Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2020.24953

178 (2020) 74–82
February

Technical and economical comparison study between operation costs of beach well intake and open intake for seawater reverse osmosis desalination in the Persian Gulf

Seyed Mohammad Hossein Fayaz[a], Roya Mafigholami[a,*], Fatemeh Razavian[b], Karim Ghasemipanah[c]

[a]*Department of Environment, West Tehran Branch, Islamic Azad University, Tehran, Iran, emails: r.mafigholami@wtiau.ac.ir (R. Mafigholami), smhfayaz@yahoo.com (S.M.H. Fayaz)*
[b]*Department of Environment, Parand Branch, Islamic Azad University, Parand, Iran, email: f.razavian@rkiau.ac.ir*
[c]*Research Institute of Petroleum Industry (RIPI), Tehran, Iran, email: ghasemipanahk@ripi.ir*

Received 13 April 2019; Accepted 21 September 2019

ABSTRACT

The intake system plays a fundamental role in improving feed water quality and has a great influence on the operating costs of the seawater reverse osmosis desalination processes. The potential risk of membrane fouling can be increased by the entry of high concentrations of compounds and biological matters associated with feed water into the desalination plant. Beach wells and galleries, an alternative subsurface intake, that provides natural filtration and biological treatment. Analyses of the changes in concentration of contaminants, turbidity, silt density index value, and pressure differential across sand filters, filter cartridges membranes, and water production rates were evaluated for open and beach well intake methods. The results indicated that a hybrid beach well intake constructed of a semi-deep open well and galleries contributed to a dramatic improvement in water quality and a significant reduction in concentrations of contaminants with biological agents including dissolved organic carbon and phytoplankton. Moreover, economic analyses showed that overall operating costs can be reduced by 24% using beach well intake systems compared to a seawater open intake.

Keywords: Intake systems; Beach well with gallery; Operation costs; Biological contaminants; Reverse osmosis system

1. Introduction

Reverse osmosis system (RO) is one of the most economical treatments for a wide range of applications including seawater desalination [1–3]. Dwindling and highly polluted water resources are stressing present conventional pretreatment techniques, and membrane pretreatment has emerged promisingly [4,5]. Open intakes have been utilized widely in most seawater reverse osmosis (SWRO) plants. Poor-quality water characteristics with high concentrations of different organic compounds impose limitations on the use of conventional open-intake [6–8]. Membrane fouling including biofouling, particulate/colloidal, organic, and inorganic fouling is one of the fundamental operational issues at most RO facilities and leads to a reduction in operational efficiency of desalination systems [4,6]. Organic and inorganic contaminants, biological deposits, barnacles and algae cause biological depositions in water intake systems, pumping stations, pretreatment units, and RO membranes, which result in increasing pressure differences, reproduction flows, and ultimately membrane fouling [9]. To prevent a short span of RO membrane lifetimes and periods of operation,

* Corresponding author.

complex and extensive pre-treatment systems are required which entail high costs [10].

An appropriate water intake system ensures high-quality water and reduces pretreatment complexity and operating costs [10]. Efficient water intake system design and operation depend on various factors such as geological conditions, system capacity, water quality, and environmental sustainability. Other factors such as technical, economic, and ecological considerations are also important [6].

Subsurface intakes act both as intakes and as part of the pretreatment system by providing filtration and active biological treatment of the raw seawater [6–11]. Vertical wells and galleries can provide reliable quantities of raw water with a higher quality than surface water intake [12]. Gallery intakes used for SWRO treatment take advantage of slow sand filtration to improve water quality by straining, filtrations and biological activity that can bind or break down many different organic compounds in seawater [6].

Missimer et al. [6] outlined that using subsurface intake systems significantly improves raw water quality, reduces chemical usage and environmental impacts, decreases the carbon footprint, and reduces the cost of treated water to consumers. These intakes include wells (vertical, angle, and radial type) and galleries, which can be located either on the beach or in the seabed.

Recent investigations in water quality improvement achieved by subsurface intakes showed a lowering of silt density index (SDI) of 75%–90%, removal of nearly all algae, 90% of bacteria, significant reduction in the concentrations of total organic carbon (TOC) and dissolved organic carbon (DOC), and virtual elimination of biopolymers and polysaccharides [6]. Additionally, other investigations demonstrated that in comparison with direct water intakes, which require more pretreatment processes, the beach well and gallery intake systems significantly reduce pretreatment costs [12–15]. The efficiency of subsurface intake systems (the good type) in terms of organic and micro-organism removal was investigated along the Red Sea coastline of Saudi Arabia. The quality of raw water extracted from the well systems was highly improved compared with the raw seawater source. It was observed that algae were virtually 100% removed and the bacterial concentrations were significantly removed by the aquifer matrix [16]. According to the surveys, the environmental performance of beach well intakes is superior to open intake plants because of lower chemical and electricity use in the pretreatment phase of open intake plants [16]. Additionally, Shahabi et al. [17] quantified the environmental and economic performances of an SWRO plant, using beach well intake and compared the results to those for an open intake plant. The results indicated that the beach well intake plant life cycle environmental burdens and levelized costs were 31% and 13% respectively, lower than those for open-intake systems.

