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# Monitoring Seasonal Variation in Important Physio-Chemical Parameters of Arabian Seawater at Karachi Used for Feeding SWRO

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This study reports the analysis of various parameters of seawater upto 3 years used for feeding to seawater desalination (SWRO) plant at French Beach, Arabian sea, Karachi city, Pakistan. The work highlights the monitoring of essential parameters of seawater intake to reverse osmosis plant for pre-treatment loop designing and optimizing the operational cost. The study was planned as limited data was available internationally from this region, which includes pH, turbidity, temperature, total dissolved solids (TDS) and total suspended solids (TSS) allied with seasonal variations before pretreatment and after getting permeate. The water production capacity of SWRO plant is 100,000 gallon per day having Filmtech polyamide membrane and equipped with energy recovery turbine. It was observed in the period since 2015 to 2017, the monitoring of intake samples *i.e.* pH, turbidity and temperature showed variation in the range of 7.9-8.1, 8-34 NTU and 21-29 ºC, respectively. The observed value of TDS and TSS of seawater were 38.0-39.5 g/L and 18-48 mg/L, respectively. The concentrations of soft metals in seawater were found to be in order of Na > Mg > Ca > K while major anions were $Cl^-$ >$SO_4^{2-}$. The TDS and pH of permeate water found to be in the range of 150-500 mg/L and 6.0-7.5 respectively, while other parameters were within WHO limit.

**Keywords: Seawater desalination, Pretreatment, Permeate, Arabian sea.**

## INTRODUCTION

Freshwater reservoirs are under depletion due to urbanization where excessive water used in industrial processes and large quantity is discharged as wastewater again in freshwater bodies. Now this has become a huge problem for fresh water bodies as a main freshwater provider. Pakistan is facing the worst ever crises of water shortage for last many years, as the water available for any given use has become increasingly scarce [1]. According to the International Monetary Fund (IMF), Pakistan is the third most water-stressed country in the world [2]. It has crossed the water stress and scarcity lines in 1990 and 2005, respectively [3]. Currently, the country's per capita annual water availability stands at 1017 $m^3$, which was about 1282 $m^3$ in 2002. With the present pace, the gap between demand and supply will reach 83 million acre foot (MAF) by 2025 [4].

According to a report by the World Resources Institute, Pakistan is on track to become the most water-stressed country in the region, and 23rd in the world by the year 2040 [5]. According to the Pakistan Council of Research in Water Resources (PCRWR), Pakistan may run dry by 2025 if the present conditions continue [6]. Water shortage is an alarming situation in the world biggest populated city Karachi where migration from rural to urban is revolutionize the every plan, in which water is crucial, therefore, seawater desalination (SWRO) are inevitable for survival of population [7].

Seawater desalination is becoming increasingly popular for production of drinking water worldwide, as many coastal municipalities and utilities are looking for reliable and drought-proof sources of new local water supply [8,9]. Scientists prediction about fresh water production through desalination plants in 2008 was fulfilled in 2016 as reported earlier [10,11].

One of the most important aspects related to SWRO design, operation and long-term management of clear water production requires monitoring of seawater parameters with seasonal variation particularly when open intake is used. The analysis of seawater is essential in smooth running of SWRO plants in relation with its membrane which is a crucial part of the SWRO plant. Seawater contains substances and particles which are potentially harmful for the SWRO plant's components. Biological substances can create fouling, solid particles can cause coagulation and deposition, dissolved solids can cause scaling and material corrosion can be accelerated [12]. Therefore, the best water quality can be achieved through suitable pretreatment of seawater as it is essential for long term sustainable reverse osmosis (RO) plant operation.

As no report is available up to our best of knowledge regarding the seawater treatment of Arabian Sea, Karachi, a largest city of Pakistan, this work highlights the monitoring of essential parameters of seawater intake for feeding to reverse osmosis (RO) plants for their pre-treatment loop designing and optimizing the operational cost.

## EXPERIMENTAL

**Sampling site:** The investigations were made at the reverse osmosis (RO) plant located on the French beach of Karachi half way between Hawkes Bay and Paradise point, rocky and clear waters are ideal for snorkelling and scuba, a small fishing village frequented by Karachi's elite and known to the locals as Haji Ismail Goth beach side of Karachi Coast (Fig. 1). The samples of seawater were collected bimonthly in one litre presterilized amber glass bottles since January 2015-2017. The bottles were carefully filled to avoid trapping air bubbles, labelled and transported in refrigerated condition to the Laboratory in Chemistry Department of Karachi University, Karachi, Pakistan.


Fig. 1. Coordinates location used for sampling and installation of plant (SWRO)

**Intake of seawater for feeding to SWRO:** Open water intakes, get the water directly from the sea *via* rectangular shape concrete channel having gate which enables unlimited raw water stream [13]. Seawater transfer from intakes usually at high tide have lowest level 4 m water level in adjacent tank (T-1, 520 $m^3$). Multistage rotating discs screens are used to stop entrance of seaweeds into tanks. High pressure multistage turbine pumps are mounted on the tank for transfer Seawater is then transferred though turbine pumps to overhead tank (T-2), which feeds to SWRO [14].

