboratory/automated testing & feedback. Process adjustment
Pumping regime	Mixing process — flocculation before filtration	Membrane management system see Ref. [1]	Backwashing regime and frequency of B/W of limestone reactors	Pumping regime
Data acquisition for monitoring sea conditions	Back wash regime of filters	Membrane inter connectors/end adaptor designs/replacements		Chlorination
	Cartridges — frequency of replacement of micron filters	2nd stage operation for optimum conditions: boron removal vs. energy consumption Cooling systems to reduce effect of high air temperatures on E&M equipment Antiscalant dosing on 1st and 2nd stages		
Overall plant optimized activities				
Energy consumption of each process stage. Reactive vs. proactive maintenance of E&M equipment				
Water quality of each stage. Laboratory tests — frequency, records, government monitoring				
Quantity (pressure) of water passing through each stage. Maintenance plant down time vs. water production targets				



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	49768.48	50569.61	51134.87	49192.53	49901.42	51086	50173.13	51613.9	47694.23	50686.9	50224.13	49696.71
2005	48585.45	48248.21	47913.16	50274.93	51123.77	51957.5	50306.42	45441.35	49118.93	50972.16	50823.37	50026.58
2004	35945	32303.17	34397	41732.4	47763.35	50023.63	48474.57	48389.03	49349.13	51664.29	49501.33	46443.26
2003	45257.77	45063.68	42978.39	47399.68	50555.84	49352.67	48655.13	43867.35	49961.53	49287.74	44500.3	40525.71
2002	45436.97	40054.86	41867.87	50401.53	49996.03	47213.13	53088	36389.03	52093.6	49208.39	47970.33	44197.32

Month

*3 DAY SHUT DOWN

Fig. 3. Average monthly water production 2002–2006.

plant the first two years of operation has concentrated in achieving the best plant efficiency as shown in Fig. 1. During the last two years the achieved efficient levels has been sustained indicating a stable, effective plant operation.

In order to demonstrate the effective plant operation, three main parameters have been evaluated:

- **Q**uantity of water produced,
- **Q**uality of water produced, and
- **E**nergy consumed (kW h/m^3)

The contractual requirements of the plant are described in a previous publication [2]. The results for an effective plant operation strategy are shown in Figs. 3–8.

3.1. Water production

The average monthly water production after the plant commissioning is shown in Fig. 3. The results indicate large variations in the monthly water production in the initial years of operation (2002–2003) and this is mainly due to (a) initial plant commissioning problems needing further attention (b) mainly due to the initial inefficiency of some process units and (c) peripheral plant activities related to the local/country/contractual issues.

As the initial problems were solved and the efficiency of the plant increased, the monthly water production reached higher, steady levels while at the same time the overall annual production increased. This is more clearly shown in Fig. 4, where, as the average monthly variation of water production (expressed as standard deviation) decreased, the annual cumulative water production increased. The plant efficiency improved during the years 2002 & 2003 (year 2004 production

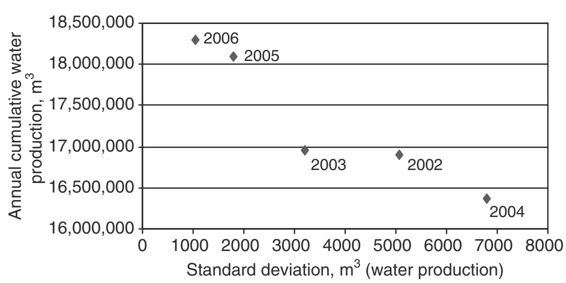


Fig. 4. Effect of stable plant operation on overall water production year 2004 – lower production due to client's instruction.