Although operational costs of beach wells and galleries relative to open intakes are highly important in desalination plants, few studies have been conducted to compare these intake systems thoroughly. The current study aims to thoroughly compare the operational costs of both direct and indirect water intake systems at the Bushehr desalination sites in the Persian Gulf which has a capacity of 2,000 m^3/d.

2. Methodology

This research was carried out at the RO desalination plant on the North West of the Persian Gulf in Bushehr. This desalination plant has been operated to supply potable water by two methods of open intake and beach well gallery. The simplified processes of direct water intake and beach well and gallery are illustrated in Fig. 1. To make them comparable, the same functional unit (2,000 m^3 of desalinated water) was studied for both open intake and beach well with gallery methods. The open-intake operation process includes the water-intake unit and pre-treatment system. Seawater is taken from a depth of 5 m by an electro feed pump in the water intake unit. Then, chemical solutions including chlorine disinfectant and coagulants are injected into the water. The pre-treatment unit involves clarifiers, gravity sand filtering, high-pressure filter, and filter cartridges. Water enters the clarifier to remove the suspended particles and water turbidity. The water then enters the gravity sand filter and pressure sand filters. The water next enters the filter cartridges to control the SDI. The filter cartridges are polypropylene cylindrical units with the pore diameters of 5 and 1 microns which prevent the passage of fine particles to the membranes. In the beach well method, seawater is collected after passing through a sandy bed. To evaluate the nature of the shallow geology in the area adjacent to the coast, a number of geotechnical boreholes were drilled and geological characterizations of the layers were carried out. The results showed combinations of clay, silt, caprock gravel and beach sand in the layers. The permeability of the layers was evaluated to determine the preferred locations for well drilling and to estimate well capacity. Afterward, drilling of well and construction of galleries was performed in the direction of coral lenses obtained from the boreholes and saturated layers. Well pumping tests were carried out in the next stage. Finally, chemical, physical and biological analyses of water were investigated for the purpose of the pre-treatment design system.

Operational data are recorded at regular intervals which are summarized in Table 1. Oxidation–reduction potential (ORP) is a measure of degree of oxidation/reduction of materials. The ORP value in this study indicates the amount of injected or residual chlorine and the usual reaction time. The amount of injected chlorine was determined by an online ORP meter (JUMO brand) every 2 h. The amount of residual chlorine in mg/L was measured by an MD200 Lovibond machine using the spectrophotometric method with the DPD specification. The turbidity level of the raw water was measured with an Aqualytic AL250T-IR turbidity meter through the Nephelometric light method. SDI measurement is based on the time required to filter a volume of the feed water through a 0.45 μm filter at a constant pressure of 20.86 kPa (30 PSI). Multiple analyses were performed and the mean values of the results were presented in this study.

Low concentration (3 mg/L) of calcium hypochlorite solution (purity of 65%) is injected daily into the inlet raw water. The amount of injection depends on the concentrations of organic and biological pollutants and the SDI value of the RO units. Coagulation and flocculation are used to reduce turbidity, algae and other microorganisms. 1–3 mg/L of UltraClear (RuSubgiri Chemical Company, RSCO) based