**Disinfection:** Initially shock dosing of sodium hypochlorite 1.5-2.0 mg/L residual chlorine ($RCl_2$) conducted to kill all microbes of intake water [15]. A continuous chlorination system was used to maintain same concentration of residual chlorine. Residual chlorine is being monitored at feed pump of pretreatment loop, which should be < 1.0 mg/L and < 0.01 mg/L at outlet of cartridge filter. Suspended particles in the feed water contaminate and block the RO membranes. Continuous dosing of sodium metabisulphite was also used to neutralize the effect of residual chlorine which is considered as a safeguard of RO membranes. Moreover, it also acts as oxygen scavenger in which helps in corrosion control. In water, sulfite is oxidized to sulfate which is a harmless seawater component.

**Pretreatment:** Seawater source contains tiny sharp objects (such as shell particles), which can easily puncture the plastic RO membranes and cause a rapid and irreversible loss of their integrity, unless the damaging particles are removed upstream of the membrane pretreatment system through microscreening. Seawater contains barnacles, which in their embryonic phase of development are 130 to 150 µm in size and can pass the screen openings unless they are 120 µm or smaller. This barnacle plankton may pass the screens and could attach to the walls of downstream pretreatment facilities, grow colonies and ultimately interfere with pretreatment system operations. Once barnacles colonies form in the pretreatment equipments, they are very difficult to remove and can withstand chlorination.Therefore, the use of fine microscreens (80 to 120 µm) is essential for reliable operation of the entire seawater desalination plant using membrane pretreatment. Microscreens are not needed for pretreatment systems using granular media filtration because these systems effectively remove barnacles in all phases of their development.Prior feeding to pretreatment an inline coagulation of iron chloride is used to overcome suspended solids [16]. During coagulation suspended particles have to be forced to form bigger agglomerations so that they can be filtered with dual media and cartridge filters [17]. There were two parallel trains each contains two multimedia filters (MMF) and one granular activated carbon filter (ACF) one is in operation at a time. Turbidity is being measured after each multimedia filter (MMF) and residual chlorine is measured after activated cartridge filter (ACF). The function of MMF and ACF is to trap suspended flocs and adsorb free chlorine and organic material, respectively. Residual chlorine and iron must be < 0.01mg/L and < 0.05mg/L for membrane film, respectively [9,13]. Finally, feed water passes through yarn type cartridge filter bags of 5.0 microns (Fig. 2) here silt density index (SDI) is measured after cartridge filter, which must be < 4.0 to safe operation of RO membrane elements [18,19].

**Analysis of samples:** pH was measured by electrometric method by HANNA HI 5222 [20]. Calibration standards solutions of 4.01, 7.01 and 10.01 Merck were used. TDS was measured by electrometric method by using instrument ADWA 1030 using standard methodAPHA 2510. Calibration standards solutions of 84 µS/cm and 1430 µS/cm Merck were used. For TSS measurement, a well-mixed, 1.0 L volume of a seawater sample was filtered through a pre-weighed glass fibre 0.20 micron Millipore Merck filters. The filter is heated to constant mass at 104 ± 1 ºC and then weighed. The increased mass divided by the water volume filtered is equal to the TSS in mg/L [21]. Similarly, silt density index (SDI) was measured by online

