

Chapter 16

Impact of the Coastal Intake Environment on the Operating Conditions of Thermal Desalination Plants: A Case Study in the United Arab Emirates

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Abstract The energy required to operate coastal thermal desalination plants and thus the relevant costs are greatly affected by coastal hydrodynamics. A multi-layered hydrodynamic model was developed in this study for a coastal area in the United Arab Emirates to investigate such an effect. The simulation was carried out using a curvilinear grid model with sigma layers in the vertical direction which incorporates the transport of salt and temperature interactively with water dynamics. Several simulations were carried out to investigate the impact of the brine and warm cooling water discharges released from the desalination plant as well as other nearby industrial facilities using a three-dimensional advection-dispersion surface formulation. The model output was used to determine suitable locations and configurations for water intakes as well as outlets to maintain the temperature and salinity of the water introduced to the plant at optimum acceptable levels, so that maximum efficiency and minimum operation cost are achieved. A number of alternative scenarios were also considered to fully assess the problem. This includes extreme desalination operation scenarios in summer and winter, possible maximum release of warm water by other industrial facilities, and scenarios of the future expansion of plant production. Three alternatives were investigated including shifting the intake to new offshore locations, moving the outfall away from the intake area, and having the outfall discharge its effluent into further and deeper zones. Cost analysis was carried out for two scenarios to evaluate the operation cost in terms of chemical and energy cost. The first alternative that involved shifting the intake location about 1 km offshore was found to be the best option as it achieved the maximum reduction of chemical and energy costs for all tested scenarios when compared with the existing configuration. 2.5 % of the total annual cost, equivalent

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to US \$1.2 million is saved, taking into consideration a major expansion to the existing industrial facilities which will produce 10 times the existing effluent levels.

Keywords Coastal hydrodynamics • Desalination • Intakes • Outlets salinity • Temperature

16.1 Introduction

Sufficient precautionary measures are usually taken in desalination plants to maintain maximum operational efficiency when transforming seawater to safe drinking water. However, depending on the local marine environment and layout of the inflow outflow water lines, the performance of the plant can be affected considerably. In the coastal water of the UAE, the natural level of salinity is very high (more than 40 parts per thousand (ppt)), while the water temperature in the shallow areas rises up to more than 30 °C during the summer (Elshorbagy et al. 2008, 2013). The discharges of brine wastewater and warm cooling water from the plants increases the water salinity and temperature in the vicinity of the plant intakes. Coastal flow dynamics and natural processes like evaporation, diffusion and dispersion, and mixing, all affect the transport of brine and warm water into the seawater that is subjected to tides, winds, and locally-generated eddies. Cooling the water used by coastal industrial facilities near many desalination plants in the UAE can cause a localized increase in water temperature. A careful selection of the intakes and outlets of these plants should therefore take into account the above considerations. The objective of the study is to determine the effect of the brine and the warm cooling water discharges released from the desalination plants as well as other nearby facilities by using a three-dimensional advection-dispersion surface model. The model outputs were used to determine suitable locations and configurations for the water intakes and outlets.

16.2 Methodology

A multi-layered hydrodynamic model has been developed for the coastal area, an industrial petroleum complex located about 230 km west of Abu Dhabi City that has a medium-size desalination plant. The study has been conducted using the Delft3D model, which considers a curvilinear grid model with sigma layers in the vertical direction, incorporating the transport of salt and temperature interactively with water dynamics. The boundary conditions of the model have been obtained from the simulation results of a regional model that simulates the dynamics of the entire Arabian Gulf. The bathymetry information has been collected from available universal charts known as “Admiralty Charts” (ATT 2001). Meteorological and other oceanographic information has been collected from various relevant

authorities and literature. The average rate of water intake and discharge in the sea has been collected from the Petroleum Port Authority (2003), and any missing data has been estimated. The simulation was carried out for the summer and winter seasons by considering the change in solar radiation, variation of wind patterns, and warm water discharges from other nearby industries.

