

N ° d'ordre : 42251



THÈSE

Présentée à

L'UNIVERSITÉ DE LILLE, SCIENCES ET TECHNOLOGIES

**ECOLE DOCTORALE DES SCIENCES DE LA MATIÈRE, DE RAYONNEMENT
ET DE L'ENVIRONNEMENT**

Pour obtenir le grade de
DOCTEUR

Spécialité : Optique, Lasers, Physico-chimie, Atmosphère

Par

Nour FAWAL

**PARAMETRES AFFECTANTS LE DESSALEMENT DE L'EAU DE MER PAR
OSMOSE INVERSE: Prélèvement; prétraitement ; procédés membranaires;
impact environnemental**

Soutenue le 12 décembre 2016 devant le Jury composé de :

Baghdad OUDDANE	Professeur, Université de Lille	Directeur
Martine LEERMAKERS	Professeur, VUB, Brussel	Rapporteur
Lahcen ZOUHRI	Professeur, Institut Polytechnique LaSalle Beauvais	Rapporteur
Jalal HALWANI	Professeur, Université Libanaise	Examinateur
Mariam COUSIN	MCF-HDR, Université Pierre et Marie Curie, Paris 6	Examinateur
Ulrich MASCHKE	Directeur de Recherche, Université de Lille	Examinateur
Isam SHAHROUR	Professeur, Université de Lille	Examinateur
Georgios TSEREPAS	Ingénieur, HUTA Company (KSA)	Invité

ACKNOWLEDGEMENTS

To only have a dream is not enough; the capabilities, the strong will, and the hope for success are important factors to have in order to achieve this dream. And the more one's ambition is high, the more possibilities, the stronger will, and the bigger hope for success are required.

In order to follow my ambition, I have had the strong will, and the hope for success has always been present but with variant chances of happening due to terms and conditions of life. However, I was short of possibilities and capabilities.

Such possibilities became available thanks to many good people who understood my situation, who loved me and supported me, whom without them neither my ambition nor my dream would be fulfilled.

Therefore, I especially thank the following:

Professor **Baghdad OUDHANE**, who accompanied and supported me, who was forever and unconditionally generous to offer all the help and all the guidance I needed, and was the secured caring shelter in my second home, France.

Professor **Jalal HALAWANI**, who believed in me and in my capabilities, who has always been a keen mentor, a wise mind, a perfect guide, and an important supporter for this project. From him I learned keeping the ambition and who really keep the hope candle burning.

My dear company **HUTA MARINE WORKS LTD.** represented by everyone who helped, who supported, who sponsored and contributed in every possible way during my studies and researches period.

My beloved wife, **Nermin**, who has given me all the logistic support and all the required needs to provide and ensure the perfect atmosphere for my researches.

My children, **Salim** and **Miral**, who enlightened my life and who were an additional ray of hope and cause to complete this research.

My Dear sisters, **Sahar** and **Doha**, my dear brother **Dia**, who not only believed in me, but also considered me as an idol to be proud of (and I hope to remain like that in their eyes).

My wonderful parents **Salem** et **Faten**, whom I can never repay them even a small part of what they have offered me, such as honest guidance, sincere advices, a warm shelter, excellent education, and most important of all: deeply sharing my moments of happiness and sadness.

For every one listed above: Thank you all from the bottom of my heart.

Nour FAWAL

Contents

ACKNOWLEDGEMENTS	2
ABBREVIATIONS	9
LIST OF TABLES	11
LIST OF FIGURES	13
LIST OF DRAWINGS	15
Résumé de la thèse – Summary	16
Preface.....	17
1- Desalination Technologies	20
1.1- Reverse osmosis.....	21
1.2- Forward osmosis	23
2- Sea Water quality	23
3- Water Safety Plan (WSP).....	25
Intake variation effect on Water Quality for SWRO	27
Abstract	27
1- Introduction: Key selection of intake factor to be taken in consideration	28
1.1- Information Needed for Evaluating the Intake Design Options	28
11.2- CONTROLLING PARAMETERS IN THE INTAKE SELECTION PROCESS	30
2- Types of intake	32
2.1- Definition, Comparison and Use	32
2.2- open intake characteristics and application	36
2.3- open intake advantage and disadvantage.....	37
2.4- subsurface application	40
2.5- Subsurface advantage and disadvantage.....	40
2.6- Conclusion	43
3- Our selection	44
3.1- Time.....	44
3.2- Available of pre-treatment facilities	44
3.3- Project duration.....	45
3.4- Stable Sea water.....	45
3.5- specific Precautions	45
3.6- Stakeholder decision.....	46

4-	Intake installation and case study	46
4.1-	Theoretical installation:	46
4.2-	First installation of the open intake pipe.	52
4.3-	First open intake modification	54
4.4-	Second open intake modification	57
4.5-	Third open intake modification	59
4.6-	Fourth open intake modification.....	62
4.7-	Fifth open intake modification	64
4.8-	Sixth open intake modification.....	69
	Conclusion	72
	The Pre-Treatment	75
1-	Introduction	75
1.1-	Definition	75
1.2	Role of Pre-treatment.....	75
1.3	General description of common Pre-treatment.....	76
1.4	Type of Pre-treatment	76
1.5	The SDI.....	78
1.6	Bad effect of pre-treatment.....	81
1.7	Water Quality sustainable maintain.....	82
2	Major Type of pre-treatment.....	82
2.1	Conventional Pre-treatment.....	82
2.2	Polymer Membrane Filtration	84
2.3	The Ceramic Filter Technology.....	89
2.4	Pre-treatment technologies comparison.....	94
2.5	Our selection:.....	95
3	Chemical Dosing and Control System	96
3.1-	General water quality.....	96
3.2	Our water quality	97
3.3	Introduction to chemical dosing	97
4	Salt in water	101
5	Antiscalant	102
5.1	Introduction	102
5.2	Historic and type of antiscalant	102

5.3	Role and function.....	102
6	Suspended Solids	103
7	Coagulant	104
8	Organic in water and Biofouling.....	105
8.1	Origin of biofouling.....	105
8.2	How it occurs.....	106
8.3	Results of Biofouling.....	106
8.4	What to do	106
9	Chlorine.....	107
10	Acid and SBS	108
11	Silica.....	109
12	Hydrogen Sulfide	109
13	Sand Filter	110
13.1	Media of Sand Filter.....	110
13.2	Operation.....	111
13.3	Back wash strategy.....	112
14	Cartridge Filter	115
15	Online meter and dosing pump	115
	THE MEMBRANE.....	118
1-	Introduction	118
2-	Type of membrane	118
3-	Material of fabrication	119
4-	Mode of filtration.....	120
5-	Membrane performance.....	121
6-	Membrane failure	122
6.1-	Scaling (Mineral Scale)	123
6.2-	Biological Fouling	124
6.3-	Metal Oxides.....	129
6.4-	Membrane degradation	130
6.5-	Clay (Alumino-silicates – Al_2SiO_5).....	133
7-	Pilot study: use of different types of membrane.....	134
7.1-	Description of the Pilot study	134
7.2-	Test Conditions.....	137

7.3- Tests details	137
7.4- Results and Discussions.....	138
8- Our case: design, material specification and principle of operation.....	149
8.1- Design and configuration of RO unit.	149
8.2- The Pressure Vessels	151
8.3- Feed, Concentrate and Permeate Piping	152
8.4- Instrument and control items on piping networks	153
8.5- Membrane autopsy	155
9- Cleaning procedure.....	156
9.1- When to clean	156
9.2- Type of foulants and cleaning solution.....	157
9.3- Dimensioning the cleaning tank, cleaning pumps and line control.	158
9.4- Importance of temperature.....	158
9.5- Importance of pH.....	158
9.6- Cleaning Procedure.....	159
Environmental impact.....	161
1- Introduction	161
2- Brine characteristic.....	162
3- Effect on marine life.....	162
3.1- Effect of high Salinity.....	163
3.2- Effect of used Chemicals	163
3.3- Zone of Initial Dilution	164
3.4- Need of action to improve the reject	164
4- Applied technologies for solution	164
4.1- Direct discharge to sea water	165
4.2- Dilution with power plant outlet.....	167
4.3- Dilution with Waste Water Treatment Plant	170
4.4- Discharge via Sewage Networks	172
4.5 – Discharge via beach well	172
4.6- Alternative treatment technique.....	173
5- Our environment & marine life at the reject point.	177
6- Membrane cleaning solution	178
Reference	180

Internet sources	180
Bibliography	180
ANNEX – 1.....	191
ANNEX – 2.....	193
ANNEX – 3.....	196
ANNEX – 4.....	203
ANNEX – 5.....	206
ANNEX – 6.....	210
ANNEX – 7.....	215

ABBREVIATIONS

ASTM = American Society for Testing and Materials
CA = Cellulose Acetate
CF = Concentration Factor
CFM = Ceramic Flat Membrane
CTA = Cellulose Triacetate
DOC = Dissolved Organic Carbon
ERT = Energy Recovery Turbine
FG = Fiber Glass
FO = Forward Osmosis
FRP = Fiber Reinforced Polymer
GRP = Glass Reinforced Plastics
HDPE = High Density Poly Ethylene
HPP = High Pressure Pump
M&O = Maintenance and Operation
MDC = Membrane distillation coupled with crystallization
MED = Multiple Effect Distillation
MF = Micro Filtration
MSF = Multistage Flash Evaporation
NSF = National Sanitation Foundation
NOM = Natural Organic Matter
O & M = Operation and Maintenance
PA = Polyamide
PH = Potential of Hydrogen
RBF = River Bank Filtration
RO = Reverse Osmosis
SBS = Sodium metabisulphite
SDI = Salt Density Index
SW = Spiral Wound
SWCC = Saline Water Conversion Corporation
SWRO = Sea Water Reverse Osmosis

T° = Temperature
TCO = Tri-Cellulose Acetate
TDS = Total Dissolved Solids
TFC = Thin Film Composite
TMP = Trans Membrane Pressure
TOC = Total Organic Carbon
TSS = Total Suspended Solids
UF = Ultra Filtration
USA = United States of America
UV = Ultra Violet
VFD = Variable Frequency Drive
VMD = Vacuum Membrane Distillation
WHO = World Health Organization
WSP = Water Safety Plan
ZID = Zone of Initial Dilution
ZLD = Zero Liquid Discharge