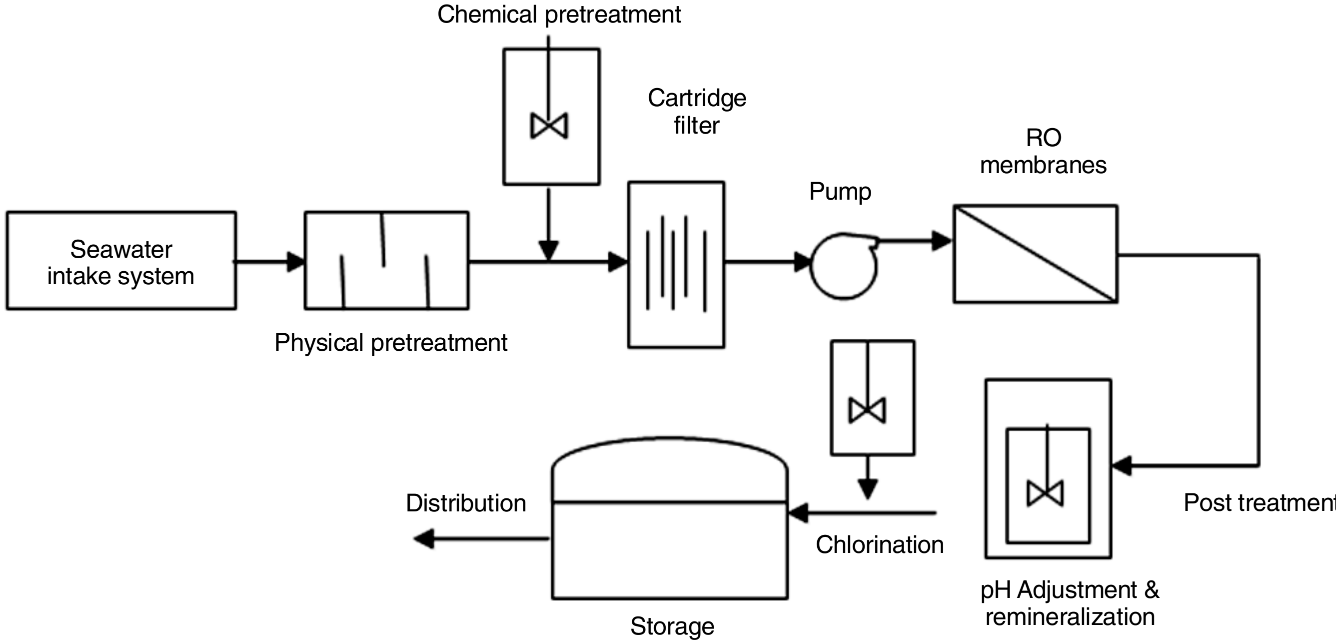

Fig. 2. Schematic layout of sea water reverse osmosis plant

passing of pretreated seawater through 0.45 micron Millipore cellulose acetate filter paper, time for 1.0 L water after 5 and 15 min.

Monovalent and diavalent cations (Na, K, Ca, Mg) were measured by flame photometer using Jenway Model FPF 7. Anions ($Cl^- > SO_4^{2-}$) were analyzed by titrimetric and UV visible spectrometer Spectroscan 50/50 UK. Turbidity and residual chlorine were measured by colorimeter Hach DR 900 and Palintest 7500. Temperature is recorded *in situ* by glass thermometer manually. ASTM and APHA standard methods were followed.

**Statistical analysis:** The data obtained were subjected to statistical analysis using IBM 20 version of SPSS. Experiments were performed one-way ANOVA, student t test and LSD. *± Standard deviation of three replicates, Asterisks (*) represent significant differences ($p < 0.05$); double asterisks (**) represent highly significant differences ($p < 0.01$).

## RESULTS AND DISCUSSION

The significance of reverse osmosis (RO) in the current era is the best frequently recycled water decontamination technology, which shares the burden of fresh water resources [7]. This covers the continuous supply of drinking water for population of mega cities as well as smaller communities. Karachi city being densely populated city in the world, facing tremendous pressure related to the continuous water supply. The operating parameters for seawater RO system are mainly a function of feed water salinity, temperature and suspended solids. The operation of SWRO plants involved in endorsing at least a minimum standard of drinking water in urban and rural areas [11]. It includes a proper mechanism for operation of RO plants for pretreatment considering pollution and seasonal variation in the Arabian sea. The study reports the analysis of various parameters of seawater up to 3 years used for feeding to SWRO plant at Karachi city for drinking water and the results are summarized in Table-1.

**Effect of change in pH on RO operation:** Properties of water are usually reflected by its pH, which also play an effective part in the operation of RO plant, as it affects chemical and biochemical properties such as chemical reactions, equilibrium conditions and biological toxicity in seawater. The current results of the pH of Arabian sea are reported in Table-1, which showed that pH of seawater is typically limited in the range of 7.9 to 8.1 during monitoring period of three years. The change of pH almost negligible as reported in Table-2. The average pH of the Arabian seawater near the surface (at sea shore) was around 8.1, which indicates alkaline nature of sea or the presence of saline material like carbonate, bicarbonate and hydroxyl ions [23], therefore, SWRO permeate pH ranges into 6.0-6.5 which was higher than that of 5.5-5.7 or less acidic as compared to intake pH of 7.4 (Fig. 3). The average pH of permeate is 6.3 which is similar to pH of other plants (Table-3). This pH show corrosive nature of water, therefore, pH adjustment is necessary to make water suitable for different purpose like drinking and potable.

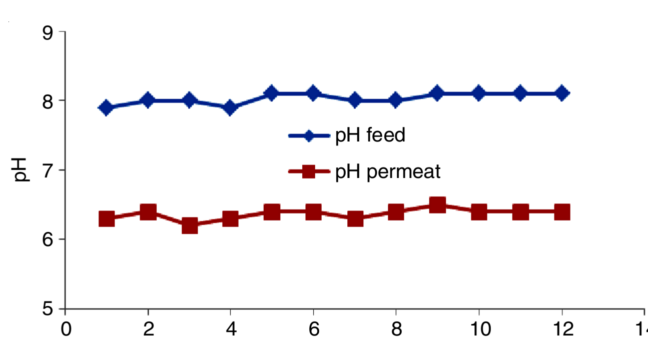

Fig. 3. Comparison of pH of feed and permeate during three years (2015-2017) of monitoring