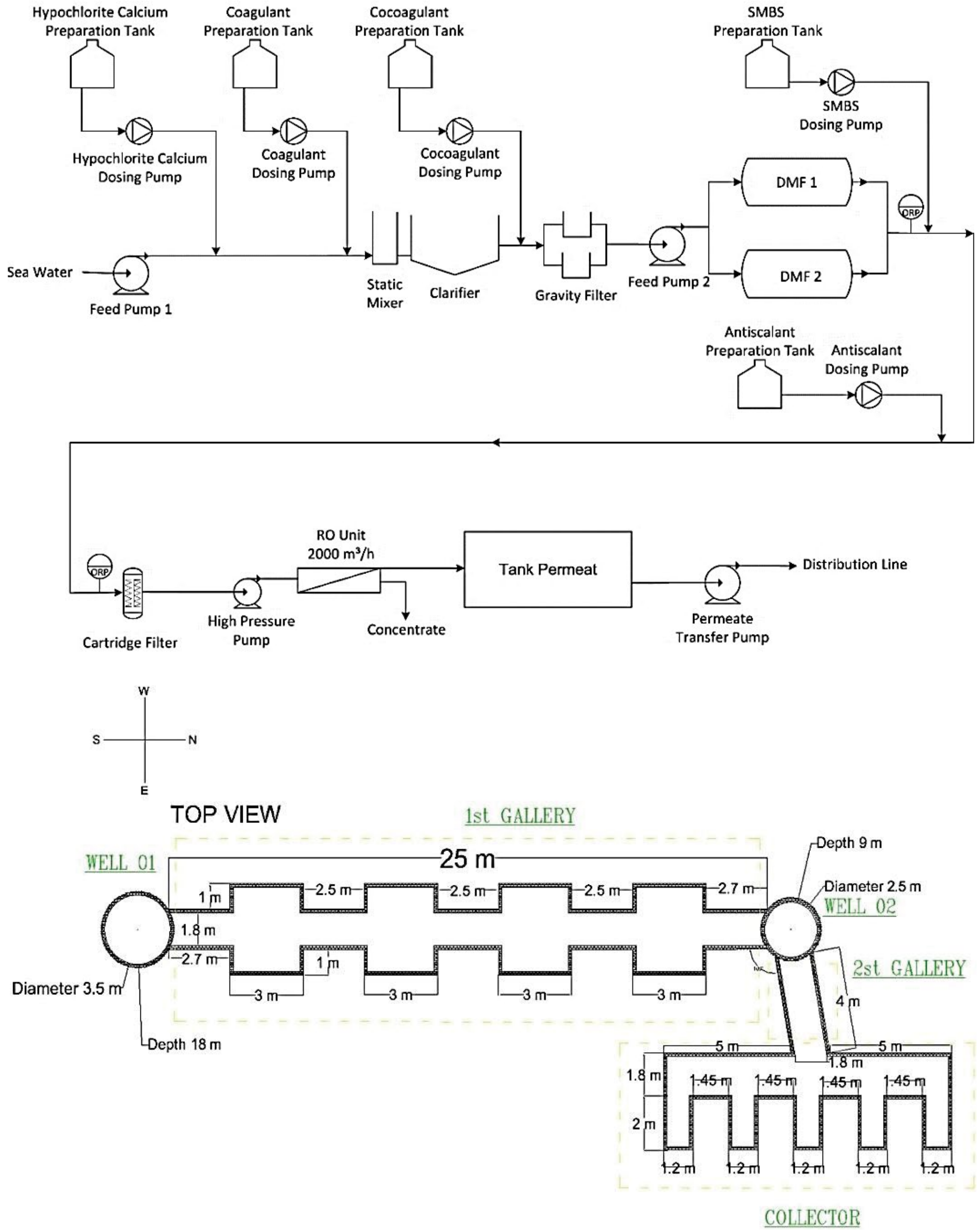

Fig. 1. Simplified process of (a) direct water intake and (b) beach well with gallery.

on polyacrylamine coagulant solution and Falcon 260 antiscalant solution are injected into the raw water. The injection rates of coagulant solution are determined by the raw water turbidity, SDI value, and jar test. The injection rate of and antiscalant solution is determined on the basis of testing performed on the raw water sample. A sodium metabisulfite (SMBS) solution is injected into raw with a concentration of 1–5 mg/L.

For the beach well intake method, there is one beach well with one gallery along with five gallery collectors. Methodology and water sampling methods are presented in Table 2.

3. Results and discussion

3.1. Physical and chemical parameters

Raw water inlet was analyzed annually in both the direct and indirect water intake surveys. General water quality parameters including turbidity, total dissolved solids, conductivity, pH, biological oxygen demand (BOD), and total hardness are summarized in Table 3. The average annual turbidity of open intake water was about 15 NTU while for beach well the turbidity was less than 1. Predominant reduction in turbidity is due to the passage of water through coral layers and initial water filtration. The amount of BOD

Table 1
Periodic factors measurements

Measurements	Factors
Every 2 h	ORP, turbidity (NTU), SDI, sand filter pressure difference, cartridge filter pressure difference, membranes pressure difference, chemical injection rate, and amount of water intake (Q).
Daily	Electrical conductivity of raw water, pH, total dissolved solids of raw water and produced water, and the amount of electricity consumed in kWh/24 h.
Monthly	Amount of cartridge filters, the amount of chemical and material consumption of parts and supplies, the maintenance and repair costs of equipment and manpower costs, transportation costs and staff costs.
Annually	Full analysis (physical, chemical, and biological) of seawater, total operating costs, maintenance, and repairs costs.