Field measurements for salinity and temperature, provided by recent studies, were collected at a number of locations in the coastal area. The water level and currents measured at selected locations for a reasonable period of time have been employed in the model. The hydrodynamic and transport models have been calibrated against the measured data. Comparison is made with water level data, current data, time-dependent salinity and temperature data. A number of optional scenarios are considered to fully assess the problem. These include extreme desalination operation scenarios in the summer and winter, possible maximum release of warm water by other industrial facilities, and scenarios of future expansion of desalination plant production. Other scenarios assess various intake and outlet configurations including their locations, depths, coastal angles and cross-sections. The salinity and temperature at the intake of the desalination plant calculated from each scenario have been utilized in estimating the operation costs of the multi-stage flash (MSF) desalination plant using an EXCEL sheet program. The calculated costs for the scenario under consideration allow the identification of the best configurations for intakes and outlets that satisfy maximum operation at a minimum operational cost.

16.3 Regional Model (Gulf Model)

The hydrodynamics of the southern Arabian Gulf plays has a significant effect on the coastal environment of United Arab Emirates where large cities and industries are located. The coastal waters are also busy with movements of oil tankers and their loading-unloading operations. Understanding coastal flow dynamics is essential for an investigation of the environmental processes of this region. The high rate of evaporation, water exchange with the Arabian Sea at the east and the seasonally varying wind field, all significantly contribute to the flow dynamic of the sea which is subject to tidal forcing through the straits of Hormuz. However, present knowledge of hydrodynamic behaviour of the southern gulf and its response to meteorological and oceanographic forces is relatively poor. The present study employs a three-dimensional numerical model to examine the sensitivity of the sea water flow in the UAE coast to tides, wind fields, salinity and to temperature.

The strategy adopted by this study is to employ a simulation of the entire Gulf area, calibrating it at a reasonable level, with the local model nested from the regional one. Since there are no available time-dependant data at the local boundary, the boundary conditions for the coastal model are extracted from the Gulf Model. The Arabian Gulf (approximately 1000 km by 200–300 km) slopes from the shallow United Arab Emirates coast to Iran at a depth of 80–100 m, narrowing at the

Qatar peninsula. Oceanographic features in the northern and southern regions of the Gulf are remarkably different. Complex physical dynamic phenomena are evidenced from a number of modelling and survey studies carried out in the Arabian Gulf. High solar radiation, the exchange of fresh water and its circulation driven by the wind and astronomical forces are the main contributory factors for such phenomena. Excessive evaporation occurs in the shallow coastal region of UAE leading to the creation of highly saline water (up to 46 ppt).

16.4 Local Model

The coastal flow pattern around the coastal industrial complex has been studied using the same 3-D hydrodynamic model. The study area is about 264 km² and partially sheltered from the open sea by islands and salt marshes. Such a configuration increases the risk of marine pollution near the industrial site. The obvious implications of such a development are the increased potential threats of pollution to the coastal ecosystem, as well as the effect of effluents, produced by the MSF desalination plant, on salinity and temperature which would affect the plant's performance. Discharge of industrial effluents, spillage in the port and the discharges of brine and of warm water may have a considerable impact on the marine environment. Hence, understanding the hydrodynamics of the area is crucial in order to assess the impact of ongoing activities. A three-dimensional model study has been conducted to understand the baseline hydrodynamic conditions of the coastal study area.

In order to establish the local model, a nesting process was carried out from the original overall Gulf model. A nesting process is used where the boundary conditions of a model are generated by a larger (overall) model onto a nested model. In principle, the nested boundary conditions are generated by bi-linear interpolation of computational results at monitoring stations of the overall model. The study area for the model is selected from the south of Sir Baniyas Island as illustrated in Fig. 16.1. The seaward extent of the model is about 15 km. The utilized model has an overall grid size of 87 × 60 and employs a curvilinear sigma system. Curvilinear grids should be smooth in order to minimize errors in the finite difference approximations. The vertical dimension is modelled in sigma co-ordinates with three layers. The bathymetry of the model is digitized from the navigational Admiralty Chart #3780. The central part of the area has a depth of up to 22 m while the areas to the east and the west are very shallow. The deep sections provide suitable entrance for large tankers. The model is calibrated against the water level and current data.