TABLE-1
SEAWATER MONITORING DATA COLLECTED IN THE YEAR OF 2015-2017

| Months | pH | Temp. (°C) | TDS (g/L) | $Na^+$ (ppm) | $K^+$ (ppm) | $Ca^{2+}$ (ppm) | $Mg^{2+}$ (ppm) | $Cl^-$ (ppm) | $SO_4^{2-}$ (ppm) |
|---|---|---|---|---|---|---|---|---|---|
| Year 2015 | | | | | | | | | |
| January | 7.9 | 22.8 | 38.4 | 11,200 | 530 | 650 | 1420 | 20,864 | 3032 |
| February | 8.0 | 23.4 | 39.5 | 11,320 | 532 | 654 | 1410 | 20,780 | 3042 |
| March | 8.0 | 24.9 | 39.4 | 11,210 | 530 | 660 | 1435 | 20,742 | 3053 |
| April | 7.9 | 25.3 | 39.4 | 11,210 | 540 | 635 | 1432 | 20,532 | 3045 |
| May | 8.1 | 24.8 | 39.2 | 11,220 | 545 | 643 | 1438 | 20,623 | 3055 |
| June | 8.1 | 26.6 | 39.2 | 11,250 | 563 | 623 | 1453 | 20,742 | 3061 |
| July | 8.0 | 28.4 | 39.5 | 11,320 | 543 | 665 | 1440 | 20,655 | 3058 |
| August | 8.0 | 27.2 | 39.5 | 11,230 | 529 | 648 | 1428 | 20,540 | 3043 |
| September | 8.1 | 27.7 | 38.8 | 11,235 | 548 | 652 | 1417 | 20,670 | 3035 |
| October | 8.1 | 27.3 | 38.6 | 11,250 | 519 | 654 | 1435 | 20,725 | 3030 |
| November | 8.1 | 26.1 | 38.7 | 11,180 | 526 | 643 | 1422 | 20,655 | 3045 |
| December | 8.1 | 24.5 | 38.6 | 11,200 | 538 | 659 | 1425 | 20,721 | 3041 |
| Average | 8.0 | 25.8 | 39.1 | 11,235 | 537 | 649 | 1,430 | 20,687 | 3,045 |
| Min. | 7.9 | 22.8 | 38.4 | 11,180 | 519 | 623 | 1,410 | 20,532 | 3,030 |
| Max. | 8.1 | 28.4 | 39.5 | 11,320 | 563 | 665 | 1453 | 20,864 | 3,061 |
| SD | 0.08 | 1.8 | 0.42 | 44.6 | 11.8 | 11.6 | 11.7 | 95.7 | 10.1 |
| Year 2016 | | | | | | | | | |
| January | 8.1 | 21.5 | 38.4 | 11,100 | 528 | 6480 | 1422 | 20,874 | 3081 |
| February | 8.0 | 23.4 | 39.3 | 11,310 | 542 | 644 | 1418 | 20,790 | 3049 |
| March | 8.0 | 24.7 | 39.1 | 11,120 | 534 | 650 | 1420 | 20,755 | 3053 |
| April | 7.9 | 23.3 | 38.8 | 11,210 | 541 | 645 | 1431 | 20,672 | 3048 |
| May | 8.0 | 24.8 | 39.2 | 11,240 | 538 | 648 | 1437 | 20,683 | 3065 |
| June | 8.1 | 27.4 | 39.0 | 11,350 | 523 | 641 | 1441 | 20,822 | 3071 |
| July | 8.0 | 28.1 | 38.8 | 11,220 | 540 | 652 | 1435 | 20,789 | 3058 |
| August | 8.0 | 27.0 | 39.5 | 11,330 | 539 | 645 | 1438 | 20,843 | 3063 |
| September | 7.9 | 26.7 | 38.8 | 11,237 | 532 | 636 | 1437 | 20,770 | 3042 |
| October | 8.1 | 23.3 | 38.6 | 11,350 | 537 | 641 | 1429 | 20,825 | 3056 |
| November | 8.0 | 23.1 | 39.1 | 11,280 | 533 | 639 | 1440 | 20,795 | 3075 |
| December | 8.1 | 22.5 | 38.9 | 11,288 | 529 | 647 | 1434 | 20,820 | 3062 |
| Average | 8.0 | 24.7 | 39.0 | 11,253 | 535 | 1,131 | 1,432 | 20,787 | 3,060 |
| Min. | 7.9 | 21.5 | 38.4 | 11,100 | 523 | 636 | 1,418 | 20,672 | 3,042 |
| Max. | 8.1 | 28.1 | 39.5 | 11,350 | 542 | 6480 | 1441 | 20,874 | 3,081 |
| SD | 0.072 | 2.2 | 0.3 | 82.2 | 5.9 | 1684.6 | 7.9 | 60.2 | 11.6 |
| Year 2017 | | | | | | | | | |
| January | 8.1 | 21.0 | 38.7 | 11,570 | 537 | 652 | 1426 | 20,712 | 3026 |
| February | 8.0 | 21.7 | 38.9 | 11,350 | 538 | 647 | 1419 | 20,821 | 3050 |
| March | 7.9 | 22.3 | 38.3 | 11,453 | 534 | 657 | 1434 | 20,584 | 3043 |
| April | 8.1 | 22.7 | 38.8 | 11,430 | 538 | 663 | 1452 | 20,632 | 3040 |
| May | 8.0 | 27.5 | 37.9 | 11,585 | 541 | 673 | 1458 | 20,623 | 3035 |
| June | 8.0 | 28.9 | 38.7 | 11,378 | 553 | 651 | 1443 | 20,742 | 3060 |
| July | 8.0 | 28.0 | 38.5 | 11,482 | 544 | 635 | 1441 | 20,755 | 3057 |
| August | 7.9 | 27.2 | 39.1 | 11,656 | 539 | 638 | 1437 | 20,640 | 3048 |
| September | 8.0 | 23.7 | 38.8 | 11,465 | 537 | 651 | 1436 | 20,711 | 3045 |
| October | 8.0 | 22.5 | 39.6 | 11,673 | 529 | 656 | 1435 | 20,682 | 3037 |
| November | 8.1 | 22.1 | 39.2 | 11,585 | 527 | 637 | 1447 | 20,750 | 3042 |
| December | 8.0 | 22.5 | 38.6 | 11,470 | 531 | 645 | 1445 | 20,723 | 3040 |
| Average | 8.0 | 24.2 | 38.8 | 11,508 | 537 | 650 | 1,439 | 20,698 | 3,044 |
| Min. | 7.9 | 21.0 | 37.9 | 11,350 | 527 | 635 | 1,419 | 20,584 | 3,026 |
| Max. | 8.1 | 28.9 | 39.6 | 11,673 | 553 | 673 | 1458 | 20,821 | 3,060 |
| SD | 0.067 | 2.8 | 0.4 | 104.3 | 7.0 | 11.1 | 10.7 | 67.8 | 9.4 |