LIST OF TABLES

1: Water Cost in some Operational SWRO Plant	18
2: Water Cost for the large SWRO desalination plant	18
3: Advantages and disadvantages of RO	22
4: Sea water quality comparison	23
5: Structural design options for seawater intakes.....	29
6: Comparison between concentrations in natural seawater VS well intakes.....	34
7: Advantages and disadvantages of open intakes	39
8: Advantages and disadvantages of subsurface intakes.....	43
9: Applicability of the various active and passive intake technologies	51
10: Daily average parameters from 18-25 September 2012	53
11: Daily average parameters from 5-18 October 2012.....	56
12: Daily average parameters from 27 October 2012 till 27 November 2012.....	58
13: Daily average parameters from 5 till 17 December 2012	61
14: Daily average parameters from 23 December 2012 till 10 January 2013	63
15: Daily average parameters from 1 to 24 February 2013	68
16: Daily average parameters from 20 March to 4 May 2013	70
17: recapitulative table for the different situation and modification.....	73
18: Process and water quality comparison for pre-treatment.....	94
19: Cost comparison of pre-treatment technologies	95
20: Major Components of Natural Waters.....	96
21: Membrane Feed Water Required Quality	98
22: Chemical used during pre-treatment in RO	100
23: Most used technique to remove the suspended solids	104
24: Sand filter media dimension	111
25: SDI drop with Media Thickness layer	111
26: Back wash sequence Process	114
27: Different types of membranes and theirs performance.....	118
28: Step of Biofouling.....	126
29: Results summary of the pilot Study	139
30: recapitulation of overall performance	148

31: Control parameter connected to the PLC.....	154
32: Chemical cleaning solution and conditions	157
33: Most used concentrate discharge technologies	165

LIST OF FIGURES

1: Most used technologies of desalination	20
2: Reverse Osmosis v/s Normal Osmosis	21
3: Basic RO stage.....	22
4: Type of Pre-treatment	77
5: Type of pre-treatment and allowed particles	77
6: SDI kit details	79
7: Bacteria, Mineral, Salts and Shell fragment on SDI filter paper	80
8: Feed Water Turbidity v/s filtrate water quality for membrane filtration	86
9: Protection of UF membrane.....	87
10: Membrane removal for external cleaning.....	87
11: Damaged membrane to be replaced.....	88
12: Accumulation of sludge & hairs between fiber bundles in the HFM	88
13: Sludge blocking between the plates in the Flat sheet membrane	88
14: Layer of the CFM	90
15: Construction and Module design of CFM	90
16: Filtration mode of CFM.....	91
17: Automatic Detergent Assisted Back flushing of CFM	91
18: Automatic Detergent Assisted Back flushing of CFM – cleaning phase	92
19: Automatic Mechanical Cleaning mode of CFM.....	92
20: Ozonation Process for CFM	93
21: Reason of membrane failure	123
22: Cartridge Filter fouled by iron	129
23: Membrane fouled by iron	129
24: Membrane Fouling caused by iron acrylate.....	130
25: identification of spacer.....	132
26: Abrasion caused by sand particles from media	132
27: Membrane failure by Clay fouling.....	133
28: Clay structure	133
29: The sand filter and the cartridge filter of the pilot unit.....	135
30: The membrane and chemical of the pilot unit	136

31: Conventional concentrate discharge with diffusers167
32: Collocation of SWRO plant & coastal Power Generation Station168
33: Collocate concentrate discharge with simplified diffuser.....169

LIST OF DRAWINGS

1: Intake old and new location	65
2: The design of the intake new manhole	66
3: How bacteria stick to the membrane.....	125
4: SDI of Raw and Filtrate water v/s Temperature	138
5: Permeate conductivity, the production flow & ΔP v/s time for XXX-H	140
6: Permeate conductivity, the production flow & ΔP v/s time for XXX-C	140
7: Permeate conductivity, the production flow & ΔP v/s time for XXX-H	141
8: Permeate conductivity, the production flow & ΔP v/s time for XXX-C	141
9: Permeate conductivity, the production flow & ΔP v/s time for YYY-4.....	142
10: Permeate conductivity, the production flow & ΔP v/s time for YYY-5.....	142
11: Permeate conductivity, the production flow & ΔP v/s time for YYY-4.....	143
12: Permeate conductivity, the production flow & ΔP v/s time for YYY-5.....	143
13: Membrane Conductivity Performance.....	145
14: Membrane Flow Performance	146
15: Membrane Pressure drop (ΔP) Performance.....	147

Résumé

Ce travail de recherche a été réalisé dans le cadre d'une étude lancée par la compagnie HUTA sur ses installations de dessalement d'eau de mer. Le procédé de dessalement d'eau de mer le plus utilisé est l'osmose inverse (SWRO). Une installation dans une zone industrielle a été choisie pour mener cette étude d'optimisation du fonctionnement et la recherche de nouvelles pistes pour réduire les coûts d'exploitation. L'impact des rejets des rejets sur le milieu naturel a été également étudié. La station de dessalement sélectionnée pour les travaux de recherches est située dans la région Ouest de l'Arabie Saoudite à 160 km au nord de Djeddah, dans une zone industrielle pétrochimique (Raffinerie PETRO RABIGH) ultra sécurisée, les captages d'eau se font dans une zone côtière proche du site à partir de la Mer Rouge.

L'étude se concentre principalement sur 3 parties:

La première concerne la prise d'eau « INTAKE », différents modes de captage ont été testés avec l'installation d'un ouvrage développé spécifiquement pour la station de Rabigh en s'adaptant aux règlements imposés par les autorités Saoudiennes.

La deuxième est réservée aux procédés membranaires et l'importance des prétraitements dans la filière de désalinisation et la dernière partie concerne l'impact environnemental des rejets industriels « OUTLET » sur le milieu récepteur.

Pour chaque partie, une synthèse bibliographique a été réalisée en plus du suivi de terrain.

Abstract

This study concerns the red SWRO desalination plant located in the West of KSA in the small city of Rabigh which is 160 km away to the north of the famous city of Jeddah. The facility is located inside the refinery of Petro Rabigh with a very high level of security.

The study focus is basically on three chapters: the first one discusses the INTAKE, the second one detailed the MEMBRANES while the third one focuses on the ENVIRONMENT. **Additional part has been inserted concerning the importance of pre-treatment.**

For each chapter theoretical studies have been done, followed by site analysis and examination showing the characteristics and the condition of the site, finally the best decision and the best operation conditions have been concluded.

Preface

Getting access to enough volume of pure and safe water for household or domestic purpose and for merchant or manufacturing/industrial uses is critical to well-being, health, life cycle and the scope to accomplish human existence and economic evolution. Persons from all around the world (especially in the arid, semi-arid and non-developed area) have historically endorsed the inappropriate access to pure and secure water: people have been forced to foot variables distances only to improve minimum water to maintain life. As a result they have had to endure health consequences and they did not have the opportunity to develop their resources and capabilities to achieve major improvements in their well-being and economic [WHO, 2007]. In the other hand, with global inhabitation expansion, certainly people will be stuck with decrease numbers of the availability of finite potable water. Desalination of salt water (sea or brackish), in parallel with arranged water reuse for other human application (for example: soil compact, irrigation ...) have quickly prospered around the world this recent decade; in fact, it is due to the sharp necessity to produce additional safe water to cover the increased consumed water quantity of the growing society.

Desalination technologies have started about 60 years ago and succeed to enhance access to potable water, however at elevated prices. Or in front of the option of no water at all and/or inadequate water, the high cost would be tolerable until finding other sources. In the other hand, the improve of novels technologies and the development of new theories allow people having access and getting potable water worldwide. Prices are still relatively high, however it shows great decrease trend with more option are available.

The required energy for sea water reverse osmosis (SWRO) plant is the electric energy to run the electrics hydraulic pumps, the biggest electric load (more than 75%) should cover the need of the high pressure pump (HHP) pumping water to the membranes stage. For a representative SWRO plant including a typical pre-treatment system and processing with a typical conversion factor of 40%, the needed electric power with energy recovery is estimated to around 5 KWh/m³.

During the last 2 decades, SWRO desalination technology has gone through a stunning transformation. The number and amplex of big SWRO plants have widely increased. Desalination plants with produced water quantity close to 400 000 m³/d are recently being erected. Conversely, the capital and process cost have decreased: desalinated water prices have been reduced from \$2.0/m³ in 1988 down to \$0.5/m³ in 2014. The importance and the remarkable of this decrease reside in the fact that the norms of produced desalinated water quality are stricter these years than what it was 30 years ago.

These economical ameliorations are due to the large competition between the different manufactured companies around the world and to the refinement of process and perfection in the membrane technology. This competitive tender process influenced prices of all the items in the

SWRO plants (essentially the membrane elements) and extract in a general cost decrease. Performance amelioration of all SWRO compound and optimization of process configuration resumed in reducing the process costs. The recent trends of water cost from large seawater RO installations are summarized in Table 1 and 2 [Wilf & Bartels, 2005].

Plant Product capacity (m ³ /d)	Status	Water Price (\$/m ³)
20.000 – Eilat	Operation Started in June 1997	0.72
56.000 – Larnaca	Operation Started in May 2001	0.83
106.000 – Tampa, FL	Operation Started in May 2003	0.56
272.000 – Askalan	Operation Started in 2004	0.54

Table 1: Water Cost in some Operational SWRO Plant [Wilf & Bartels, 2005].

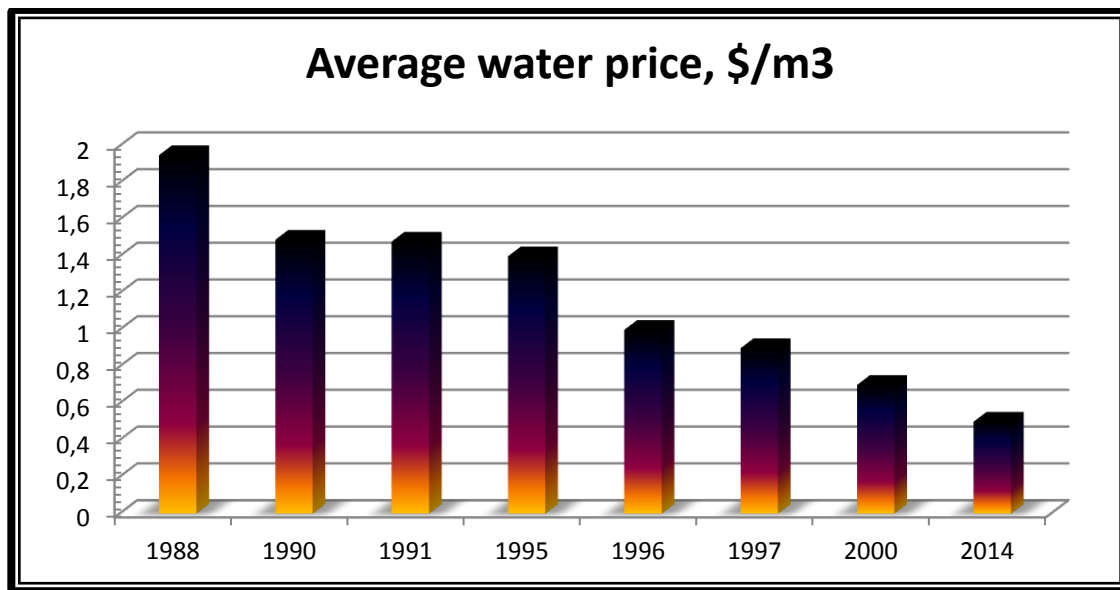


Table 2: Water Cost for the large SWRO desalination plant [Wilf & Bartels, 2005].