Table 2
Methodology of sampling

Sample	Intake method	Sampling place	Sampling tools
Raw seawater	Open	Pond center (at depth of 5 m)	Suction sampling bottle (using pump at different depths)
Raw seawater	Beach well	Well immersed pump outlet	Sampling valve

Table 3
Analysis of raw input water for open intake and beach well with gallery systems

Parameter	Beach well	Open intake
pH	8.29	8.26
Electrical conductivity, µS/cm	67,100	67,000
Turbidity	≤1	15
Total dissolved solids, mg/L	39,000	38,800
Chemical oxygen demand, mg/L	5	<3
Biological oxygen demand, mg/L	2	<1
Total organic carbon, mg/L	3	<1
Dissolved oxygen, mg/L	4.9	4
Total hardness ($CaCO_3$), mg/L	7,000	7,000
Mg, mg/L	5,600	5,700
Na, mg/L	11,650.0	11,600.0
K, mg/L	672.02	632.19
Total alkalinity, mg/L	122	124
Bicarbonate, mg/L	122	124
Chloride, mg/L	21,622.5	21,500.9
Sulfate, mg/L	2,950	2,920
Fluoride, mg/L	0.50	0.48
Ammonium ion, mg/L	0.03	0.07
Nitrite, mg/L	0.015	0.037
Nitrate, mg/L	0.88	0.88
Phosphate, mg/L	<0.01	<0.01
Oil and fat, mg/L	<0.1	<0.1
Total petroleum hydrocarbons, mg/L	<0.001	<0.001
Total coliform count, MPN/100 ml	4	0
Fe, µg/L	0.273	0.320

and TOC which are indicators of the presence of biological contaminants are less in the beach well water than the open intake system. The chemical oxygen demand is also significantly less in beach well intake. Moreover, due to the passage of water through the underground layers of the earth in the beach well with the gallery system, the amount of dissolved oxygen in water is less than open intake. The pH value of seawater from the wells is slightly higher than that measured in the open intake sample.

3.2. Microorganism

A thorough comparison between open intake and beach well with gallery method in terms of biological contaminants was made to evaluate the removal efficiency. A wide range of biological agents was analyzed and a summary of this characterization is presented in Table 4. The bacterial agents are fallen into four main categories; including *Bacillariophyceae*, *Chrysophyceae*, *Cyanophyceae*, and *Euglenophyceae*. *Bacillariophyceae* (diatoms) which occupy a wide range of habitats at different levels of pollution are potential indicators of water quality. These bio-indicators have unique properties including high reproduction rate and a high sensitivity towards different levels of polluted water [18]. *Chrysophyceae*, *Cyanophyceae*, and *Euglenophyceae* are the principle phytoplankton taxa in the ocean [19,20] the phytoplankton population in the open intake water was about 1,525 cell/L and in the well samples, it was about 225 cell/L. Abdullah et al [16] showed significant concentration differences of *Cyanobacteria*, *Prochlorococcus* and *Pico/Nano plankton* between open intake and well intake systems. Several studies indicated that dramatic improvement in water quality can be obtained through beach well intake in comparison with open intake systems [21–25]. Thorough

Table 4
Different concentrations of biological agents in two intake methods

Group	Type	(Cell/L)	
		Indirect water intake	Direct water intake
Bacillariophyceae	*Amphora*	10	40
	Amphiprora	5	30
	Biddulphia	5	20
	Bellerochea	0	15
	Bacteriastrum	0	30
	Campylodiscus	0	5
	Cyclotella sp.	50	360
	Dactyliosolen	0	15
	Diploneis	0	10
	Eucampia	0	5
	Lauderia	5	10
	Melosira sp.	10	40
	Navicula sp.	10	230
	Nitzschia sp.	10	200
	Pinnularia	10	40
	Rhizosolenia setigera	4	15
	Stephanopyxis	5	5
	Thalassionema	0	5
Chrysophyceae	*Dictyocha*	0	5
Cyanophyceae	*Anabaena*	10	30
	Phormidium	20	30
	Spirulina sp.	20	35
	Oscillatoria sp.	0	15
Dinophyceae	*Alexandrium*	0	10
	Ceratium	0	0
	Dinophysis	5	10
	Gymnodinium sp.	10	230
	Oxytoxum	0	5
	Protoperidinium	20	40
	Scripciella	0	0
Euglenophyceae	*Eutreptia*	0	40

comparative surveys of water quality influenced by different biological contaminants are presented in Table 5. According to this survey, membrane biofouling as a result of lower concentrations of algae, bacteria, and organic compounds can be less in a good intake system comparing with the open intake system.