Elahi *et al*. [23] reported the pH of Balochistan coast, Pakistan in the year of 2004 to 2006, a significant variation of pH of this region was observed, which is contradictory in comparison of reported pH of different sea like Gulf, Al-Jubail and Arabian sea (Table-4). Qari *et al*. [24] studied the variations of pH in surface seawater of Nathia Gali (24º 50′N, 66º 42.5′E) almost same location of present SWRO plant at Arabian sea, Karachi coast during January 1989 to December 1991, where they observed no significant changes in pH values. Shahzad *et al*. [25] reported the pH of Karachi coast (Rehri Creek, Bin Qasim) in their study pH of seawater was 7.9 ± 0.2, and this study signifies that marine water quality was badly contaminated with dumping of industrial and cattle colony effluents [25].

Variations in feed pH can also affect the rejection of ions [26,27]. For example, fluoride, boron and silica rejection are lower when the pH becomes more acidic. Feed and concentrate

TABLE-2
THREE YEARS COMPARISON OF DATA 2015 TO 2017

| Parameters | Year 2015 | | | Year 2016 | | | Year 2017 | | | Change (%) '2015-2017' |
|---|---|---|---|---|---|---|---|---|---|---|
| | Min. | Average | Max. | Min. | Average | Max. | Min. | Average | Max. | |
| pH | 7.9 | 8.0 | 8.1 | 7.9 | 8.0 | 8.1 | 7.9 | 8.0 | 8.1 | 0% |
| Turbidity (NTU) | 8 | 15 | 28 | 8 | 21 | 37 | 8 | 18 | 34 | 39% |
| Temperature (°C) | 23 | 26 | 28.4 | 22 | 25 | 28.1 | 21 | 24 | 28.9 | 7% |
| TDS (g/L) | 38 | 39 | 39.5 | 38 | 39 | 39.5 | 38 | 39 | 39.6 | 1% |
| TSS (ppm) | 18 | 31 | 50 | 18 | 31 | 48 | 17 | 29 | 44 | 5% |
| $Na^+$ (ppm) × 1000 | 11.1 | 11.2 | 11.3 | 11.1 | 11.2 | 11.3 | 11.3 | 11.5 | 11.6 | 2% |
| $K^+$ (ppm) | 519 | 537 | 563 | 523 | 535 | 542 | 527 | 537 | 553 | 0% |
| $Ca^{2+}$ (ppm) | 623 | 649 | 665 | 636 | 636 | 652 | 635 | 650 | 673 | 2% |
| $Mg^{2+}$ (ppm) × 100 | 14.1 | 14.3 | 14.5 | 14.1 | 14.3 | 14.4 | 14.2 | 14.4 | 14.6 | 1% |
| $Cl^-$ (ppm) × 1000 | 20.5 | 20.6 | 20.8 | 20.6 | 20.7 | 20.8 | 20.5 | 20.6 | 20.8 | 0% |
| $SO_4^{2-}$ (ppm) × 100 | 30.3 | 30.4 | 30.6 | 30.4 | 30.6 | 30.8 | 30.2 | 30.4 | 30.6 | 1% |

TABLE-3
COMPARISON OF PH OF SEAWATER AND PERMEATE FROM INTERNATIONAL SWRO PLANTS

| Feed | | Permeate | |
|---|---|---|---|
| pH of Arabian Sea, Karachi | International pH | pH of Arabian Sea, Karachi | International pH |
| 8.1 | 8.1 Gulf Al-Jubail<br>8.1 Copenhagen, Denmark<br>8.1 Dekhelia Cyprus | 6.3SWRO | 6.3 Canary Islands |

TABLE-4
COMPARITIVE VALUES OF MAJOR PARAMETERS OF SEAWATER

| Ions | Worldwide[a] average | Mediterranean[b] sea | Wonthaggi, Australia | Arabian Sea, Karachi | Gulf, Al-Jubail |
|---|---|---|---|---|---|
| Chloride | 18,980 | 21,000-23,000 | 20,200 | 20,864 | 24,090 |
| Sodium | 10,556 | 10,945-12,000 | 11,430 | 11,000 | 13,440 |
| Sulphate | 2,649 | 2,400-2,965 | 2,910 | 3,032 | 3,384 |
| Magnesium | 1,272 | 1,371-1,550 | 1,400 | 1,400 | 1,618 |
| Calcium | 400 | 440-670 | 420 | 660 | 508 |
| Potassium | 380 | 410-620 | 490 | 530 | 483 |
| Bicarbonate | 140 | 120-161 | NR | 141 | 176 |
| Bromide | 65 | 45-69 | 62 | NA | 83 |
| Borate | 26 | NR | NR | 2 | 3 |
| Strontium | 13 | 5-7.5 | 7.6 | 1.7 | 1 |
| Fluoride | 1 | 1.22-1.55 | 0.9 | 1 | 1 |
| TDS | 34,482 | 38,000-40,000 | NR | 38,500 | 43,800 |
| pH | 8.1 | 8.1-8.0 | 8.1 | 8.1 | 8.1 |