The actual big SWRO Plants are distinguished by the following technical features:

- Using of good-efficient High Pressure Pumps regularly equipped with Energy recovery turbine, including use of variable speed drivers (VFD).
- Adjusting the recovery rate in accordance with power consumption.
- The possibility to increase the number of membrane in one Vessel (up to 8) with the prospect switch between single-stage and multi-stage array.

- More efficacy two-pass configuration.
- Sharing the reject (cooling water) of power plant as intake to SWRO.
- Propagation of testing unit using UF/MF as pre-treatment for SWRO.
- Better performance of seawater RO membranes: higher permeability and higher salt rejection.

Desalination technologies of seawater, brackish water and waste waters is a well sophisticated and integrated group of drivers that have a high degree of complexity in comparison with the traditional process of drinking water production from natural sources; it is true they have many technologies in common, but the desalination technologies have a huge advance and amelioration from the typical technologies normally used to relatively better quality water sources. As a result, it is normal that production prices are higher than from freshwater sources, but sophisticated technologies are generally used in regions where the water need is greater, therefore water prices would normally be higher.

This study details the process of potable water treatment and production, the items that are involved during this procedure, in addition to an integrated management approaches for ensuring the high quality and security of potable water. This study focuses upon sea water desalination and inspects the basic technologies, the newest process, the health considerations and the environmental effect and protection that are in addition to naturally normal water production using natural sources.

As of the start of 2011, close to 14,900 desalination plants have been installed and are running around the world with water produced quantity around 64.9 million cubic meters of water per day and an additional 10.6 million cubic meters of capacity are contracted (WDR, 2008). As described before, the number is expanding as speedily as the need for potable/drinking water supplies become more acute and technologies ameliorate and general costs are decreased.

About 45% of the capacity exists in the West Asia Gulf region. North America has about 12%, Asia apart from the Gulf about 9.6% and North Africa and Europe account for about 6.5 % and 12.5%, respectively, and Australia a bit over 3.2% [WDR/DesalData, 2011]. This distribution is changing as demand increases in Australia, Europe and North America [Cotruvo J. et al, 2010]; desalination market is predicted to grow by 14% per year to 2011. Capacity is expected to reach 94 million m³/day by 2015 [WDRr Water, 2006].

SWRO Plants differ by sizes and designs, production capacity may range from more than 1,000,000 m³/day to 10 m³/day. Some small sized RO (Reverse Osmosis) home units produce only a few liters per day. Over the next 10 years at least 100 billion USD for desalination is projected to be needed in the Arab states alone just to keep up with economic growth and water demand, according to a 2006 report [EMS / Reuters, 2006].

1- Desalination Technologies

Desalination technologies means any process that ensures the removal of excess salt (sodium chloride) and other minerals from water, such as seawater or soil, to make it suitable for human consumption (even drinking water), animal consumption, irrigation and/or industrial use. Desalination can be achieved by means of evaporation – freezing (MSF), reverse osmosis, ion exchange, and electro dialysis (Figure 1). The most common desalination methods employ reverse-osmosis [Gude Veera Ganeswar, 2016] in which salt water is forced through a membrane that allows water molecules to pass but blocks the molecules of salt and other minerals.

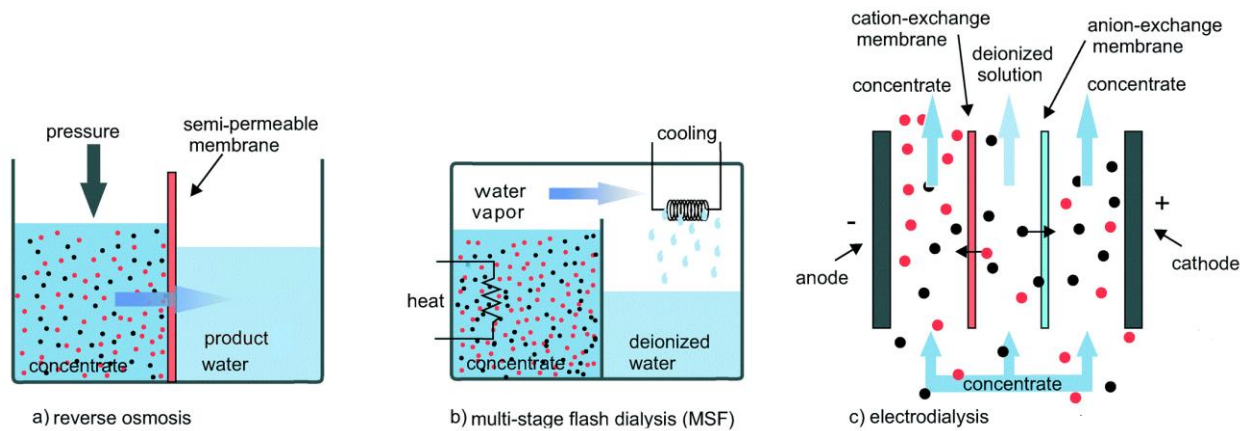


Figure 1: Most used technologies of desalination

Per definition of the drinking water systems, it must ensure the production, in some time the delivery to customers, the healthy potable/drinking water having quality under all the norms and National Standards. Several applied technologies are currently used to produce the best water quality from non fresh raw water.

Desalination processes utilize non-traditional water sources and technologies and produce drinking water that is different from usual sources and processes [Cotruvo J., 2005].

Desalination Technologies can be rated reference to the implicated process, for example:

- Process of phase alteration in water, like distillation, freeze segregation, and hydrate division.
- Process involving surface characteristics of membrane, example electro dialysis or reverse osmosis.
- Process using ion-selective characteristics of solids and liquids; as is ion exchange and solvent extraction.
- Process utilizing the different forms of required power basically temperature, mechanical, electrical or chemical.

The Osmosis natural process consists of liquid transport or migration across a semi permeable membrane from a place of lower solute concentration toward one of higher solute concentration to offset the free energies.

1.1- Reverse osmosis

Reverse osmosis systems reverse this natural process (Figure 2), RO utilizes pressure to push water molecules and force them to pass via semi-permeable film or membrane which does not allow particulate or dissolved ions and organic compound to drive through, the force necessary to accomplish this is the application of pressure greater than the osmotic pressure of the saline solution; in fact external pressure is used to the high solute (concentrated) water to force liquid (water) to pass through the membrane leaving the solute (salts and other non permeates) in a more concentrated reject. The flow of water will stream until the pressure created by the osmotic head draws the osmotic pressure of the salt solution.

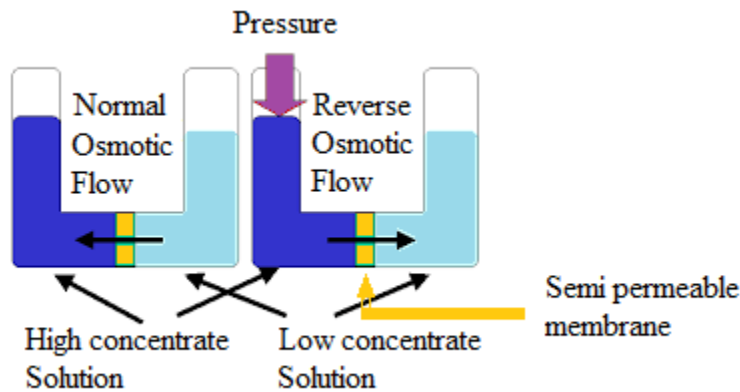


Figure 2: Reverse Osmosis v/s Normal Osmosis

Reverse Osmosis is a forward application that used high technologies to progress over the year; starting from small specialized unit 60 years ago to be recently applied via Mega projects at national level and being an important part for the economics of different countries.

Figure 3 illustrates the basic RO process, which includes Intake, Pre-treatment, Membrane Transport, and Post Treatment prior to distribution. RO processes can produce water in the range of 10 to 500 mg/L TDS.

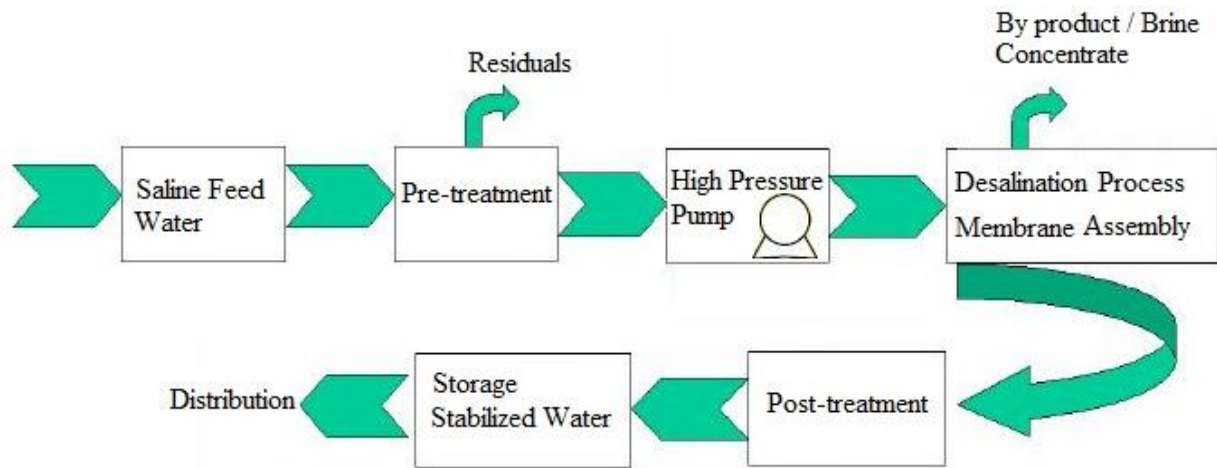


Figure 3: Basic RO stage

The basic revolution of the SWRO application reside in lowering the power consumption; to be noted that the energy needed to run this process varies in parallel with the intake water salinity. Some technical challenge persists like: manufacturing, level of semi-permeability, fouling, membrane supports and energy recovery. Table 3 summarizes the main characteristics of RO process.

Advantages	Disadvantages
<ul style="list-style-type: none"> • Suitable for both sea and brackish water 	<ul style="list-style-type: none"> • Comparatively Low quality of permeate (TDS =120 – 500 mg/L)
<ul style="list-style-type: none"> • Flexibility in water quality and quantity 	<ul style="list-style-type: none"> • Requires high quality feed water
<ul style="list-style-type: none"> • Low power requirements compared with other desalination processes 	<ul style="list-style-type: none"> • High Pressure requirements
<ul style="list-style-type: none"> • Flexibility in site location 	<ul style="list-style-type: none"> • Long construction time for large plants
<ul style="list-style-type: none"> • Flexibility in operation, start-up and shut off 	

Table 3: Advantages and disadvantages of RO [www.sswm.info 2010].

Although the mentioned disadvantages, when applied properly, RO technology has been classified as the best desalination process in terms of economic, technical and environmental aspects.

1.2- Forward osmosis

Recently, Forward osmosis (FO) is an innovation technology under study at laboratory level. In this new approaches, ammonia (NH₃) and Carbon Dioxide (CO₂) are added to raw (intake) water on the opposite side of the membrane from the saline water to augment the ammonium carbonate concentration. In this case, the water – at the salt solution – will naturally pass via the membrane to the ‘draw’ solution without external pressure. The diluted ‘draw’ solution is then heated to drive off the ammonia and carbon dioxide which are captured and reused [McCutcheon et al., 2006]. In comparison with RO, the main advantages of FO include: no external pressure is required; high recovery efficiency; lower energy costs.