3.3. Silt density index

The annual average value of SDI in both open intake and beach well intake samples are summarized as Table 6. The SDI values of beach well intake samples are much less than that for an open intake method, which plays a key role in the entry of contaminants and fouling. The decrease in contaminant concentrations directly affects SDI values.

3.4. Economical aspect

3.4.1. Chemical material

Economics is one of the predominant factors in selecting intake systems for desalination plants. An economic analysis was carried out for maintenance cost, chemical material, filter cartridge, electrical energy consumption, and membrane replacement. Operational costs of a beach well with gallery intake in comparison with open intake in terms of chemical material are given in Table 7. Calcium hypochlorite ($Ca(OCl)_2$) as a powerful oxidizing agent is used effectively to remove and oxidize various organic and biological contaminants. Relatively low concentrations of calcium hypochlorite are used for the beach well intake compared with the direct water intake system due to the initial natural filtration of water. The concentrations of calcium hypochlorite required for the beach well and indirect water intakes are about 5 and 1 mg/L, respectively. Chlorine is injected to remove the organic and biological elements in the raw water. The residual chlorine is removed to prevent corrosion damage of membranes by SMBS injection. Since chlorine injection results in SDI reduction, the amount of remaining chlorine in direct water intake and beach well with gallery intake is adjusted to be in the range of 0.5–0.6 mg/L, and 0.1–0.2 mg/L, respectively. The optimum amounts of SMBS injected to remove the residual chlorine in direct and beach well with gallery intake are about 3 and 1 mg/L, respectively. The chemical consumptions in the beach well system are reduced to 55% of that for a direct water intake, which has benefits effect on operation costs. The amount of flocculants injection and its related cost for both direct and beach well with gallery intake are provided in Table 7. A considerable amount of flocculants is required to reduce the turbidity and SDI value in the direct water system. However, due to the initial natural filtration of water, there is no need to inject flocculants agents on the beach well with the gallery system. The optimum antiscalant injection for both systems is about 3 mg/L. Table 7 shows the amount of chemicals used to wash membranes. Due to the introduction of various contaminants through direct water intake to RO desalination systems and high value of SDI entering the filter cartridges and membranes during the unit's operation, the fouling of the membranes occurs. The need for chemical washing processes in the open-intake method occurs more frequently for the beach well with the gallery intake system which inevitably increases the involved costs. The interval of chemical washout in beach well with gallery intake is every 4 months, but for direct water intake at the interval is 2–2.5 months. For each calculation, all consumed parts along with their unit cost were determined, which were then calculated per month.

3.4.2. Filter cartridge consumption

Cartridges of one-micron filter are used to remove suspended material entering the RO system to reduce SDI to values less than 5. Based on the operation data, SDI values for the direct seawater intake ranged from 3 to 5 during 85% of the operation of the pre-treatment system, and 15% of the time it was above 5. However, on the beach well intake, SDI was less than 3, and in most cases, the value was

Table 5
Comparison between different types of biological and organic contaminants in the well intake and open intake desalination sites

Location	Contaminants	Open intake	Beach well
Persian Gulf, Iran [present study]	*Bacteriastrum*, (cell/L)	30	0
	Cyclotella sp., (cell/L)	360	50
	Navicula sp., (cell/L)	230	10
	Gymnodinium, (cell/L)	230	10
	TOC, (cell/L)	3	<1
	Phytoplankton, (cell/L)	1,525	225
Dahab, Egypt [21]	DOC (mg/L)	1.6	1.2
	UV-254 (m^{-1})	1.4	0.8
Fuerteventura Island, Spain [22]	TOC (mg/L)	0.5	0.7
	UV-254 (m^{-1})	0.36	0.55
	Phytoplankton, (cell/L)	57,720	0
Al Birk, Saudi Arabia [23]	Dissolved protein (mg/L)	2.73	0.75
	Dissolved carbohydrates (mg/L)	1.57	0.52
SWCC Al Jubail test sites [24]	TOC (mg/L)	2	1.2–2
	UV-254 (m^{-1})	1.8×10^3	1.3×10^3
Mediterranean Location-Spring [25]	Total picophytoplankton (cells/ml)	1.6×10^3	1.3×10^2
	Synechococcus (cells/ml)	1.3×10^3	1.0×10^2
	Picoeukaryotes (cells/ml)	1.1×10^3	1.9×10^1
	Nanoeukaryotes (cells/ml)	1.2×10^2	1.7×10^0
Jeddah, Saudi Arabia [16]	*Cyanobacteria*	1,507	≤5
	Prochlorococcus	140	≤5
	Pico/nano plankton	30	≤5