Fig. 16.1 The Arabian Gulf and the study area

16.5 Calibration

The model is calibrated by adjusting parameters within practical ranges to attain agreement with measured hydrodynamic data. All measurements are obtained from recent studies (Elshorbagy et al. 2006). Comparison of the measured and simulated water level data at coastal location near the study area is shown in Fig. 16.2, where a satisfactory agreement can be noticed. The match of the estimated water level with observation appears to be satisfactory. The current is generated under the influence of tidal forcing on the bathymetric variation, wind force and density gradient. A stream enters the local study area from the west towards the centre, south and east of the study area at the near shoreline. An outflow occurs in the east and northeast. As the tidal force and the gradient of temperature-salinity remain almost unchanged in both seasons (summer and winter), seasonal variation of wind force is apparently the prime source of such a flow pattern (Azam et al. 2006). It was observed that the current flow pattern is dominated by the wind direction.

Temperature-salinity dynamics is a three-dimensional process and as the atmospheric heat exchanges with the water-mass, evaporation occurs at the surface and the evolved density variation moves the water under the influence of gravity. It was observed that the higher salinity and temperature near the eastern shoreline are intensified due to the brine discharge and effluents from industries, especially from the eastern industrial facilities effluents.

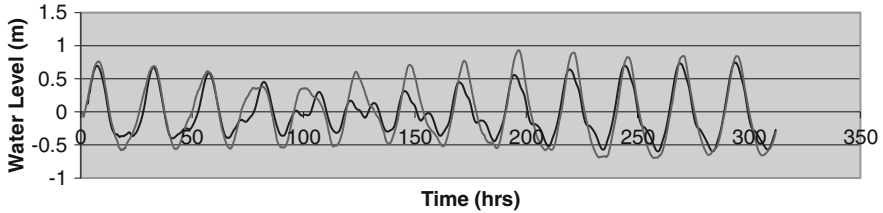


Fig. 16.2 Comparison of measured and simulated water level near the study area

16.6 Simulation Results

16.6.1 Considered Scenarios

The study evaluated the salinity and temperature at the desalination intake generated from several scenarios, the effect of wind magnitude and direction on the simulation results, and the impact on the MSF plant performance in terms of technical and commercial parameters. There are three main scenarios to be considered for both the summer and winter seasons. The first scenario uses the existing facilities, including all the basic data/information created to formulate the basic design model that considers the wind effect as the one caused by the most commonly-observed prevailing wind direction (north and north-west).

The second scenario considered the assumption of moderate expansion to the existing facilities, which leads to increase in the effluent discharge of the existing facilities by about five times the original base model. Third scenario considered the assumption of major expansion to the existing facilities, which leads to increase in the effluent discharge of the existing facilities by about 10 times the original base model. The salinity and temperature were investigated at the General Utilities Plant (GUP) desalination intake area. A summary of the above mentioned scenarios is illustrated in Table 16.1. The capacity of existing desalination plant at coastal area is about 64,000 m³/day in the basic scenario considered herein. The discharge increases relatively with the increase in plant distillate capacity. It is assumed that the relation between plant capacity represented as distillate flow rate required and the effluent discharge representing the salinity and temperature is almost leaner. On the other word, the increase in distillate (water need) in addition to the expansion of adjacent industrial facilities increases the effluent discharge from all these industrial facilities into the sea. Consequently, this will lead to an increase in temperature and salinity at the shoreline area.

The capacity of the existing desalination plant in the coastal area is about 64,000 m³/day in the basic scenario that has been mentioned above. The discharge increases relative to the increase in plant distillate capacity. It is assumed that the relationship between plant capacity, represented as M_d (Distillate flow rate required), and the effluent discharge, representing the salinity and temperature, is almost leaner. In other words, the increase in distillate (water need) in addition to

Table 16.1 List of scenarios considered for the evaluation of the MSF desalination plant performance

S/N	Scenario	Description	Season
A	Basic	Current discharges from existing facilities (Q)	Summer
			Winter
B	Moderate expansion	Discharge increased five times (5Q)	Summer
			Winter
C	Major expansion	Discharge increased ten times (10Q)	Summer
			Winter

the expansion of adjacent industrial facilities increases the effluent discharge from all these industrial facilities into the sea. Consequently, this will lead to an increase in temperature and salinity in the shoreline area.