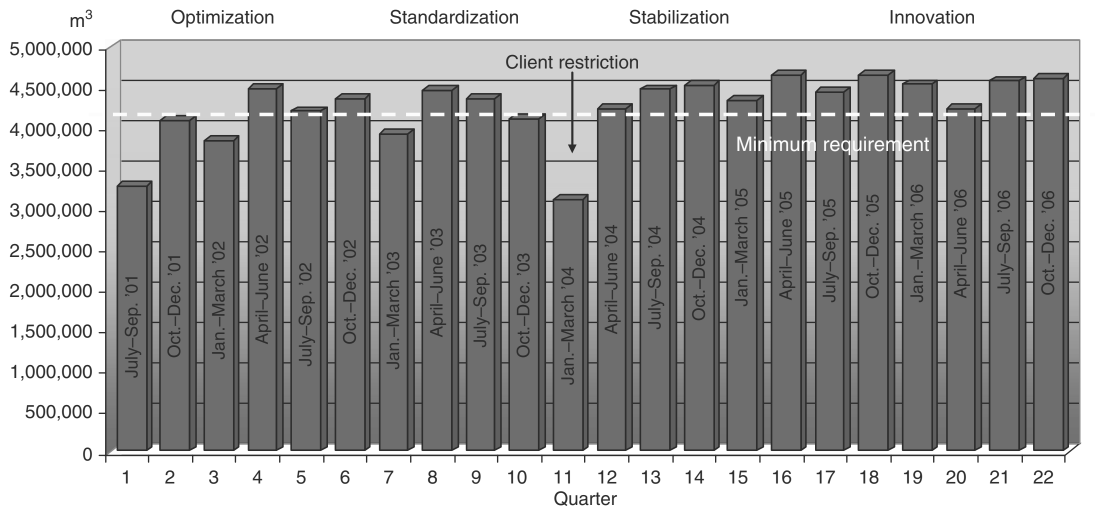


Fig. 5. Quarterly water production 2001–2006.

was lower due to forced reductions by the client) and clearly the last two years 2005 & 2006 have been the best performing years, as a result of the effective plant operation strategy.

The plant operations strategy from an efficient to an effective plant is also shown in Fig. 5, where the water production from the date of plant commissioning up to date (end of year 2006) is shown in the form of quarterly water production. Any significant quarterly water production variations have taken place up to Quarter 7 (March 2003) which marked the end of any month/quarter not meeting its water production target. After that, the plant consistently achieved more than the contractual minimum water production requirements (except that of Quarter 11 where production was forced to be reduced by the client). As part of the plant operational strategy, all the plant activities and operations were done on the basis of sustaining a stable plant performance, with careful maintenance planning to avoid unnecessary or unexpected plant down time. The result was to maintain and increase the water production, with 2006 being the best plant performance, although year 2005 was considered to be the plant's reference year.

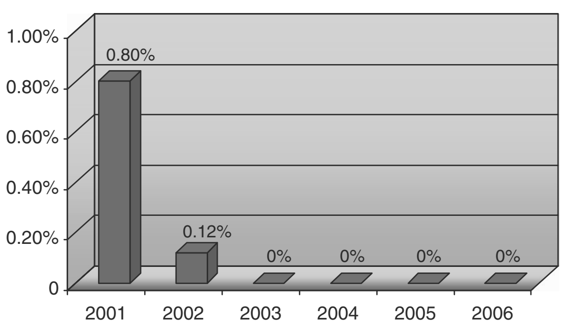
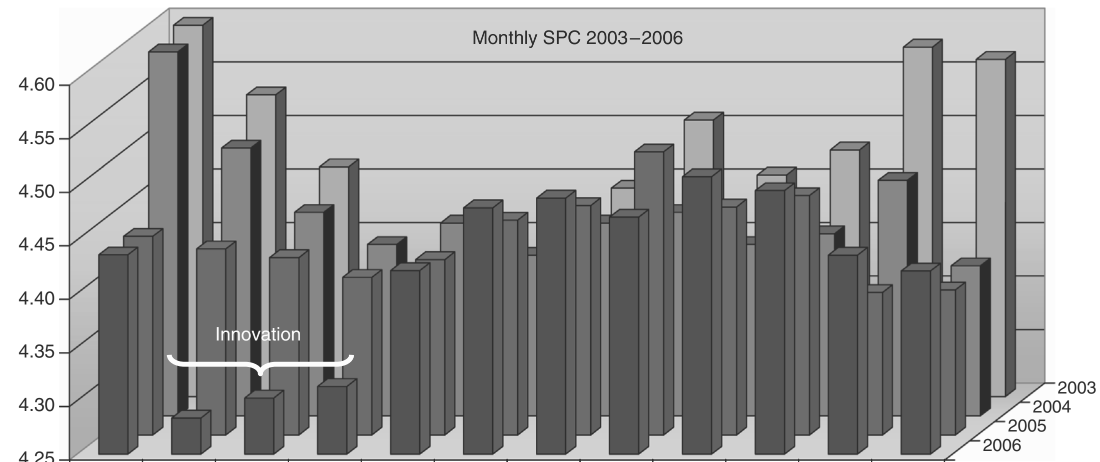