Table 6
SDI value measured for open intake and beach well with gallery intake methods

Raw water intake methods	SDI
Open intake	85% of total measurements ranges between 3 to 5
	15% of total measurements ranges more than 5
Beach well with gallery intake	85% of total measurements less than 1
	15% of total measurements ranges between 1 to 2

Table 7
Benefits of operation costs of beach well with gallery intake over open intake in course of chemical material

Intake	Description cost	Dosing mg/L Min. Max.	Average dosing mg/L	Daily row water (m^3)	Average dosing kg/month	Unit cost ($)/kg	Month cost ($)	Cost ($/$m^3$)
Open intake	Calcium hypochlorite 65%	4, 5	4.5	5,714	784	0.9	706	0.012
	SMBS 97%	5, 3	4	5,714	697	0.35	244	0.004
	Flocculant	2, 4	3	5,714	2,091	1.1	2,301	0.0094
	Antiscalant	3, 3	3	5,714	523	4	2,091	0.034
	CIP cleaning	Alkaline	–	–	62	2.5	124	0.0026
		Acid	–	–	40	2.5	80	0.0013
Beach well with gallery	Calcium hypochlorite 65%	1, 1	1	5,714	174	0.9	157	0.003
	SMBS 97%	1, 3	2	5,714	174	0.35	61	0.002
	Flocculant	0, 0	0	0	0	1.1	0	0
	Antiscalant	3, 3	3	5,714	523	4	2,091	0.034
	CIP cleaning	Alkaline	–	–	21	2.5	51	0.0009
		Acid	–	–	10	2.5	20	0.0003

between one and two. Table 8 shows the consumption of filter cartridges in direct and beach well with gallery intake of seawater, with relevant costs. It should be noted that the number of cartridges used in the unit of washing cleaning in place (CIP) filters is a function of the number of washings per year, as calculated in Table 6. The operating time range of the cartridge filters is 15 d – 1 month in the case of direct water intake and is about 1.5–2 months for beach well with gallery intake. This decrease in frequency is due to the reduction in the suspended solids concentrations and the SDI value. Therefore, the cartridge filter replacement cost was reduced to 66 percent with method well intake. All types/models/producers of cartridges are the same for both intake methods.

3.4.3. Membrane replacement

RO system membranes are the most important part of the desalination system, and their supply is from external sources. The membranes used in the desalination unit are FILMTEC SW400. The period of membrane replacement in direct seawater intake with inlet water quality conditions, organic and mineral suspensions, SDI values at the test site is about three years, but in the case of beach well with gallery mode, it is up to five years. Table 9 shows the period of membrane changeover and related costs in two direct and beach well with gallery intake modes.

3.4.4. Electrical energy consumption

Energy consumption is a fundamental parameter affecting the choice of desalting system and final water cost. The beach well system is the appropriate process as it reduces energy consumption and specific investment cost. Power consumption in direct and beach well with gallery intake is about 4 and 5 kW h/m^3, respectively. The reasons are; more backwash of sand filters, chemical injections, frequent flushing of membranes, and multiple chemical washings, which result in increasing the number of stops, repairs, and filters replacement. Table 10 shows electrical energy consumption and related costs in both direct and beach well with gallery intake modes.

3.4.5. Maintenance cost

The maintenance cost assessment includes repairs of filtering equipment, cleaning the units, chemical washings, cartridge filters, and manpower costs. Table 11 shows average maintenance costs in two modes. Approximately 9% reduction in maintenance costs occurs for operation with beach well with gallery intake systems. A direct water intake requires a thorough pre-treatment system with complementary units, such as dual media filter for the first and second stages as well as coagulation and flocculation units, more filters backwash and cleaning units increase

Table 8
Cartridges filters consumptions for open intake and beach well with gallery intake systems

Intake	Description cost	Period of change			Number	Monthly consumption (No)	Unit cost ($)/kg	Monthly cost ($)	Cost ($/m^3)
Open ontake	Cartridge Filter	Pre treatment		0.5 month	64	128	2.5	320	0.0052
	1 micron	CIP		2 month	62	31	2.5	78	0.0013
								–	
Beach well	Cartridge Filter	Pre treatment	1.5	1.5 month	64	43	2.5	107	0.0017
with gallery	1 micron	CIP	6	6 month	62	10	2.5	26	0.0004

Table 9
Membrane replacement period and related costs in both direct and beach well with gallery intake modes