Data from Department of Sustainability and Environment 2008 [Ref. 35], Gaid and Treal [Ref. 36], Suckow *et al.* [Ref. 37]
[a]Prepared by the Hydrographapic Laboratory of Copenhagen, Denmark.
[b]Values for the Mediterran Sea are taken from Gibraltar and Toulon (France).

(reject), pH can also affect the solubility and fouling potential of silica, aluminium, organics and oil. However, there is no universally accepted reference pH-scale for seawater and the difference between measurements based on different reference scales may be upto 0.14 units (Table-2). It is reported that the long term exposure to pH 4 or pH 11 may cause irreversible membrane damage [13]. Similarly, environments in the oceans could be destroyed if the pH variation continuously [27]. At this time, it is important to consider, a decrease in pH is due to increasing uptake (combustion or consumption) of fossil fuel, $CO_2$ into the oceans. Before the industrial revolution, the average pH at the ocean surface was about 8.2 [28]. Current ocean pH is roughly 8.0 (Table-3), which is comparable with worldwide pH of different seawaters. This drop of 0.1 pH units represents a 25% increase in acidity over the past 200 years followed by the stress on marine life due to acidification (lowering the pH) which leads to dying or severely affected ecosystems [28].

**Turbidity reduction in pretreatment:** The seasonal changes showed variations in turbidity of seawater (Fig. 4). The collected data showed the least turbidity found in summer season whereas it was high in winter and monsoon seasons (Fig. 4). This is due to reason that the effect of low temperature in winter season favours the growth of under water plants, algae and mangroves which cause the suspension [29]. Turbidity also varies with tide level and flow velocity. Typical RO element warranties list a maximum of 1.0 NTU for the feed water [30]. Moreover, in monsoon season, due to heavy rain, silt density in the intake channel tremendously increases with tide variation (turbulence), therefore, SDI (silt density index) increases from normal limit *i.e.* $SDI_{15} > 4.0$ [12]. Highest value of turbidity

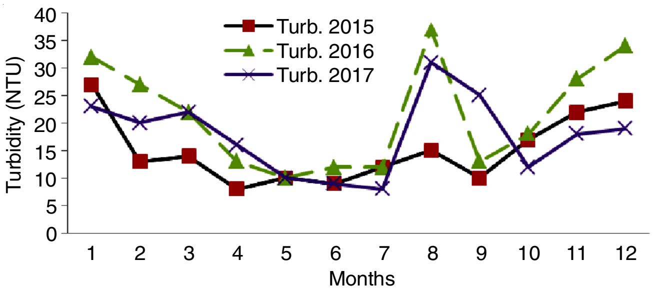

Fig. 4. Turbidity of seawater during three years (2015-2017) of monitoring

was observed during month of August and December to February (Fig. 4). During these months turbidity spikes of 45 NTU or more which continue for a period of morethan 1 h, in this condition sedimentation time in the overhead tank was increased. The heavy load of turbidity due to above mentioned parameters affects the pretreatment procedure to be more complex. It is found that the turbidity values during monsoon in the years 2016 & 2017 were high because of heavy rains (Table-2) on the other hand, it was low in 2015 due to insignificant rain therefore no spikes in turbidity noted (Fig. 4). During extreme rough condition of sea, seawater contains high levels of organics, algal content and suspended solids. The average value of seawater turbidity range during normal condition is around 10 to 18 NTU for which seawater conditioning by coagulation and flocculation followed by filtration through granular media, which was similar to the earlier reported work [13]. Most seawater particles and microorganisms have a slightly negative charge which has to be neutralized by coagulation. In addition, these neutralized particles would need to be agglomerated in larger flocs that can be effectively retained within the dual filter media. Ferric chloride was selected in comparison of aluminium salts (such as alum or polyaluminium chloride) as coagulants for source seawater conditioning prior to sedimentation or filtration. It is difficult to maintain aluminium concentrations at low levels in dissolved form since aluminium solubility is very pH dependent. To remove turbidity, ferric chloride as coagulant dose is to be adjusted and settling time (sedimentation) in the overhead tank was also increased.It is stated in several reports that small amounts of aluminium may cause mineral fouling of the downstream SWRO membrane elements [16,31]. Well operating filters can remove particles as small as 0.2 µm.