Fig. 6. Water loss due to quality 2001–2006.

3.2. Water quality

Improving the plant's efficiency with subsequent effective plant operation could not be achieved only by increasing water production. It requires improving or at least maintaining the water quality within the contractual parameters. Some process units' inefficiency was translated to loss of some water due to bad water quality during the years of 2001 and 2002, amounting to 0.80% and 0.12% loss of water respectively. Although relatively small volumes of water, it had an effect not only on loss of revenue but also the energy consumption per m^3 of water (an additional energy criterion which the plant had to achieve



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	4.43628	4.28377	4.30247	4.31332	4.42162	4.48016	4.48929	4.47148	4.50921	4.49629	4.43605	4.42121
2005	4.43555	4.42385	4.41572	4.39722	4.41377	4.45075	4.46425	4.5145	4.46311	4.47366	4.38302	4.3856
2004	4.59	4.5	4.44	4.41	4.43	4.4	4.43	4.44	4.41	4.42	4.47	4.39
2003	4.59689	4.53176	4.46451	4.36536	4.37485	4.41657	4.44471	4.50824	4.4569	4.4804	4.57637	4.565

Fig. 7. Monthly energy consumption, 2003–2006.

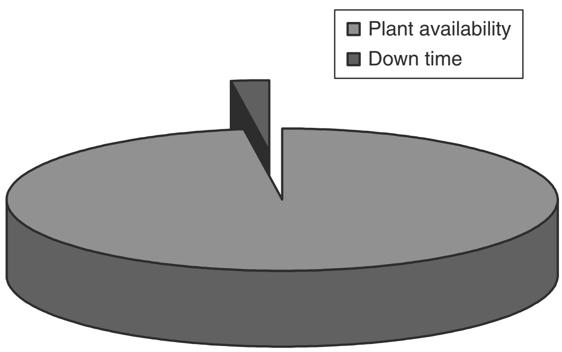


Fig. 8. Plant availability as 100% full plant operation, 2006.

i.e. ≤4.52 kW h/m^3). However, as a result of the operational strategy, for the last 4 years (2002–2006) all water produced was within the contractual limits (as shown in Fig. 6) fully accepted and paid for by the client.

3.3. Energy consumption

The initial unstable plant operation produced also large monthly variations in energy consumption as shown in Fig. 7 up to the year 2004. It was not until plant optimization was completed, followed by stable plant operations, that sustained energy reductions were achieved (from 2005 onwards). This was the result of energy optimization of all individual process stages, units and in particular the turbine energy recovery system itself (Table 2). Significant energy reductions have been reached and maintained over the last 2 years of operation. Innovative approach of

Table 2
Average annual energy consumption

	kW h per m^3 produced				
Year	2002	2003	2004	2005	2006
Average annual energy consumption	4.66	4.48	4.44	4.44	4.42

operating the RO plant, has resulted in being able to operate the plant without the need of a 2nd stage for a period of 2–3 months as shown in Fig. 7, resulting in significant energy savings, while at the same time increasing the water production during the traditionally low water producing months of winter (less water wasted as brine of the 2nd stage) and at the same time maintaining the water quality. The energy consumption results of the operational strategy, moving from improved efficiency to standardize procedures, and then operating the plant effectively with further innovations is shown in Table 2.