16.6.1.1 Hydrodynamic Results for Dominant Wind

Summer Results

The summer temperature and salinity that cover the majority of the year (about 7 months) range from 34.5 to 35.2 °C and from 45.5 to 46 ppt, respectively. The contour profile shows a higher temperature in the south close to the shoreline. The temperature in the west is the lowest. Similarly, the salinity is slightly higher in the south and becomes lower in the west. Such findings indicate that the basin receives less saline and cooler water from the north and the west near the open boundaries, while the more saline and warmer water forms at the shallower eastern side where industrial facility discharge brine water with a high temperature and greater salinity. The highest temperature and salinity are observed close to the shore in the east where the GUP and industrial facilities outfalls are located. Density force, convection and dispersion generate such movement of warm and highly saline water. While tidal circulation brings fresher water from the west and northwest which mixes with the central and lower basin water before leaving through the north, the tidal flow close to the east helps in mixing the water with industrial facility effluent where this mixtures moves towards the north of the basin. The impact of the industrial facilities is clearly noticed at the close area that surrounds the outfalls of these facilities, where the temperature and salinity concentration increases in that area.

On the other hand, a moderate expansion of the existing facilities is considered and its effect has been clearly observed. The temperature and salinity in the southeast are increased and even spread towards the north, where the possibility of adversely affecting the desalination intake (the area of concern to be studied) is more pronounced. In summer, an extreme scenario of major expansion of the exiting industrial facilities is considered, where the discharge was increased by ten times the discharge of all existing facilities. This scenario shows a very high

temperature and salinity, not only at the shoreline, but the effect of this scenario covers a major part of the coastal shoreline and even spreads towards the north at the centre of the basin, yielding minimum success to the opportunity of proposing alternative intake and outfall configurations to overcome such a situation. It is noticed that a moderate expansion of the facilities increases the salinity and temperature at the intake from an average of 45.24–45.36 ppt and from 34.8 to 35.3 °C, respectively. The major expansion increases the salinity and temperature to an average of 45.48 ppt and 35.9 °C, respectively.

Winter Results

Winter salinities and temperatures at the desalination plant intake for the three scenarios are presented in Figs. 16.3 and 16.4.

The winter temperature and salinity, which spans over about 30 % of the year, ranges from 21.8 to 23.2 °C and from 45 to 46 ppt respectively. Again, the western side shows a relatively lower temperature and salinity as in the summer. As illustrated previously with the case of summer conditions, the existing industrial facilities had an influence on the salinity/temperature distribution, especially at the surface level of the shoreline. The wind plays a significant role in the mixing process, and the prevailing north-western wind greatly enhanced the overall circulation. The change in salinity for all three scenarios is found to be insignificant. However, the temperature at the intake desalination area increased from an average of 22.1 °C (existing facilities) to an average of 23 °C. The salinity increased from 45.10 to 45.65 ppt considering the basic and major expansion models.

16.6.1.2 Hydrodynamic Results for Reversed Wind Scenario

Eastward wind direction is considered in this scenario as east wind direction (90° Deg.). The objective of this scenario is to evaluate the effect of the reverse direction of the wind on the desalination plant operation cost. It is noticed that the temperature and salinity at the intake increased slightly in the reverse wind direction. This is attributed to the wind direction that plays a major role in transporting the effluent of the industrial and GUP facilities towards the intake location. However, the increased flow coming from the eastern boundary helps in diluting that effluent and alleviates the effect of brine discharge of industrial facilities on the intake. The reverse wind direction also reduces the impact of industrial facilities effluent on the intake condition. Since the effect of a reverse wind direction is limited, and it occurs for only about 23 % over the whole year, the alternative proposed scenarios discussed later will consider only the most dominant wind direction that represents the most prevailing conditions during the year.

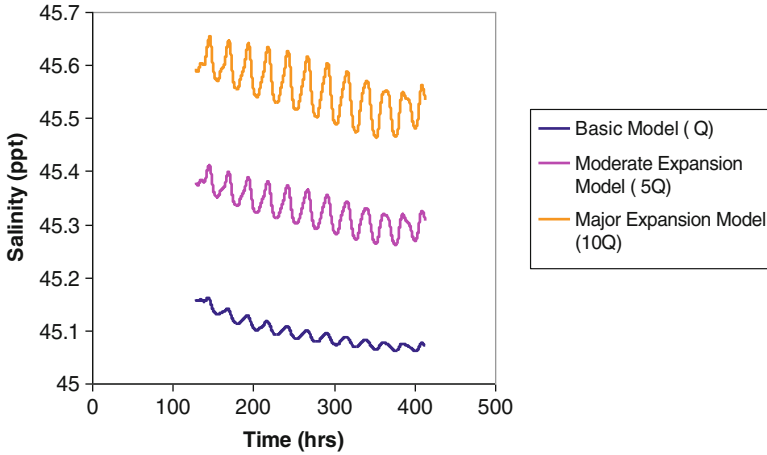


Fig. 16.3 Comparison of the salinity results considering the three different scenarios at the desalination intake in winter