The desalination plants are erected to desalinate water from variable sources like brackish surface water from rivers and lakes, brackish groundwater from wells, municipal and industrial wastewater, and basically seawater. Our case study concern the SWRO, therefore we will focus on sea water characteristics and all the SWRO desalination process.

2- Sea Water quality

The sea water is a variable natural water source, having the water quality affected with the location, the environment, the temperature, the season and the maritime activities. In general the sea water quality is summarized in the following table# 4. The sea water quality represents a huge importance since it has big influence on the selection of the type of intake, the pre-treatment steps and the membrane quality.

Constituent	Normal Sea Water	Eastern Mediterranean	Arabian Gulf	Jeddah	Ummlujj	Haql	Diba	Al-Birk
Sodium Na+	10556	11800	15850	12500	12850	12930	12900	12282
Magnesium Mg ⁺⁺	1262	1403	1765	1520	1550	1550	1550	1531
Calcium Ca ⁺⁺	400	423	500	490	480	480	500	480
Potassium K+	380	463	460	410	460		412	460
Chlorine Cl ⁻	18980	21200	23000	22300	23000	23406	23100	23000
Sulphate SO ₄ ⁻⁻	2649	2950	3200	3189	3100	3240	3150	3100
BiCarbonate HCO ₃ ⁻	140	-	142	146	153	140	150	150
Silica SiO ₂ (mg/l)	0.1	-	0.15	0.182		0.05	0.09	0.2
TDS	34483	38600	45000	41268	41400	42210	41600	40900
conductivity	49200	55100	64280	58500	58400	60300	58500	58500
pH	8.1	8.18	8.2	8.16	8.2	8.25	8.26	8.2
Turbidity	-	-	-	0.11	0.2	0.7	0.29	0.2
Bromide Br ⁻	65	155	80	72	-	-	-	-

Table 4: Sea water quality comparison [Hassan et al., 1991], [Al-Mutaz, 2000].

In the first stage of SWRO desalination plant, sea salty water is fed into the SWRO plant from a sea intake installation, the intake pumps push it to pass through the desalination system (reverse osmosis membranes). The permeate (product) will be stabilized either through lime addition or blending with another source, then it could be sent into the distribution system (for potable water), or it could be re-mineralized (for drinking water this is typically to a minimum hardness of ~40 mg/L as CaCO₃ and a minimum alkalinity of ~40 mg/L as CaCO₃) [Erin et al., 2011]. Finally, it is disinfected using chlorine / chloramide. The concentrate (brine) is generally discharged through an outfall back to the sea.

The proposed desalination plant will have a nominal capacity of 20.000 m³/d; it is designed of two units, each unit ensures the production of 10.000 m³/d. The desalination plant includes the following:

- Three Feed pumps, 2 in duty, one in standby mode
- Five sand Filter to remove fine solid particles
- Two back Wash pumps for the sand filters
- Chemical Dosing System including: Chlorine, SBS, Sulfuric acid, antiscalant.
- Two cartridge filter to remove all particles size above 5 microns
- Two High Pressure Pumps (HPP) with Energy Recovery Turbine (ERT)
- Two Racks of membranes inserted inside the Vessels
- Two Cleaning pumps for the RO units
- One Cartridge Filter for the cleaning liquid
- One Storage Tank of 22.000m³ capacity
- Three filling pumps for water distribution through pipe line and filling station.
- One electrical room containing 7 Generators, coolers, transformers, soft starter, main electrical distribution Panel and Generators control.

The purpose of this SWRO desalinated Plant is to reduce the sea water salinity from the level of 41200 ppm at the intake to not more than 500 ppm in the storage tank. The level of mineralization for waters is generally accepted between the minimum of less than 100 mg/liter to a maximum concentration of 1000 mg/liter

As mentioned before, the SWRO Plant is designed to work in two units, each unit will ensure the production of 10.000 m³/d; the estimation considers the plant production using one unit for the first 20 months.

Therefore, for the first 20 months, the plant will produce a treated (desalinated) water volume of 10.000 m³/d, say 416 m³/h based on 24 hours operation. The produced water will be stored in the 22000 m³ tank capacity located 60 m to the east of the RO.

Sea water having an average Total Dissolved Solids (TDS) level close to 41.000 ppm at 25°C will be driven by stainless steel centrifugal pumps at the rate of 1040 m³/h (10.000 m³/d). For the construction and installation of our SWRO plant, high quality materials have been used; all the equipped components are anti-corrosive in order to minimize damages due to saline water.

3- Water Safety Plan (WSP)

In order to permanently keep the produced potable/drinking water safe during the product phase and management of water hierarchy, a Water Safety Plan should be used as a comprehensive planning, risk assessment and risk management approach that cover all the phases of water supply starting from the intake of raw water till the customer. WSP approach - based upon the understanding of water system function- is a successful practice for managing water quality [WHO, 2007].

The WSP precept is based on fundamental standard of sanitary surveys, preservation, many barricade, variable valuation, and quality management systems; WSP is designed and applied in order to ensure the production of healthy water, therefore the three major phases (intake source, water treatment process, and distribution) should be executed with the best design and the highest level of operation and maintenance.

WSP is applied via three set up points: system assessment; measures and analysis to govern and monitor detected risks; and management plans fixing task to be done during operations and incident. These are guided by health based targets, and overseen through surveillance of every significant aspect of the potable water system.

- System assessment to decide if the train system phases (intake/source to customers) can permanently produce water under the desired quality target (depending on the future use of water). This includes assessment of design criteria for new systems as well as modifications.
- Measures and analysis to govern and monitor detected risks (or deficiencies) and confirm to reach the determined health targets. For every monitor measure, suitable operational must be determined and applied in order to quickly notice deviations.
- Management plans fixing task to be done during operations and incident conditions, and documenting the system assessment (especially the system upgrades and amelioration), controlling, and communication policies and supporting programs.

The primary objectives of a WSP are the minimization of contamination of source waters, reduction or removal of contamination through appropriate treatment processes, and prevention of contamination during processing, distribution and storage.

CHAPTER 1 : Intake variation effect on Water Quality for SWRO

Intake variation effect on Water Quality for SWRO

Abstract

The majority of the ocean/sea water intakes around the world are used at the electrical industry where this source of water is commonly served for cooling aims in wide and huge surface condensers. In the other hand, thermal desalination plants (for example the multistage flash evaporation (MSF) and multiple effect distillation (MED)) also use intake water sources for cooling purposes exactly like the electrical power factories; between all this factories, the SWRO started to take place and special intake for this SWRO desalination plants have been constructed. But SWRO is expected to be the dominate desalination technology in the near future since it is giving the needed results with the minimum cost.

As populations' numbers grow, the actual available domestic water sources are suffering to meet the new water request. Therefore people looked for new sources to produce domestic water, using the desalination technology is getting more popular and provides population with fresh water from the sea/ocean salt water. Or before taking place and be in operation, all the desalination plants should respect the national/regional norms, rules and law from all sides: environmental regulation, ecological, social and industrial challenges/obligations. Of the three components of sea water desalination plant (intake, treatment, and concentrate discharge), intake -design and location - is mostly the most challenging aspect of the system in terms of technical strategy, regulatory challenges, and public perception [Erin et al., 2011].

Sea water intake is the essential process of Sea Water Reverse Osmosis (SWRO) desalination and is of utmost importance for desalination projects since it conditions other processes like pre-treatment, membrane selection, membrane treatment and post-treatment, and it influences product water quality. The objective of seawater intakes is to provide reliable and consistent high-quality feed water with lowest environmental impact.

Refinement of the intake water quality feeding the RO help diminishing the complexity of pre-treatment process, for example: minimizing the step of physical cleaning including the dosing chemicals, and ameliorating the operational reliability of the plant. In parallel, providing better quality of feed water to the primary membrane process ensure the reduction in the rate of organic biofouling, reduced capital cost for construction of pre-treatment processes, and reduced operating costs for maintenance, chemical use, and accessory operations [Missimer et al., 2013].

Intake designs are mostly site specific, even more than any other aspect of the desalination facility. The field survey, design, monitoring, and permitting activities that surround them, may represent between 15-20% of the capital cost of the entire facility, and it is basically that intake-related issues may ultimately determine the feasibility and performance of the desalination plant itself.

The construction stage, testing, commissioning, operating and maintenance of the intake may badly affect the environment. The concerns related to construction phase include erosion, disturbance of the local ecology, habitat destruction, impact of construction materials (drilling, cement, pipe material, lubricants), and the potential for disturbance of pollutants from the soil/sea bed [Erin et al., 2011].

This study will focus on its main and essential part: THE INTAKE; decision key, general type of intake, our selection and our case study.

1- Introduction: Key selection of intake factor to be taken in consideration

The feasibility of several intake designs is related to project specification, site options and geology, local ecology, cost, regulations, and stakeholder considerations.

A good intake design will not only protect downstream equipment and reduce environmental impact on marine life; it will improve the performance and reduce the operating cost of the pre-treatment equipment [Pankratz, 2004].

Taking in consideration all the above mentioned points and concerns, from business point of view, the decision on intake type and treatment process for SWRO projects relies on an economic comparison.

The first and most important concern for comparing and selecting the proper design of the sea/ocean intakes is the direct resulting construction cost of the inlet of the SWRO plant, and the reduction of treatment cost due to the improved feed-water quality [David et al., 2009].

The second concern is the indirect cost representing the environmental impacts of pumping sea water directly from the sea or from the groundwater system (impact on the local ecosystem, impact on the sustainability of fresh groundwater for existing and planned pumping wells) [Schwarz, 2003]. The choice of seawater intake should therefore be based on technical, economic and environmental considerations and is generally considered to be very site and project specific.

The first step in developing a decision methodology is to identify the key issues and decisions that guide the decision-making process.

1.1- Information Needed for Evaluating the Intake Design Options

The required essential information needed to define the planning and design process (how the Decision Tool should guide the decision maker to select their intake scenario) for sea water intake scenarios are defined here is as follows:

1.1.1. *Required intake capacity*: The decision maker must know the needed capacity of the intake. In global, feed water volume requirements generally range from approximately two times the plant production capacity for reverse osmosis (RO) systems.

1.1.2. *Regulatory region*: Each country, each area, each State and maybe each property has her own regulation that must be respected, having more detailed regulatory guidance will help a lot to avoid some scenario or to restrict the choice on specifics scenarios. In general, regulatory guidance for any locations is restricted to the Federal level.

1.1.3. *Site location types*: The geology and geography of the desired intake location(s) under consideration. • Beach • Bay • Estuary • Cliffs • Rocky Coastline • Co-location with an existing intake

1.1.4. *Technical options as a function of installation location*: The geology and geography of the desired intake location help to restrict what types of intakes could be feasible. Table 5 lists the intake structure options that are technically feasible for the different types of site locations.