The optimum coagulant dosage is pH dependent and established by on an on-site testing in which, an stock solution of $FeCl_3$ 950-000 ppm was prepared in 200 L day tank in a brackish water and a dose of 0.5 ppm $FeCl_3$ was adjusted in main feedwater stream of 33 $m^3$/h. This is achieved through dosing pump 6.0 L/h. The turbidity, SDI and residual iron were measured at feed pump and at inlet of RO element. The dosing point was about 700 m away from feedwater pump to provide sufficient contact time. It was observed that the maximum reduction of turbidity value was from 15 to < 1 NTU at 70% dose rate of dosing pump and SDI were reduced from 6.5 to 3.2 at the inlet of RO membrane, which is in accordance to the report of Kumar *et al.* [31]. However, this setting of dosing pump varies with seasonal variation. It is also observed during experiment that the overdosing of coagulants raises the turbidity and SDI values. It is reported in the literature residual iron < 50 ppb which is the most frequent causes for SWRO membrane mineral fouling [13]. When overdosed, coagulant accumulates on the downstream facilities and can cause fast-rate fouling of the cartridge filters and SWRO membranes [32].

The optimum dose rate was found manually by adjusting the dosing pump flow rate from 100% to 50 %. Ultimately the reduction in SDI values within the limit was achieved by adjusting the turbidity values. To make coagulation process more effective pH adjustment to slightly on acidic side by sulphuric acid and coagulant aid (polyacrylamide) favours the flocs formation during coagulation.

**Effect of temperature variation:** It was observed during three year period (2015 to 2017) that seawater temperature of ranged at intake was between 22-29 ºC, which is under the limits of international pretreament values, suitable for energy units as well as membrane life (Table-1), which is comparable with the temperature range of Gulf sea is 18-33 ºC [32]. The temperature changes related to the seasonal variation as in winter *i.e.* 22.8 ºC (January) while in summer 28.4 ºC (July) in all three tested years (Table-2). In July, Karachi urban maximum temperature reveals impact of urban activities on the local extreme temperature fluctuations. For a given feedwater salinity and salt rejection of the membrane elements used, the permeate salinity is a function of feed water temperature, recovery rate and permeate flux. The temperature of Arabian seawater examined and found in between the extreme boundaries of temperature for the process of RO, which is 5 to 45 ºC [13]. An increase in feedwater temperature results in an increased rate of salt and water diffusion across the membrane barrier at the rate of about 3-5%/ºC. Because RO plants usually operate at a constant flux rate, the changes of permeate salinity closely follow the changes in feed water temperature. It is reported that increase in air temperature and low precipitation decrease working efficacy of membrane [16].

It is reported that if the source seawater is at relatively cold (*i.e.* average annual temperature below 15 ºC) and at the same time is of high organic content, a layer of granular activated carbon (GAC) of the same depth is used instead of deeper layer of anthracite because the biofiltration removal efficiency will be hindered by low temperature [13]. While during biofiltration a portion of the soluble organics in the seawater is metabolized by the microorganisms that grow on a thin biofilm formed on the granular filter media, the GAC media removes a portion of the seawater organics mainly by adsorption [17,29].

**Reduction of total dissolved solids (TDS):** Total dissolved solids (TDS) are the combination of all ion particles that are smaller than 2 microns, which can only be removed by thin film RO membrane. However, high TDS requires high pressure which means more energy consumption. It is reported that both salinity and density observed to increase with depth, with density being higher in restricted areas. In restricted areas of oceans and seas, seawater can exhibit temperatures up to 37 ºC, while observed to decreases with depth and varies with current-systems and season [33]. The average value of TDS in Arabian seawater in the three tested years was found to be 38.8 g/L (Table-1) with the negligible difference of about 1% (Table-2). This TDS value of Arabian sea is slightly greater than worldwide average value (34.48 g/L) and approximately same to seawater at Wonthaggi, Australia (Table-4). The seasonal change doesn't affect the solubility of salts soluble in Arabian seawater because the effect of temperature is negligible which is shown in (Table-1). Variations occur in ocean salinity due to several factors. The most common factor is the relative amount of evaporation or precipitationin an area.

Initially in 2014, when plant was newly commissioned, TDS of permeate water was around 150 mg/L after two years continuous operation, salinity in permeate was gradually increased to 500 mg/L. The plant is operated for seawater feed 38.00 g/L TDS salinity and water temperature in the range of 18-28 ºC, recovery rate is in the range of 35-45%, with an average permeate flux in the range of 11.9-15.0 $m^3$/h. At the above operating conditions, the feed pressure is in the range of 800-1000 psi (55-70 bar) and permeate salinity is in the range of 150-500 mg/L TDS over three year operation. So membrane cleaning with cleaning solutions was performed after which TDS reduced to 360 mg/L but recovery was slightly reduced from 35% to 30%. The reason of increasing TDS was investigated and found the biofouling is prominent which was due to improper chlorination at feed water. It is noted that the added chlorine was returned back in the sea with thelow tide. The sodium hypochlorite was dosed (shock dose) just before level transfer of feedwater to the overhead tank and concentration of each batch of biocide was monitored in every week.

It is also noted that after two years operation TDS of permeate was suddenly rise to 2000 mg/L. To investigate the problem individual vessels, samples were analyzed and found that interspacer connector of membrane element were slightly loose due to which feedwater was leaking to permeate. The practice was improved by preserving membranes with 10% solution of sodium metabisulphite weekly.