Intake	Consumption	Monthly consumption (No)		Unit cost ($)/kg	Monthly cost ($)	Cost ($/m^3)
Open intake	Each 3 year	154	4	650	2,781	0.00046
Beach well with gallery	Each 5 year	154	3	650	1,668	0.00027

Table 10
Electrical energy consumption and related costs in both direct and beach well with gallery intake modes

Intake	Description cost	Average consumption (kWh/m^3)	Monthly consumption (kW h)	Unit cost ($)/kW h	Monthly cost ($)	Cost ($/m^3)
Open intake	Electrical energy	5	305,000	0.02	6,100	0.1
Beach well with gallery	Electrical energy	4	244,000	0.02	4,880	0.08

Table 11
Average maintenance costs in direct and beach well with gallery intake modes

Water intake	Cost description	Monthly cost ($)	Cost ($/m³)
Open intake	Maintenance	3,500	0.0574
	Manpower (9 persons)	4,048	0.0664
Indirect water intake	Maintenance	2,500	0.0410
	Manpower (9 persons)	4,048	0.0664

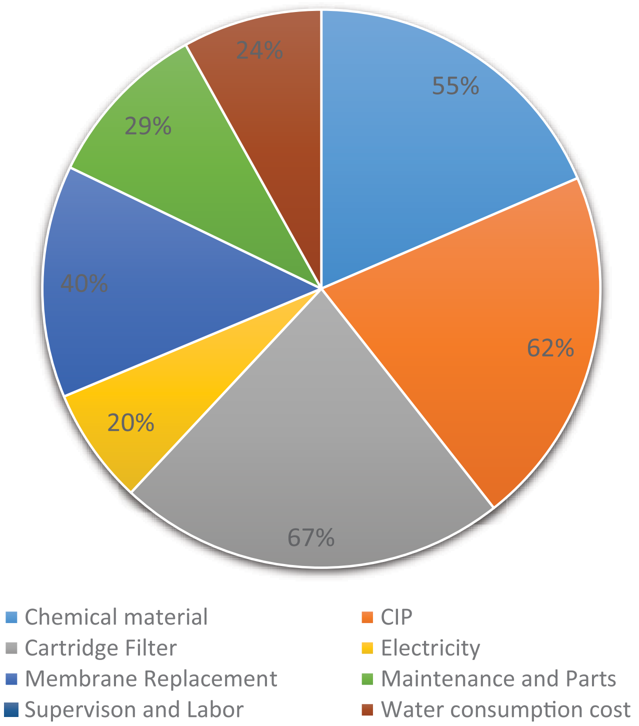

Fig. 2. SWRO plant cost reduction for the beach well with a gallery in comparison with direct water intake.

the duration of the stop, repairs cost and ultimately maintenance costs.

Fig. 2 and represents the estimation of maintenance costs for each type of intake system. There is a considerable decrease in operating costs of the beach well with the gallery intake system.

4. Conclusion

Membrane biofouling as a result of lower concentrations of algae, bacteria, and organic compounds can be less in a good intake system compared to an open intake system. SDI value of water produced from a beach well with gallery intake is much less than that from an open intake method. Reductions in the consumption of chemical materials, and less frequent cartridge filter and membrane replacement, and the quantity of energy and the overall cost of water to the consumer are the main advantages of beach well intakes over open-intake systems. Beach well intakes produce a higher quality of feed water compared to conventional open-ocean intakes due to the reduction in concentrations of contaminants. This improvement in water quality leads to the simplification of required pretreatment processes with the elimination of many processes. Supplying water through indirect water intake system (coastal well) not only increases the quality of water but also reduces the cost of operation, maintenance and repairs up to 24%.