Beach	Bay	Estuary	Cliffs Rocky	Coastline	Co-location
Open Intake	Open Intake	Open Intake	Open Intake	Open Intake	Co-location
On-shore	On-shore	On-shore	On-shore	On-shore	
Off-shore	Off-shore	Off-shore	Off-shore	Off-shore	
Vertical Wells	Horizontal Wells	Horizontal Wells	Horizontal Wells	Horizontal Wells	
Horizontal Wells	Slant Wells	Slant Wells	Slant Wells	Slant Wells	
Slant Wells	HDD Wells	HDD Wells	HDD Wells	HDD Wells	
HDD Wells	Infiltration Gallery	Infiltration Gallery	Infiltration Gallery	Infiltration Gallery	
Infiltration Gallery					
Co-location					

Table 5: Structural design options for seawater intakes [Erin et al., 2011].

1.1.5. *Water sources characteristics*: Depending on the quality and specifications of the inlet raw water feeding the SWRO plant via the intake, an important relative impact affects the design and the operation of the desalination plant from performance (later cost) and environmental point of view. Although physical factors (turbidity, conductivity, temperature ...) are generally stable in one location, but it doesn't mean that water body characteristics are not vulnerable seasonally at another spot. Also, other points should be taken in consideration, especially when having high ship movement, natural storms, sea/ocean water movement (currents, waves, tides ...) and some shoreline specifications, all these may be crucial to decide which intake design will perform from area to area.

1.1.6. *Ecology and environment concerns*: The construction of the water intake and the operation of the SWRO facilities influence some species of marine biota; the impact relays on different factors: the intake itself (location, design, and operation of SWRO), the existing flora and fauna and the nature of the local water body. The tough confrontation of the intake (especially during the operation) is to reduce the influence and concerns of impingement and entrainment of the marine species.

1.1.7. *Economic considerations*: The designer has to consider cost and prices while taking decision, in fact, the essential economic precast should be defined since the beginning. The intake is generally under estimate and considered as the part with the lowest cost in the project, therefore the Stakeholder and financier must be involved and informed in order to get the right and the best budget estimation.

1.1.8. *Stakeholder Considerations*: By the end, the owner of the project has his own aim and incentive, especially when the stakeholder has other project or future project and visualization in the working zone.

11.2- CONTROLLING PARAMETERS IN THE INTAKE SELECTION PROCESS

In order to choose the best and effective intake application for a particular SWRO plant, the designer has to estimate and study the evaluation of the available raw water options based on the previous recapitulative elements: starting with water (quality / quantity), passing by all environmental, ecologic, regulation and notification issues, and ending with the long sustainability. Or conditions will vary from place-to-place, therefore each factor that influence the M&O of the sea water intake must be studied and analyzed, report to be issued for the most effective selected alternative. In some cases, one key element may alone determinate the alternative solution to be followed.

1.2.1. *Capacity*: The designed capacity of the SWRO desalination plant may impose the intake type the most applicable. For low capacity units (<15,000 m³/d), a low cost well is the best effective alternative; however for big systems (>50,000 m³/d), an open intake will be the straightforward, widely used, best cost-effective solution. For remaining mid-range plants (15,000 to 50,000 m³/d), designers generally analyze different alternatives.

1.2.2. *Geology*: Geologic and hydro-geologic conditions easily determine the type of intake to be applied, that is way the geology maybe the first and the critical item to be studied. If the seaboard composite is formed by low permeability silts and clays, or low permeability consolidated (rock) formations, it will be tricky or out of question to built a subsurface intake or infiltration gallery. To be practical and being reasonable to use subsurface intakes, it is recommended that the water transmission be $>1,100 \text{ m}^3/\text{d}/\text{m}$ [Schwarz, 2000; Voutchkov and Bergman, 2007] for a depth of $\geq 14 \text{ m}$ [Voutchkov and Bergman, 2007]. Conversely, when analyses of seaboard geology prove that it contains porous, more probes and tests should take place for the designed bearing zones to get better evaluation about the potential for provision the needed quantity of water with the better quality.

1.2.3. *Cost*: Following the public mentality and local government rules, utility directors generally evaluate the establishment possibility of SWRO desalination plant, its' cost which is predominately matched with other alternatives. This comparison is an important data when determining whether or not the project worth to be established [Wright and Missimer, 1997]. Since few number of SWRO Plant are available and accessible in our region, and since most of the existing SWRO Plant belong to government, therefore all information are classified as confidential ; it was impossible to have access to know and exactly evaluate the cost of the different types of intake.

1.2.4. *Water Quality*: The layout of the pre-treatment steps for a SWRO desalination plant will relay on the quality of the raw feed water; therefore, this have huge effect on the type of intake to be selected. Due to the presence of different items, particles and organisms like dissolved natural organic matter (NOM), aquatic organisms, floating or suspended debris, oil and grease [Erin et al., 2011], water coming from an open intake must follow effective pre-treatment to take out anything that could foul or affect the membranes (the main treatment system). Additional pre-treatment cost should be taken in consideration when comparing alternative possible intake option. Typically, the good design and the proper installation of subsurface intake take advantage of the natural geologic soils to ensure a premium filtration of the feed water before it pass to the pre-treatment sequence. Results from testing at facilities using well and gallery systems typically show that raw water turbidity and silt density index (SDI) values are maintained below membrane manufacturers' recommendations [Rovell, 2001]. Depending on the withdrawal location, the conductivity and TDS of the feed water may differ. To be noted that in the case of well intake, some inorganic minerals (example the iron and manganese) may exist at high concentration, which requires specific pre-treatment before passing to the SWRO.

1.2.5. *Environmental Impacts*: Typically, most of the SWRO plants are located near the sea, thus imposing the intake in the important coastal zone. This coastal zone is generally so important from economical point of view (touristic and entertainment) and from environmental point of view; therefore it will be hard and costly to convince the society, the zone and project owners, and the government authority. Environmental restrictions could be decisive about the type of intake to be adopted. For this purpose, the designer must provide certificates, shows the used technologies, and explains the construction plan and whatever possible to prove that lovely aesthetics, ecosystems, marine fauna and flora, fishes, land use, existing water aquifers and contamination will be respected, in other way, all environmental concerns will be minimized and the long term operation of the SWRO plant will not have negative degradation effect.

Other issues, such as seasonal erosion patterns, groundwater contamination, impacts on sea water intrusion, and recharge/infiltration characteristics would also need to be evaluated during this stage.

1.2.6. *Permitting*: In many cases, it is regular conducting for proper studies and tests, completing the requisite forms, and otherwise respecting the requirements of permitting controls in charge for any activity or facility to be approved. In addition, where the source water may be a blend (naturally mix) of sea water and fresh water from local sources, water rights issues may also be involved [Erin et al., 2011]. Groundwater rights can also be an issue in some states.

1.2.7. *Sustainability*: the intake facility should hold and operate in good condition to provide steady flow rate for at least the life span of the construction; for this reason the used design must shows minimum level of confidence including consideration of both the need within the forecasted situation.

2- Types of intake

There are various types and configurations of seawater intakes and these can be classified into two main families [WateReuse Association, 2011]:

- Surface water intakes or also known as Open intake (direct)
- Subsurface water intakes (indirect)

In the first type, water is withdrawn directly at different depths while in the second type, water crosses through natural soil or sand bed and is naturally filtered before being withdrawn.

2.1- Definition, Comparison and Use

As seen and detailed before, the best suitable place and type of a SWRO intake should be decided once coastal zone has been evaluated and environmental forecast has been analyzed. Sea water intakes are globally classified as *Open intake (surface intakes)*, in this case, water volume is pumped from above the seabed, and *subsurface intakes* where water is obtained via beach wells, infiltration galleries, or other locations beneath the seabed.

SWRO plants, especially the large capacity ones (>30,000 m³/d), are normally and most frequently fed by surface open intakes that collect water directly from the sea via a collecting pipe with open side protected by an intake screen. However, this intake systems transport unfiltered and globally variable feed water quality (red tides, oil spills) that requires costly pre-treatment and can lead to significant environmental impact during operation (aspiration). In order to improve efficiency of SWRO plants and avoid some of the inconvenient associated with surface intakes recently research and projects tend for the use of subsurface intakes to collect the clearest water and feed SWRO plant, it gained momentum in recent years. In fact such systems have already been in operation for many years in several countries around the world (Malta, Spain, Canary Islands, Greece, Saudi Arabia, USA, etc.) [Jamaluddin et al., 2007; Bartak et al.,

2012], they have usually been restricted to smaller scale plants and it remains to be seen whether subsurface intakes can be suitable for large scale plants [Schwarz, 2000 and Wang et al., 2007].

Comparative analyses of seawater quality between open sea/ocean intakes and wells show that well intakes significantly ensure lower concentrations of particulate matter, algae, bacteria, and organic compounds that promote membrane biofouling [Schwarz J., 2003; Hassan et al., 1997; Teuler et al., 1999; Choules et al., 2007; Laparc et al., 2007]. Table 6 shows, for different sites, the better water quality that has been withdrawn using the well versus the Open sea intake.

Location	Parameter	Seawater	Well 1	Well 2	Well 3	Well 4
Dahab, Egypt [Hassan et al., 1997]	DOC (mg/L)	1.6	1.2	2.3	0.6	0.8
	UV-254 (m ⁻¹)	1.4	0.8	0.9	0.8	0.6
Fuerteventura Island, Spain [Teuler et al., 1999]	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 [Jamaluddin et al., 2007]	Dissolved protein (mg/L)	2.73	0.75	ND	ND	
	Dissolved carbohydrates (mg/L)	1.57	0.52	0.77	0.5	
SWCC Al- Jubail test sites [Hassan et al., 1997]	TOC (mg/L)	2	1.2-2			
	Bacteria (CFU/mL), 0 h	1800	1300			
	Bacteria (CFU/mL), 24 h	1.1 × 10 ⁵	3.3×10 ⁵			
	Bacteria (CFU/mL), 72 h	5.6 × 10 ⁴	4.0×10 ⁶			
Dahab beach well system, Egypt [Bartak et al., 2012]	DOC (mg/L)	1.6	1.2	2.3	0.6	0.8
	UV-254 (m ⁻¹)	1.4	0.8	0.9	0.8	0.6
Mediterranean location- spring [Choules et al., 2007]	Total picophyto-plankton (cells/mL)	1.6 × 10 ³	1.3×10 ²			
	Synechococcus (cells/mL)	1.3 × 10 ³	1.0×10 ²			
	Picoeukaryote (cells/mL)	1.1 × 10 ³	1.9×10 ¹			
	Nanoeukaryote (cells/mL)	1.2 × 10 ²	1700			
Site 1 [Laparç et al., 2007]	TOC (mg/L)	1.2	0.9			
	Polysaccharides (mg/L)	0.12	0.01			
	Humic substances + building blocks (mg/L)	0.5	0.4			
	Low-molar mass acids &	0.25	0.16			

	neutrals (mg/L)		
	Low molar mass compounds (mg/L)	0.33	0.29
Site 2 [Laparc et al., 2007]	TOC (mg/L)	0.9	0.6
	Polysaccharides (mg/L)	0.4	ND
	Humic substances + building blocks (mg/L)	0.26	0.16
	Low-molar mass acids & neutrals (mg/L)	0.22	0.13
	Low molar mass compounds (mg/L)	0.38	0.3

Table 6: Comparison between bacteria, algae, organic carbon compound concentrations in natural seawater verses well intakes from select sites.