As part of an overall effective plant operation strategy, it is vital to balance proactive with reactive maintenance work. Furthermore, in a most automated site, such as the Larnaca desalination plant, a trained multi-skilled maintenance team enables efficient early fault diagnosis and with a well organized maintenance plan, repeated defects could be addressed with long term solutions. The end result is reducing the plant down time. Larnaca desalination plant in 2006 has achieved a 97.7% availability (Fig. 8) i.e. 356 days of the year, full plant production with 8% more water production than the annual minimum contractual quantity.

4. Conclusions and recommendations

The Larnaca desalination plant is now in its 6th year of successful operation meeting all its contractual requirements. The selected operational strategy for its 10-year project life time was to initially make the plant more efficient, and subsequently operate the plant effectively in order to sustain a stable, efficient plant operation, maximizing plant performance in the long term. This plant operational strategy included generic steps, which are

- Optimization of process
- Review and standardize operational procedures
- Operate a stable plant, maintaining plant efficiency and performance
- Introduce innovations based on plant operational experience and new technology developments

The plant performance of the Larnaca desalination plant has proven that the suggested operational plant strategy in this paper has produced sustained plant performance which exceeded the minimum contractual criteria both in energy and water quantity while at the same time meeting all the water quality requirements. The good plant performance is supported by systems in place relating for example to membrane replacements (Ref. [1]), plant operation and maintenance planning (Ref. [2]) which resulted in 97.7% plant availability operating in full capacity in 2006.

References

[1] E. Koutsakos and D. Moxey, Membrane management system, Desalination Strategies in Southern Mediterranean Countries, EDS Conference, Montpellier, France, May 2006.

[2] E. Koutsakos, K. Savvides and K. Savva, Larnaca desalination plant operation — a client and contractor perspective, Desalination, 184 (2005) 157–164.

Appendix A: Data sheet for monitoring the trial dosing of SP-0111 antiscalant as agreed between L.W.P. and SOLUTIA

Table 3a
General data (date: 8 May 2007; time: 15:30)

Parameters	Values
Sea (feed) water temperature (°C)	19.8
SDI (after micron filters)	2.27
Feed water pH	8.20
Feed water conductivity (µS/cm)	53.600

Table 3b
Train data for normalization

Parameters	Train					
	A	B	C	D	E	F
Srarting Dp	1.57	1.80	1.98	1.12	1.64	1.32
Dp	1.60	1.77	1.98	1.10	1.65	1.43
Concentrate flow (m^3/h)	400	400	410	409	410	400
Permeate flow (m^3/h)	354	371	358	380	381	364
Feed pressure (bar)	75.3	76.2	75.7	73.3	73.6	73.7
Concentrate pressure (bar)	72.1	74.4	73.2	71.9	71.3	72
Permeate conductivity (µS/cm)	622	644	760	445	606	529

Table 3c
Phosphonate – antiscalant analysis for all Train 7 May 2007

Parameters	Train					
	A	B	C	D	E	F
Recovery (%)	47.5	48.3	46.8	48.25	48.1	47.9
Phosphonates in feed (ppm)	1.548	1.548	1.584	1.512	1.512	1.548
Phosphonates in brine (ppm)	2.952	2.916	2.880	2.772	2.844	2.844
Rejection (%)	100.12	97.39	96.73	94.88	97.62	95.72

Overall trends before and after the test (today): feed pressure reduced on all trains – naturally (as expected due to temperature); brine flow the same; permeate flow increased – naturally (as expected); recovery % increased.