References

[1] M. Elimelech, W.A. Phillip, The future of seawater desalination: energy, technology, and the environment, Science, 333 (2011) 712–717.
[2] S. Lattemann, T. Höpner, Environmental impact and impact assessment of seawater desalination, Desalination, 220 (2008) 1–15.
[3] WateReuse Association, Seawater Concentrate Management, WateReuse Association White Paper, 2011.
[4] H.S. Vrouwenvelder, J.A.M. van Paassen, H.C. Folmer, J.A.M.H. Hofman, M.M. Nederlof, D. van der Kooij, Biofouling of membranes for drinking water production, Desalination, 118 (1998) 157–166.
[5] W.B. Gollnitz, J.L. Clancy, B.L. Whitteberry, J.A. Vogt, RBF as a microbial treatment process, J. Am. Water Works Assn., 95 (2003) 56–66.
[6] T.M. Missimer, N. Ghaffour, A.H.A. Dehwah, R. Rachman, R.G. Maliva, G. Amy, Subsurface intakes for seawater reverse osmosis facilities: capacity limitation, water quality improvement, and economics, Desalination, 322 (2013) 37–51.
[7] G. Cartier, P. Corsin, Description of Different Water Intakes for SWRO Plants, Proceedings of the International Desalination Association World Congress on Desalination and Water Reuse, Maspalomas, Gran Canaria, Spain, October 21–26, 2007.
[8] E.D. Mackey, N. Pozos, W. James, T. Seacord, H. Hunt, D.L. Mayer, Assessing Seawater Intake Systems for Desalination Plants, Water Reuse Foundation, 2001.
[9] A.M.M. Alhadidi, B. Blankert, A. Kemperman, J.C. Schippers, M. Wessling, W.G.J. van der Meer, Effect of testing conditions and filtration mechanisms on SDI, J. Membr. Sci., 381 (2011) 142–151.
[10] N. Prihasto, Q.-F. Liu, S.-H. Kim, Pre-treatment strategies for seawater desalination by reverse osmosis system, Desalination, 322 (2013) 37–51.
[11] N. Voutchkov, Thorough study is key to large beach-well intakes, Desal. Water Reuse Q., 14 (2005) 16–20.
[12] H.M. Baalousha, The potential of using beach well with gallerys for reverse osmosis desalination in Qatar, Model. Earth Syst. Environ., 97 (2016) 1–12.
[13] N. Voutchkov, SWRO desalination process: on the beach – seawater intakes, Filtr. Sep., 42 (2005) 24–27.
[14] H. Baalousha, Desalination status in the Gaza Strip and its environmental impact, Desalination, 196 (2006) 1–12.
[15] B. David, J.-P.P., M. Morrillon, Beach Well with Gallery for Large Scale Reverse Osmosis Plants: The Sur Case Study, Proceedings of the International Desalination Association World Congress on Desalination and Water Reuse, Atlantis, The Palm, Dubai, UAE, 2009.
[16] A.H.A. Dehwah, S. Al-Mashharawi, N. Kammourie, T.M. Missimer, Impact of well intake systems on bacterial, algae, and organic carbon reduction in SWRO desalination systems, SAWACO, Jeddah, Saudi Arabia, Desal. Wat. Treat., 55 (2015) 2594–2600.
[17] M.P. Shahabi, A. Mchugh, G. Ho, Environmental and economic assessment of beach well with gallery intake versus open intake for seawater reverse osmosis desalination, Desalination, 357 (2015) 259–266.
[18] A. Michels, Use of diatoms for water quality assessment in tow tropical streams in Costa Rica, Rev. Biol. Trop., 46 (1998) 143–152.

[19] S. Palleyi, R.N. Kar, C.R. Panda, Influence of water quality on the biodiversity of phytoplankton in Dhamra river estuary of Odisha Coast, Bay of Bengal, J. Appl. Sci. Environ. Manage., 15 (2011) 69–74.
[20] P.P. Baruah, B. Kakati, Water quality and phytoplankton diversity of gopeswar temple freshwater pond in Assam (India), Bangladesh J. Bot., 41 (2012) 181–185.
[21] A. Hassan, A.T.M. Jamaluddin, A. Rowaili, E. Abart, R. Lovo, Investigating Intake System Effectiveness with Emphasis on Self-Jetting Well-Point (SJWP) Beachwell System, Proceedings, 2nd Acquired Experience Symposium on Desalination plants O & M, Al-Jubail, Saudi Arabia, Sept. 29–Oct. 3, 1997, pp. 1350–1350.
[22] A. Teuler, K. Glucina, J.M. Laine, Assessment of UF pretreatment prior to RO membranes for seawater desalination, Desalination, 125 (1999) 89–96.
[23] A.T.M. Jamaluddin, A.M. Hassan, A. Al-Reweli, M.O. Saeed, Operation of Al-Birk Plant Introducing Beachwell Intake System, International Desalination Association World Congress on Desalination and Water Reuse, Singapore, 2007.
[24] A.M. Hassan, A.T.M. Jamaluddin, A. Rowaili, E. Abart, R. Lovo, Investigation Intake System Effectiveness with Emphasis on Self-Jetting Well-Point (SJWP) Beachwell System, Proceedings, 2nd Acquired Experience Symposium on Desalination Plants O & M, Al-Jubail, Sept. 29–Oct. 3, (1997), pp. 1350–1365.
[25] P. Choules, J.-C. Schotter, J. Leparc, K. Gai, D. Lafon, Operation Experience from Seawater Reverse Osmosis Plants, Proceedings, American Membrane Technology Conference and Exposition, Las Vegas, Nevada, 2007.