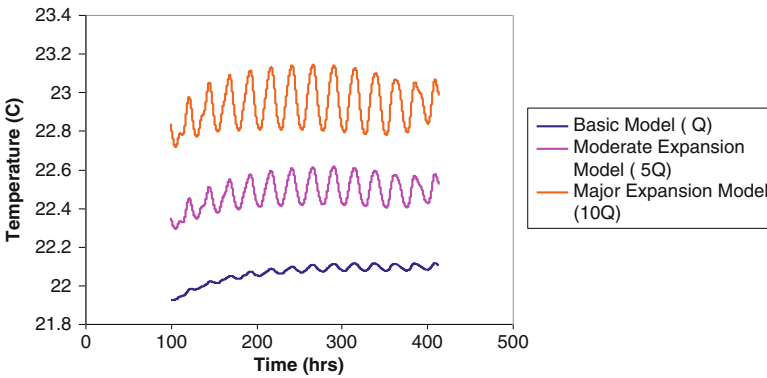


Fig. 16.4 Comparison of the temperature results considering the three different scenarios at the desalination intake in winter

16.7 Proposed Alternative Configuration

In order to minimize the negative impact of brine circulation towards the intake for the proposed scenarios, several proposals are investigated for the intake and outfall configurations. These proposals can be summarized as follows:

- Alternative 1 (Alt.1): Change the intake configuration by extending the intake location offshore to an area receiving cooler and less saline water.
- Alternative 2 (Alt.2): Change the outfall configuration by extending the desalination outfall in a location that has a lower impact on the intake location.

- Alternative 3 (Alt.3): Change the outfall configuration to discharge the effluent in a deeper zone.

In addition to the above alternatives, the salinity and temperature at different depths close to the intake location are evaluated. Results of the hydrodynamic simulations conducted for the three alternatives are summarized below.

16.7.1 Results of Alternative 1

Table 16.2 lists the average salinity and temperature as a result of adopting Alternative 1 and existing conditions. Table 16.3 shows the operation cost calculation for chemical and electrical power expenses (assuming constant pumping cost) for summer and winter. Table 16.4 shows the reduction in cost when Alternative 1 is employed for the three scenarios. It is noticed that the reduction in cost is insignificant. Salinity and temperature in the summer and winter are decreased. However, it is observed that the reduction in temperature in winter is quite noticeable compared to summer temperature.

16.7.2 Alternative 2

Extending the outfall location by about 1000 m away from the nearby zone in summer and winter improves the intake water properties slightly in terms of receiving less saline water which is cooler (See Table 16.5). Although the reduction difference in salinity and temperature is insignificant, the Alternative 2 emphasizes the importance of identifying the most suitable location and configuration for the outfall system, especially when an expansion of the existing industrial facilities is being planned. The results show that moving effluents away from the shoreline when considering the circulation process, wind direction and current movement, the new location helped in reducing the intake water salinity and temperature. It is worth mentioning that the bloom that flows from the easterly direction helped in lowering the effects of the brine effluent from the industrial facilities due to an effective mixing process.

Table 16.6 shows the comparison between existing conditions with the old outfall location and Alternative 2. Selecting the outfall location is considered to be an important factor in setting out the MSF location. By applying the two alternatives (Alternatives 1 and 2), the effect of the brine discharge will be minimized.