2.2- open intake characteristics and application

Globally, open intakes are used with high plants production ($> 50,000 \text{ m}^3/\text{d}$), they are located above the seabed thus they have direct contact with seawater body. Generally, open intakes draw sea water by concrete channel, high density polyethylene (HDPE) PE100, SDR11 or 17, or Glass reinforced polymer (GRP) pipes with concrete surround support. The pipe/channel end is protected by screens to prevent residual and particulate vestige (both organic and inorganic) from penetrating into the intake pipe line. Therefore, open intakes involve additional pre-treatment train prior to the desalination unit to essentially take out marine organism and minuscule particles in the inlet water.

The design of a surface (or direct) open intake can be as simple as connecting an inlet piping/trench and screen combination to an available framework, or easily by amendment an available old intake (or outfall) that have been left; it could be as complex as building specified, stand-alone infrastructure. From sea to feeding pumps, a traditional open intake scenario consists of: intake screens at the open side of the pipe located in the sea (ocean) water, conveyor (pipe or trench transporting the water from the screen to the feed pumps), and a feed pump room.

Common intake design alternatives include the following [Erin et al., 2011]:

- Dock-, pier- or bulkhead- (existing structure) mounted screens
- Wet well intake sumps with subsurface intake lines that extend to off-shore screens
- Wet well intake sumps with exposed intake lines anchored on the seabed extending to off-shore screen
- Wet wells constructed into rock bluffs/cliffs with an intake line drilled through the rock into the seawater with or without an attached screen
- Shoreline structures with open bay and bar rack screens
- Directionally drilled lines under and through the seabed with screens, and/or
- Pump stations in sheltered settings (sloughs or coves).

The pump station design is often a wet well or sump infrastructure where pumps are installed to be under the intake point level. It should be placed near the sea shore to permit easy connection to both the intake and the SWRO plant. The pumping house should have easy access, enough large to hold the pumps (at least 2: 1 in duty and one standby), the electrical controls Panels, chemical dosing equipment (if used), huge primary screening (for example bar rack screens), and a backwashing facility (in some specific application). Many ancient plants adopt intake point at the shoreline and therefore faced relatively bad water quality, that is way in the modern orientation designer prefer going more deep in the sea to be away from the shoreline and avoiding trash, debris and other floating rubbishes resulting from the habitation nearby.

The best hydraulic scenario having intake features that take into consideration to provide the SWRO facility with enough water quantity; that impose adjusting the withdraw point in an appropriate height in the sea, ensuring stable water column above the intake point to evade picking up floating particles, and provide reasonable height over the seabed evading saltation, seabed particles and the existing or future layer of marine vegetation.

Not only the water quality, but although the marine status development and the biological factors will affect the operation (as seen before) and also the maintenance of the direct intake. Major and normal components may exist or occur like the growing up of sea grass and eel grass, the apparition of sea boat traffic accompanied with their negative effects (oil, grease ...), the permanent STP discharge, the seasonally storm water reject, the natural biological grow up ecology system (algae, mussels, red tides, barnacles,...); logically, all this components may cause mechanical hydraulic problem to the intake system by fouling and plugging the opening of the screen, this will affect the water quantity and quality reaching the membrane forcing more additional treatment in the pre-treatment stage and in some case for the membrane equipment itself. The best solution to reduce or even avoid this effect is by periodically ensuring visual check and inspection of the intake, and once plugging is noted to directly start cleaning and maintenance action to keep the intake system working at high performance.

Entrainment is one of the major ecological problems that badly affect the marine organisms when open intake design is adopted; in order to reduce this side effect, big importance should be taken into consideration to the vertical stratification of entrainable species at the water column above the intake submerged withdrawal point which should place in area where the frequency of entrainment is the minimum. Off-shore intakes typically terminate at a vertical riser of the inlet conduit in 9 to 15 m of water. Since the same volume of intake water must pass through an off-shore inlet with an opening much smaller (commonly 4.6 to 6.1 m) than the existing shoreline intake, the flow rate would need to be reduced to maintain the intake velocity design standard of 0.15 m/s) [Erin et al., 2011].

2.3- open intake advantage and disadvantage

Each intake system has his positive strong characteristics and his weak and negative effects. Each decision maker(s) have to study and analysis the advantages and disadvantages of each intake scenario sited and summarized below; only after considering them, he can select the appropriate intake scenario that tie in, in the best way, to the main target of the project and satisfy the aim and intention of the owners.

2.3.1. Advantages of the Open (surface / direct) intake:

Despite providing generally poorer water quality, surface intakes are technically feasible almost anywhere along the coastline, at any kind of geology zone, from coastal composite that consist of low permeability silts and clays, or low permeability consolidated (rock) formations, or coastal geology showing that one or more porous geologic systems are available.

In all circumstance, once ensuring appropriate fouling attenuation and control equipment are located, the open intake offer greater certainty in terms of achieving the desired capacity including for large scale SWRO plant, because transporting the needed raw water is controlled by the diameter of the conveyance piping and the dimension and multitude of intake screens. In summary, open intakes provide flexible water volume starting from low water flow (hundred of liters per minute) to huge water flow (up to several hundred million liters per day).

The basic framework of hydraulic designs for open intakes is well documented, studied, and thus can be applied relatively simply in less time and less effort. Once the decision has been taken, it will be matter of few weeks before the open intake will be ready from A to Z.

Conventional intakes, on the contrary, have a relatively large economy of scale with regard to construction costs [David et al., 2009], to compare it with the subsurface study and analysis phase, samples, land and geological studies and tests, construction and investigation.

The best ever advantage for an open intake is the quick, easy, low cost implement solution in case any problems or natural obligations have occur. The intervention time is generally short, and if big water storage tank is available, the water delivery may even not be affected at all. For example, increasing the size of a screen and the diameter of subsea intake pipes will help receiving double the water flow results in a lower construction cost/unit volume of capacity.

Finally, the visual environment footprint and effect are at minimum level, even they may be unobserved on the land, on the contrary, most of the SWRO plants have green spaces and vegetation all around the site witch give best visual land and beach view.

2.3.2. Disadvantages of the Open (surface / direct) intake:

The sea and specially the ocean is an active entity characterized by steadily variable shoreline profile. In fact, strong waves and changing currents may harm intake facilities, affect water depths, and dramatically alter water quality. Operational problems are increased by seawater's corrosiveness and the marine organisms that can attack and foul equipment and systems [Pankratz, 2004].

Therefore, while using open intake alternative, special precaution (more expensive) has to be taken using corrosion-resistant materials. Also the extent, respectively the cost, of the intake pipes varies from a coastline location of the pumping room to an intake point several meters to several hundred meters deep in the sea. These impose additional instantaneous construction cost and future permanent inspection and maintenance.

With an open intake, the poor feed water quality must be pretreated before entering the cartridge filters and membrane desalination system; different type of chemicals may be used, coagulant (ferric chloride), Chlorine for disinfection, more anti-scalant will be added to the inlet lines, this adds significantly to both capital and on-going O&M costs.

Since the intake is constructed in open water, the appurtenances of the intake system will be subject to corrosion, plugging, biological growth, erosion, wave activity, and storm effects that can affect performance, service life, Operations and Maintenance (O&M) requirements, and sustainability [Erin et al., 2011].

Natural seawater contains a variety of macro- and micro-organic components that affect the treatment process [Hellmann et al., 2002]. Open-ocean intakes are seasonally clogged in some regions by seaweed [Kreshman, 1985] and some pre-treatment systems are periodically fouled by influx of jellyfish. Also, natural environmental events, such as harmful algal blooms and red tides, can overwhelm pre-treatment systems and cause temporary shut-downs of SWRO plants [Berkday, 2011; Anderson and McCarthy, 2012].

From environmental point of view, the concerns focus on the influence of dosing chemicals used to maintain the intakes and relative pipes free of organic growth, disposal of coagulants required in the pre-treatment processes, and disposal of macro-organic debris that accumulates on the traveling screens (seaweed, fish, jellyfish, etc.) and other parts of the pre-treatment train [WateReuse Association, 2011].

In the other hand, since the intake protecting screen are not planned to eliminate all the organisms within the raw water body during the intake process there may be an increased focus on the environmental protection aspects of the intake operation. This will likely increase the reporting and permitting needs for the project relating to entrainment and impingement of biota.

2.3.3. Summarized table:

The main advantages and disadvantages associated with the open intakes are summarized in Table 7

S.N.	Advantage	Disadvantage
1	Suitable for most terrains and projects	Lower and more variable feed water quality
2	High flow capacity	Poor water quality
3	Relatively easy to build (save time)	Vulnerable to marine variation conditions
4	Low cost	Requiring costly pre-treatment
5	Rapid implement solution	Higher operational cost (maintenance)
6	Smaller footprint and less visual impact on the seashore	Significant environmental impact during operation (aspiration, clogging)

Table 7: Advantages and disadvantages of open (surface / direct) intakes

2.4- subsurface application

In the subsurface intake, the sea water is drawn through the subsurface into the intake pipe. Subsurface intake systems use the natural geological properties of sediments and rocks to strain and biologically remove organic matter, suspended sediment, and dissolved organic compounds before they enter the treatment processes [Missimer, 2009]. Even that the subsurface geology theoretically limits water quantity and performance (when compared to direct intakes); however, the extensive pre-treatment required for surface intakes is either totally eliminated or greatly reduced because the subsurface acts as a natural filter. It functions in a similar manner to river bank filtration (RBF) or bank filtration systems used to treat freshwaters in Europe and the United States for over a century [Ray et al., 2002; Hubbs, 2005].

Generally, subsurface intakes are not frequently used for huge plants because of their finite water capacity and, sometimes, the obligation to build a filter bed around the screens.

Subsurface intakes are buried pipes and/or wells dug beneath the shoreline or ocean floor. Subsurface intake types can be grouped into two categories which include wells and galleries [Missimer, 2009].

Wells can be subdivided into conventional vertical wells, horizontal wells or drains, angle/slant wells, and Ranney wells or collectors. Gallery-type intakes include seabed filters or galleries and beach galleries [Missimer et al., 2013].

A key issue is the pre-design technical assessment of the hydro geological conditions before the facility design and bid process begins. The pre-design geological and geotechnical investigations should be phased with a preliminary investigation scope developed to assess “fatal flaws” that would eliminate the use of any subsurface intake type and a primary investigation that would provide sufficient data upon which to base at least a preliminary design [Missimer T.M., 1994; Taylor & Headland, 2005; Cartier & Corsin, 2007; Pankratz, 2006^A; Pankratz, 2006^B; Mackey et al., 2001; Voutchkov, 2005].