**Control of total suspended solids (TSS):** Total suspended solids (TSS) is required to assess the amount of residuals generated during pretreatment. It is expected to vary with the tide level due to the change in flow velocity of seawater, which results in different sediment carrying capacity of the flowing water. However, it cannot be correlated well with turbidity beyond 5 NTU [18]. It is also reported that the correlation of average TSS at seabed, mid-depth and at the surface in shallow water can be determined [15]. The collected data showed variations in TSS of seawater (Fig. 5). The collected data showed the TSS found maximum during monsoon season when sea was rough. Similarly, it reaches on highest value when algal concentration in winter reaches at peak values (Fig. 5). In addition, plankton in seawater was dominated by small algal cells with diameter less than a few micrometers, typically referred to as pico-plankton 0.2 to 2.0 µm. As compared to fresh waters from lakes and rivers where pico-plankton usually does not dominate the algal community while in seawater pico-plankton is associated with more than 50% of the chlorophyll a (algal content) in most ocean waters [13] and in the cases of tropical or subtropical seawater, this content may reach 75% or more [19].

It is, therefore, recommended to draw water closer to the free surface in order to reduce the TSS load entering into the intake channel. It is also found that TSS level reduces significantly (40% to 60%) when the flow velocity of seawater is minimum. During high currents, the carrying capacity of the sediment of the seawater usually high, it is better to avoid taking the seawater into overhead tank [29].

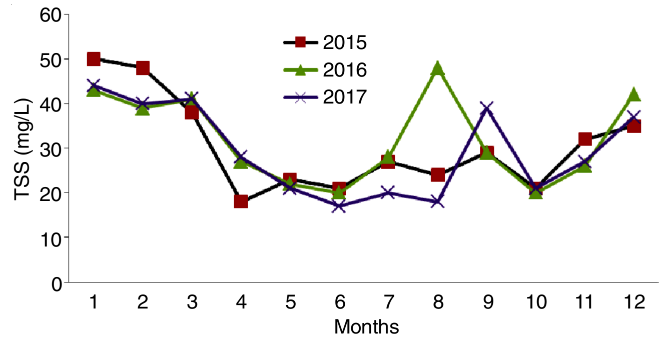

Fig. 5. TSS of seawater during three years (2015-2017) of monitoring

**Effect of chemical constituents in RO efficiency:** The concentrations of soft metals in seawater during three year were found to be in order of Na > Mg > Ca > K while major anions were $Cl^- > SO_4^{2-}$ all the other ions exist at much lower concentrations. The overall ion content of the Arabian sea is higher as compared to the other oceans and the Mediterranean sea (Table-4), the effect of seasonal change is negligible (Table-1), and this is considered inthe sizing of the reverse osmosis system. However, these differences of ionic content not impact the selection of the pre-treatment strategy [10,13]. It is reported that the most of the dissolved chemical constituents found in seawater have a continental origin. Only six elements and compounds comprise about 99% of sea salts: chloride ($Cl^-$), sodium ($Na^+$), sulphates ($SO_4^{2-}$), magnesium ($Mg^{2+}$), calcium ($Ca^{2+}$) and potassium ($K^+$) [22]. During reverse osmosis process, at high pressure the salts tend to precipitate and scaling occurs when the solubility of dissolved salts is exceeded. As result of the desalination process the concentrations of salts are rising and eventually reach the solubility limits. Calcium carbonate scales form quickest. Solubility levels decreased with rising temperatures which poses an additional problem for thermal plants [15]. Scale formation reduces the RO membrane performance and supports fouling. In order to avoid scaling, sulphuric acid and antiscalant (Vitec 5100 Avista) were continuously dosed. It is reported that calcium sulphate scales cannot easily be removed by anti scalants [19]. The concentration of calcium sulphate can be artificially increased when sulfuric acid is added to water to adjust pH. In this case, $Ba^{2+}$ and $Sr^{2+}$ must be analyzed accurately at 1 µg/L (ppb) and 1 mg/L (ppm) level of detection, respectively, since $BaSO_4$ and $SrSO_4$ are much less soluble in water than $CaSO_4$ and moreover, barium and strontium sulfate scales are extremely difficult to redissolve. Though, fouling and scaling cannot be completely avoided by means of regular pre-treatment (addition of sulphuric acid). Fine films will form eventually. Therefore, periodic chemical cleaning has been carried out additionally [17].

## Conclusion

It is concluded that the seawater reverse osmosis (SWRO) required continuously monitoring for their proper operation.

Various factors interfere on efficiency of reverse osmosis (RO), which include ionic contamination (calcium, magnesium, *etc*.), dissolve organic carbon (DOC), bacteria, viruses, colloids & insoluble particulates causing biofouling and scaling results in destruction of the RO membrane. In current study, most of parameters show no significant changes in parameters like pH, temperature, TDS and ionic concentration of soft metals and anions except turbidity, TSS vary significantly with seasonal variation. To mitigate damage, an effective pretreatment must be design based on site parameters monitoring. Inhibitors for fouling are biocides (as oxidants against bacteria and viruses), like chlorine, ozone, sodium or calcium hypochlorite should be optimized to minimize the chemical waste. At regular intervals, depending on the membrane contamination; fluctuating seawater conditions or prompted by monitoring processes the membranes need to be preserved and cleaned. Therefore, prior to design and installation of SWRO system regular monitoring of seawater parameters with seasonal variation is necessary. The pre-treatment system can be economically designed, consisting of cost-efficient micro filters. Moreover, the environmental problem of brine discharges from a technical, legal and economic point of view and feasible and cost-efficient technical solutions in order to mitigate the marine impacts of desalination plants need to be explored.

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## CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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