Table 16.2 Salinity and temperature results for Alternative 1 compared to existing conditions

Scenario	Summer Alternative 1		Winter Alternative 1	
	Salinity (ppt)	Temp. (°C)	Salinity (ppt)	Temp. (°C)
Basic	45.23	34.6	45.06	21.06
Moderate expansion	45.32	35.1	45.25	22.3
Major expansion	45.42	35.5	45.50	22.6
	Summer existing conditions		Winter existing conditions	
	Salinity (ppt)	Temp. (°C)	Salinity (ppt)	Temp. (°C)
Basic	45.24	34.8	45.07	22.1
Moderate expansion	45.36	35.3	45.30	22.5
Major expansion	45.48	35.9	45.60	23.0

Table 16.3 MSF desalination plant annual chemical and electric cost

Scenario	Basic model		Moderate expansion		Major expansion	
	Summer	Winter	Summer	Winter	Summer	Winter
Intake salinity (ppt)	45.24	45.07	45.36	45.30	45.48	45.60
Temperature (°C)	34.8	22.1	35.3	22.5	35.9	23.1
M_f (kg/s)	2092	2077	10,511	10,485	21,125	21,229
M_{cw} (kg/s)	8397	970	48,778	5098	111,914	11,046
M_b (kg/s)	1352	1337	6811	6785	13,725	13,829
M_{total} (kg/s)	11,841	4384	66,100	22,368	146,764	46,104
Power (KWh)	1871	692.89	10,447	3535	23,196	7287
Pumping cost (M\$/year)	1.23	0.46	6.86	2.32	15.24	4.79
Chemical cost (M\$/year)	3.59	3.56	18.02	17.98	36.22	36.40
Subtotal (M\$/year)	4.82	4.02	24.89	20.30	51.46	41.19
Total (M\$/year)	4.58		23.51		48.38	

Table 16.4 Total annual costs in US \$ for three scenarios considering Alternative 1

Scenario	Existing conditions	Alternative 1	Difference in cost	Saving (%)
Basic	4,576,840	4,553,330	23,500	0.51
Moderate expansion	23,511,996	23,221,017	291,000	1.24
Major expansion	48,382,096	47,189,741	1,193,000	2.46

16.7.3 Alternative 3

Changing the outfall depth to discharge at a lower sea water level had no significant impact at the intake location since the effluent discharge had transported to saturate the full vertical alignment of the water profile especially in the coastline area.

Table 16.5 Salinity and temperature results in existing conditions for Alternative 2

Scenario	Summer		Winter	
	Salinity (ppt)	Temp. (°C)	Salinity (ppt)	Temp. (°C)
Basic	45.23	34.8	45.06	21.8
Moderate expansion	45.36	35.3	45.25	22.4
Major expansion	45.48	35.9	45.50	22.6
	Summer existing conditions		Winter existing conditions	
	Salinity (ppt)	Temp. (°C)	Salinity (ppt)	Temp. (°C)
Basic	45.24	34.8	45.07	22.1
Moderate expansion	45.36	35.3	45.30	22.5
Major expansion	45.48	35.9	45.60	23.0

Table 16.6 MSF plant total annual cost in US \$ (chemical and electric cost) in winter for Alternative 2

Scenario	Basic conditions	Alternative 2	Difference in cost	Saving (%)
Basic	4,576,840	4,573,609	3,231	0.07
Moderate expansion	23,511,996	23,496,427	15,569	0.07
Major expansion	48,382,096	48,305,722	76,374	0.16

Changing the outfall location in terms of vertical alignment should be studied carefully and the non-hydrostatic aspects considered, especially in areas where many industrial facilities exist and where brine discharge is very high.

16.8 Effect of Salinity and Temperature on MSF Performance

Salinity and temperature at the desalination intake are considered one of the determining factors that affect the operation process of a desalination plant. Change in salinity may affect feed water requirements and change in intake seawater temperature may affect cooling water requirements. These changes in the feed and cooling water (M_f & M_{cw}) have an impact on pumping and chemical treatment requirements. The increase in salinity concentration at the intake, and the effect of this change on the MSF parameters, is illustrated in the previous model. The following relationship was obtained showing that the increase in the intake salinity concentration (X_f) will lead to an increase in feed water (M_f).

16.9 Cost Evaluation

Costs can be divided into capital and operational costs known to be largely site-specific. The performance ratio selected affects not only the investment cost, but also the subsequent operating cost. Calculations of unit product cost depend on the process capacity, site characteristics and design features. The system capacity specifies the size for various processing equipment, pumping units and for the required membrane surface area. Site characteristics have a strong influence on the type of pre-treatment and post-treatment equipment and on the consumption rate of chemicals. Process design features affect the consumption of electric power, of heating steam and of chemicals. Production cost is divided into direct and indirect capital costs and annual operating costs.