2.5- Subsurface advantage and disadvantage

The subsurface intakes generally ensure better and less variable water quality but, for this reason, require favorable site conditions and are considered to be more risky in terms of achieving the required capacity, particularly for large scale SWRO plants and especially if no sufficient studies and data have been assessed.

2.5.1. Advantages of the subsurface intake:

In general, sea water reverse osmosis plants equipped with indirect water intake benefit from huge amelioration of the feed water quality, therefore the degree of needed pre-treatment will be reduced, including decrease in the cost of pre-treatment (equipment, chemical, dosing system, headache ...), thus lowering the water prices to costumers; also the negative side effect on environment will be minimized and the carbon foot print on ecology will be mitigated. The general type of subsurface intake are wells (at all the available types: radial, vertical and angle) and galleries, all this type could be near the shoreline or under the seabed [Gollnitz et al., 2004].

Basically, subsurface intakes play both roles: as water intakes and involving in the pre-treatment stage benefitting from the natural soil filtration and active biological treatment of the feed sea water; in fact, the raw water produced from sea water intake wells typically has been pre-filtered through the rock formation, greatly reducing or eliminating the need for pre-treatment prior to the desalination process. Recent investigations of the improvement in water quality made by subsurface intakes show reducing of the concentration of suspended solids, lowering of the silt density index by 75 to 90%, removal of nearly all algae [Missimer et al., 2013], very effective in reduction or elimination of pathogens in the filtered water (removal of over 90% of bacteria), reduction in the concentrations of TOC and DOC, and virtual elimination of biopolymers polysaccharides [Weiss et al., 2005; Laszlo et al., 2002; Gollnitz et al., 2003; Gollnitz et al., 2005], and organic matter entering the primary treatment processes [Kivimaki et al., 1998].that cause organic biofouling of membranes.

The biggest advantages of subsurface intakes is not only the better water quality, but also the stability of this water quality notably in terms of lower Silt Density Index (SDI), suspended solids, oil and grease, natural organic contamination and aquatic micro-organisms. In addition, naturally passing through stable existing soil ensure long term stability of water quality and radically reduce the temperature ranges.

The use of subsurface intake systems helps to reduce operating costs [Missimer, 1994]; in fact, the water withdrawn from such intakes generally requires less pre-treatment, which in turn means lower capital costs (pre-treatment) and operational cost for the SWRO plant: plenty of cost deduction in operations which comprise abolition of traveling screens, cancellation of waste disposal of marine debris (fish, jellyfish, and seaweed), decreasing of chemical usage, saving of electrical and maintenance costs for the pre-treatment systems [Missimer, 2009].

Although of the high capital cost of the subsurface intake compared with the open intake, but a reasonable long term economical study and analysis prove that this high capital cost will be easily recovered and offset in the future reduction of the whole system as previously descript. In fact, economic analyses show that overall SWRO operating costs can be reduced by 5 to 30% by using subsurface intake systems, a preliminary life-cycle cost analysis shows significant cost saving over operating periods of 10 to 30 years [Missimer et al., 2013], this study and the shown number make indirect intake more interesting.

Other advantages may also include lower environmental impact during operation and greater operational flexibility All types of the indirect intake are not directly in contact with the open water, therefore water have to migrate from the open water (Sea/ocean) and pass through the natural existing soil, that is what fishes and the other marine organism can't do, thus the potential for entrainment and impingement is totally annulled and the aquatic life is saved. This environment approach is attractive from a regulatory standpoint.

Finally, subsurface intakes are generally less vulnerable to accidental pollutions (oil spills) and to algal blooms (red tides).

2.5.2. Disadvantages of the subsurface intake:

For huge capacity SWRO plants, aquifer situation limits the yield available from single wells; therefore many supplement wells must be arranged to ensure the water volume needed for

the plant [David et al., 2009]. But, free land are not always or easily available in order to extend the project land, or if available it should be purchased to construct the extra wells, which impose additional cost [Missimer and Winters, 1998], raising the project costs which are relatively high since the beginning due to the vast, huge, intensive and expensive studies of the coast geology and hydro geology.

The soil filter material is typically natural; therefore it is complicated to estimate what will be the real capacity as pre-construction shoreline groundwater analysis is often restricted or impractical. The well intake yield maybe evaluated using sophisticated and specified model calculations [Jamaluddin et al., 2005], or to adopt conservative estimation recapitulated from analogue experience.

As the sea water is filtrated and pass through aquifer that may be rich in different minerals, the water quality may contain excessive concentrations of certain minerals like iron and manganese, which may require specialized pre-treatment prior to the desalination process.

In global, the layout of a submerged intake is composed by fine filter layers and limited grading of media sizes, in fact scientific anticipate the arrival of particles and organic materials with the feed water, which will block interstitial pores and accumulate within the screening and conveyance portions of the intake [Erin et al., 2011].

The performance of the natural soil filter and their ability to provide the desired water volume are subject for alteration and conversion due to the effect of marine activities (wave, current ...) and erosion. These impose permanent inspection and maintenance to sweep blocking debris and restore the accepted performance [Voutchkov., 2005].

Logically the intakes are located near the raw water source, since most of the water sources are located near the sea/ocean, thus it is quite normal that the intakes are located near the coastline which expose them to natural forces (like ground-swell, seasonal erosion). These events may affect, altered and damage the intake facilities and in some cases the facilities may become even exposed; therefore the performance of the intake is negatively affected from quantity and quality point of view which impose maintenance intervention and could even disturb the water delivery. The intervention and maintenance are not easy and could not be done as quickly as the case of open intake, the plant may be stopped for a long period, and the delivery will be affected and could not cover all the customers need during the period of shut down.

Environmental restrictions can lead to costly maintenance problematic.

- The groundwater aquifers could be affected when intake is in operation and well water sources have been pumped, in this case, local, obligation of paying attention to hydraulic influence and maintaining the local groundwater aquifers intact may cause huge problem if it has occur during operation (once all the installation has been completed) [Jamaluddin et al., 2005].
- Production of dredging mixture of soil and water has negative environmental effects and disposal issues. Or, this can be avoided by adopting alternate disposal techniques [Schwarz , 2000].
- The coastal visual beauty will be changed and affected by the construction facilities, the works procedure and the protection limit of the project. This may not be acceptable for some stakeholder and/or land, project owner(s) [Ko and King, 2005].

2.5.3. Summarized table:

The main advantages and disadvantages associated with the subsurface intakes are summarized in Table 8

S.N.	Advantage	Disadvantage
1	Water quality improved	Limited flow capacity
2	Stable water quality for long term	Higher risk of insufficient flow capacity
3	Reduce cost of pre-treatment & operation	Additional pre-treatment maybe required
4	Respect the aquatic life	Plug of interstitial pore
5	Less vulnerable	Slow implement solution in case of problem
6		Significant environmental impact: groundwater, coastal beauty and mud.
7		High construction cost.

Table 8: Advantages and disadvantages of subsurface intakes

2.6- Conclusion

Both types of intakes also offer their own specific challenges and opportunities in terms of operation and maintenance, as well as from an environmental impact point of view.

Well intake systems have proven to be a reliable means of providing feed water with positive impact on water quality [Andrews and Bergman, 1986; Kammourie et al., 2008].

It is a common misbelieve that subsurface intake systems are limited for use on only moderate and small capacity SWRO systems [Bonnelye et al., 2004; Brehant et al., 2003].

[Greenlee et al. 2009] stated “Today, as larger and larger RO plants are designed, beach wells cannot always provide enough water, and open seawater intakes are the only feed source option.

Seawater intake wells have proven to be quite economical for desalination plants with a capacity smaller than 38.000 m³/d (production), while open ocean intakes have found wider application for large sea water desalination plants. In general, regulatory agencies have indicated a preference to subsurface intake technologies (where feasible) as opposed to direct, open-water intakes due to the reduced environmental impacts associated with these systems.

Therefore, from a purely economic viewpoint, the use of subsurface intake systems is preferred over an open-ocean intake system [Missimer et al., 2013].

3- Our selection

Starting from the general opinion of most regulatory agencies and following the most existing small SWRO (less than 38.000 m³/d) plant concerning the prefer use of subsurface intake scenario against the open intake especially for the small SWRO units.

Based on the theory concerning the beach regions telling that coastal zone underlain by thick deposits of permeable sand, gravel, or a combination of these materials also have a high probability of successful subsurface intake installation and operation [Ko and King, 2005; David et al., 2009].

And since our project zone have huge sandy beaches that are relatively stable and have weak wave activity; we recognize having a good probability to install and use successful and useful subsurface intake.

But other factors have to be taken in consideration in order to take the right decision and being able to make the best selection of the intake type. The following points have been discussed:

3.1- Time

The land owner (ARAMCO Saudi Arabia) and main contractor (Petro Rabigh) were in hurry, they have fixed a dead-line for the starting of the plant within eight months from the contract date, after this date a penalty should be applied against HUTA in case no water has been produced and delivered to the storage tank.

In the other hand, in order to make the right, successful and appropriate subsurface intake, technical assessment of the hydro geological and geological conditions must be done, providing historical aerial photographs, geological maps, bathymetric map of the offshore, bidders with overall coastal conditions package.

In addition, a pre-design geological and geotechnical investigation must take place including: drill test borings on the beach area, construction of detailed geologic logs, collection of samples from the beach, having the grain size distribution, construction of –at least- one observation well to get an idea about the hydraulic conductivity, water sampling collect from sea and well for chemical and bacterial analysis, effecting an aquifer performance test and produce a site specific report.

All this work could be done by our team, but we faced the problem of racing time against the dead line fixed date.

3.2- Available of pre-treatment facilities

The main SWRO plant has been purchased as a complete station located on floating barge, the station include: intake pumps, sand filters, back wash tank for the sand filters, back wash pumps for the sand filters, air blower, air compressors, cartridge filters, HPP (High Pressure Pumps), Vessels, steel base of vessels, back wash pumps for the membranes, all

electrical Panel and control, Generators, Transformers, all electrical systems and most of the valves.

The only missing items were: the membranes, the chemicals systems, and the backwash tank for the main unit of membranes, all the pipes connections, some valves and sensors.

For this reason, no more cost were desired especially that the sand filters are present and could ensure the proper pre-treatment and ensure good water quality to be fed to the cartridge filters.

3.3- Project duration

The project is for only 5 years (may be extended for additional 2 years depending on work progress onsite), for this reason, and refer to paragraph 2.5.1 (the subsurface intake is rentable and will shows significant cost saving over operation periods of 10-30 years) [Missimer et al., 2013], the question of economic does not exist anymore, and the main focus was to accomplish the construction, the test and commissioning at time.

3.4- Stable Sea water

During all the period of installation, the sea water entity conditions have been observed, no powerful wave were observed at our coastline, no storm has took place, no important currents were detected, and no big marine organisms that could attack our infrastructure and structure were noticed. Also, we did not face any seaweed invasion; either no jellyfish were observed at any stage. Finally, we did not face any natural environmental events, such as harmful algal blooms and red tides.

Off course this observation (for the period of 6-7 months) is not good enough to make a final decision of the absence of such natural marine fluctuations, thus we launched an assessment and statistic survey with all the old fishermen and the specialized in red sea characteristics at our project zone. Also, Petro Rabigh helped us and arranged sufficient data to confirm the rare case of natural marine fluctuations at this area.