16.10 Conclusion and Recommendation

The current study highlighted the importance of selecting suitable locations for the intakes and outfalls of the MSF desalination plants. The selection was made so that the effects of environmental conditions of the intake feed water, mainly the salinity and temperature, upon the overall MSF performance is optimized and the operational cost is eventually minimized. Water dynamics and circulation prevailing in the coastal area dictate the status of temperature and salinity of the intake feed water. To achieve these goals, two hydrodynamic analyses were conducted in the study; the first for the entire Arabian Gulf and the second for the local study area of the coastal zone. That modelling was carried out using the well-known Delft3D model. The model results were favourably calibrated against the water levels of the Abu Dhabi coast. The local hydrodynamic model of the selected coastal area was also calibrated against water observations as well as against salinity and temperature field measurements. There was significant agreement between the simulated and observed variables.

The study evaluated the direct effect of intake salinity and temperature upon the operational cost of a MSF desalination plant. The operational costs were subdivided into two major groups; chemical costs and energy costs. Chemical costs were associated with the chemicals added at the feed point, such as anti-scalants, antifoams, etc. The energy costs were associated with lifting and pumping the feed water and the cooling waters throughout various desalination processes. The conducted cost analysis showed that an increase in salinity of about 33 % led to an increase in the chemical cost by about 33.5 % while an increase in the intake water temperature of about 20 % led to an increase in the energy cost by about 78 %. Such results indicated that the intake water temperature has a more pronounced effect on the annual operational cost of MSF desalination plants, thus showing energy costs are much higher than chemical costs.

In order to evaluate the impact of high salinity and temperature on the MSF overall performance and associated operational cost, three scenarios were considered. The first scenario considered existing conditions, while the second and third scenarios assumed moderate and major expansions, of the existing facilities as well as of their discharged effluents. The moderate and major expansions were represented by effluent discharges which increased by 5 and 10 times respectively the existing discharges from the current facilities. A cost analysis was carried out to evaluate the significance of each scenario and of its impact on the MSF performance. The annual operational costs estimated for the three scenarios were estimated at about US \$4.58 million, US \$23.5 million and US \$48.4 million.

It is worth mentioning that such operational costs were based on hydrodynamic simulation results associated with the most frequent wind conditions prevailing in the area, the north-western wind of 5.2 m/s average magnitude. To decide on the optimum intake/outfall configuration, three alternative configurations were considered and evaluated. These alternatives are:

- Alternative 1: Change the intake configuration by extending the intake location offshore to an area receiving cooler and less saline water.
- Alternative 2: Change the outfall configuration by extending the desalination outfall in a location that has a lower impact on the intake location.
- Alternative 3: Change the outfall configuration to discharge the effluent in a deeper zone.

The hydrodynamic simulation results showed little overall reduction in the salinity and temperature achieved with all the tested alternatives and considering the three scenarios, especially the first scenario of existing conditions. This indicates that the current existing intake/outfall configuration has been carefully selected in anticipation of various environmental conditions and different future expansions. The sheltered location of the intake minimized the effect of effluent brine discharged from the existing industrial facilities on the desalination intake.

Alternative 1 did, however, achieve noticeable savings in annual operational costs compared to the existing configurations for moderate and major expansions (1.2 and 2.5 %). Such percentages even though they look small, represent major annual savings estimated at US \$291,000 and US \$1,193,000 USD respectively.

Studying the effect of the less-frequent reverse wind direction upon the MSF performance reflected a higher operational cost than in the case of dominant wind direction. This was tested for the case of the basic scenario (current effluents) of the existing intake/outfall configuration. Such a result suggests that further savings can be achieved with different alternatives in case of considering the reverse wind direction, especially if future expansion is limited to the western effluents of industrial facilities only. The results indicate that locating the intake near the shoreline in the case of large amounts of discharged effluents is not advisable since the coastal shore water is shallow and is highly affected by any increase in temperature and salinity due to a slow mixing process and low circulation. Although extending the intake configuration requires initial capital costs, the savings attained from the running operational cost can definitely cover such costs

in a few years after which savings will be achieved. Finally, the study outcomes strongly recommend greater attention to be paid to studying and investigating the selection of the intake and outfall configurations, especially when there is a plan for a major expansion of the existing facilities. This selection should be made in line with a fuller understanding of the hydrodynamic phenomena prevailing in the area under study as well as an awareness of the relevant environmental conditions, bylaws and regulations.

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