3.5- Specific Precautions

In order to minimize the marine effect on the operation system, cement, structure and infrastructure, the used cement have been ordered with a special combination in order to utmost prevent the sea attack against the cement bases. Also, all steel base have been treated and painted with specific coating materials to utmost protect the steel from possible corrosion. Finally, we used Glass Reinforced Plastic (GRP) pipe; even the high cost of the GRP pipes, but this kind of

pipings could handle the wide temperature change between day and night, the high water pressures (up to 16 bars – as per the suppliers) and especially these pipes are inert via water contact and/or water aggressively.

3.6- Stakeholder decision

The essential point that was the Key factor to select the scenario of our intake is the Land owner (ARAMCO); in fact, our project is located inside a petrol refinery, therefore the area is classified as a high security zone area, no question to make any underground drilling that may affect the existing constructions and structures. In the other hand, the available and given land is too short to make huge construction, and other projects are planned to take place in the future, thus it was impossible to make any environment change in that coastal area.

For all the reasons mentioned above, and despite of the adequate subsurface intake scenario that best matches with our case, the stakeholder decision and time factor were the key factors that affect the decision to use and install an open (surface / direct) intake.

4- Intake installation and case study

4.1- Theoretical installation:

Installing the open intake was not an option that we took, it was the only solution available for us and we have to deal with it in the best way in order to ensure the arrival of the best water quality to the pre-treatment trains, before entering the main treatment unit of membranes.

Therefore we tried to ensure the best ever condition of installation, we used the best material, we made the maximum sea bed investigation, we took as many sea water samples as possible, and we found the important following points:

4.1.1- The sea bed of Rabigh beach is quite unique and has a strange characteristic of keeping the same sea bed ground level of -1 to -2m under sea level from a distance of 5m from shoreline till around 30-40 m from shoreline; then, the sea bed ground level suddenly drops to a deeper bottom (-6 to -9 m from sea level, depending on the zone). Then this depth keeps increasing normally as long as we go far away from the shoreline.

This information was essential, since it helped us a lot:

- 4.1.1.1- in order to get the clean water, the intake pipe line must be aligned far away from the shoreline, for a minimum distance of 80 m from the intake pumping room. The best zone is located at 95m from shorelines where we could get 9 meters of water column above the intake pipe line, and having respective separation distance between the lower layer of the intake pipe to the sea ground level (10 – 11 meters).

- 4.1.1.2- the almost stable sea bed ground level for the first 40 meters helped us a lot by reducing the huge cost of intake installation, we have used small cements base, instead of using huge one with complicated fixation system
- 4.1.1.3- we are getting the water from a far point from the shoreline, around 70 water samples have been taken, and the bacteria test showing the total absence of any kind of bacteria at that zone.

4.1.2- The available aqua organisms are essentially the big fishes, which will greatly help us with the screen maintenance and cleaning procedure.

4.1.3- No boat or ship movement has been noticed in this area, the nearest boat/ship is at least 2 km away from the intake point.

4.1.4- The sea water at that zone was so stable and having excellent clarity, the turbidity was around 0.54 – 0.67 NTU.

As per the studies and research [Cartier and Corsin, 2007], the best is to get the water from the deep, therefore, the best solution rely on installing the direct line as described in paragraph 4.1.1.1; in this way, we will ensure have the cleared possible water, almost without any pathogen and bacteria, also we will get the best water temperature, and the installed screen will not need frequent cleaning and maintenance.

Also, we contrive and design at T connection to be installed at the end of the opening side of the intake pipe line immersed in the sea, therefore two protective screens will be available, and in this way and in case we faced any problem with any intake, we will be able to totally close it and put it under maintenance and repair while the other opening intake still under working condition.

4.1.5- Screen use, study and characteristics.

As with all other natural surface sea/ocean water source currently used for fresh water supply around the globe, sea water contains aquatic organisms (algae, plankton, fish, bacteria, etc.)

Some open intakes draw water in through an open pipe, operating problems have been reported with the entry of plants, marine organisms, and debris where no screens are used. Therefore, in order to protect the open intake from the entry of non-desirable materials and organisms, ocean/sea intakes employ screening devices to block large objects from entering the intake pipe.

Generally, mesh screen dimension of nearly 1 cm (3/8 in.) to 2 cm (6/8 in.) are commonly used; some screens are recently equipped with revolving wire mesh panels having 6 mm (5/8 in.) to 10 mm (3/8 in.) openings [Poseidon Resources Corporation, 2004].

As many engineer and designer are involved, the intake design is so different and variable. Engineers and designers examine intake design based on screen location in order to evade zones of near-coast habitat for existing marine life, and they will impose entrainment treatise.

The screen protection barriers are basically used to protect the fishes from entering into the intake facilities, for this reason the essential concern is the inlet water velocity while getting into the screen and the screen opening dimension. Therefore, once any protection screen has been selected to be installed, the whole system must be conforming to the related national or regional guidelines.

The protection screen could be as sophisticated elements (first consisted of barricade treaded on heels by fine screen) or as mere screen mounted far from water zone known to have the highest marine organisms and fishes in the water column. As describe before, the screen dimension must respect the regulation of the marine life protection, some assembly systems (screen + intake) are equipped with backwash system, this will keep the screen superficies clear from any items that may block the fine screen opening, and that help maintaining the raw water velocity and the working performance of the intake. The assembly must take in consideration the access for future inspection, even more, for future removal (for service) of the protection screen especially in area where biological growth is elevated. For this reason, some intakes are better to be equipped with standby screen in order to keep the intake systems in operation and avoid the stop of the SWRO plant. Depending upon the screen design, a fish trap or diversion/avoidance feature may also be required [Erin et al., 2011].

Operation of the intake structure has two major impacts on the aquatic biological organisms in the source water body: impingement and entrainment; in fact, tides, waves and currents, including currents induced by operation of the intake itself, may push inside the intake planktonic organisms that have mediocre swimming potency. Generally the impacts of working intake on planktonic species at a population level are very limited with the exception of sensitive, localized species that might normally occur in very low numbers [Erin et al., 2011].

WHAT IS IMPINGEMENT AND ENTRAINMENT?

The planktonic passage through the intake system can be fatal depending upon the species. The plankton's proportion in the sea marine is mutable depending on the location and season. As nature rules, the planktonic community composed of phytoplankton (plants) and zooplankton (animals) is prosperous in marine zone rich by nutriments; following this rules, the open coast, poor in nutriments, has small planktonic proportion, conversely estuaries and gulfs are rich by nutrients thus rich in plankton; the water body heat, the sunlight and sequence of season contribute on the vicissitudes in food and on the plankton population. Demersal species (living at the bottom) are less susceptible to entrapment than those at the midwater depths.

Once the protection screen is properly installed and the intake is working perfectly, the impacts on the marine organism and plankton will be different: due to the influence of intake pumps currents, the big invertebrates and fishes are power enough to swim and creep away from the screen opening inlet and obviate being entrained or impinged, while it is not the case of the small and fragile species.

Impingement occurs when marine organisms sufficiently large to avoid going through the screens are trapped against intake screens by the intake velocity and force of flowing source water through which exceeds their ability to move away; impingement typically involves adult aquatic organisms (fish, crabs, etc.) that are large enough to actually be retained by the intake screens (algae, plankton and bacteria are not exposed to impingement). The destiny of impinged organisms differs between intake designs and among marine life species, age, and water conditions. Some hardy species may be able to survive impingement and be returned to the sea, but the 24-hour survival rate of less robust species and/or juvenile fish may be less than 15% [Pankratz, 2004].

On the other hand, *Entrainment* occurs when smaller marine organisms pass through an intake screen, enter the desalination plant intake, draw into the intake system, and pass through to the treatment facilities into the process equipment. Entrainment mainly affects aquatic species small enough to pass through the particular size and shape of intake screen mesh. Organisms entrained into process equipment are generally considered to have a mortality rate of 100%.

A third term, “*entrapment*,” is then used when describing impacts associated with offshore intake structures connected to an on-shore intake screen and pump station via long conveyance pipeline or tunnel [WateReuse Association², 2011].

In order to minimize the negative effect of the open intake facility on the aquatic marine life and organisms, mitigation must be considered, modeled, studied, tested and applied. The quantity and velocity of the raw water surely influence the number of impacted species. When the inlet water velocity is reduced, fishes swim away from intake screen and evade impingement or entrainment, however, capacity of swimming isn't the essential element in impingement cases, low temperature, seasonal vicissitudes and migration or growth are additional important elements.

Many mitigation measures have took places in few facilities basically depending on the environment obligations forced by the stakeholder or project/land owners. Mitigation may include reducing the intake velocity, using fine meshed screens to exclude smaller organisms, and placing the intake location in a less sensitive area.

Comparatively small sea water intake scenarios involve design that reduces impingement and entrainment of marine organisms. Passive thin mesh and tight slit screens are dynamic at minimizing entrainment, or using of this very fine screening design did not perform in the marine life since their efficiency is trapped to blocking by biofouling and maintenance issues occur and force intervention; one of the best applications is to place the intake screen system in strong and powerful ambient currents to favorite the thin screen performance. The performance of narrow slit screen and thin mesh to minimize impingement and entrainment could be expressed by the ratio: intake velocity / ambient current [Erin et al., 2011].

Biofouling is a big concern especially for open intake since intake facilities and inlet pipes provide an important area for natural marine biofouling settlement and growth. In order to reduce this problem on the fine mesh and thin screen of the intake, many scientists have introduce the use of the antifouling coatings materials, even though it is still at experimental stage, a number of sea/ocean intake designs have used and were able to reduce the biofouling.

In global, accurate arrangement, specific construction, and determined maintenance can substantially affect the individual contribution to entrainment and impingement impacts that is made by each part at a given facility. They are as follows:

- *Intake location*: Open coastline, bays, harbors, estuaries.
- *Primary screening*: Usually very coarse screenings, large-sized mesh or gaps in bar rack systems located at or near the intake entrance(s). These systems are usually stationary screens or bars.
- *Secondary/fine screening*: Traveling water screens used to catch smaller organisms and particles not removed by the primary screens. The mesh size varies from about 20 mm (1 in.) down to 1 mm (0.04 in.). These screens can be equipped with fish-return systems [Erin et al., 2011].

Different mitigation methods are preferred for certain intake locations (Table 9). Unfortunately, most of open intakes are unscreened and anything or any organisms can easily enter the facilities. If the ratio velocity to the feed water is low ($< \sim 0.15$ m/s) and this low velocity is the same along the intake pipes, fishes could swim in and out of the system without problem. Or at elevated velocities, fishes passing in the intake system will not be able to move out, but remain captured in the intake facilities without becoming impinged on the in-shore screens.

Intake technology		Ocean / Sea		Bay / Estuary	
		Off-shore	On-shore	Off-shore	On-shore
Active screening technologies	Adjustable vertical barriers		X	X	X
	Angled screens			X	
	Center-flow/dual-flow screens		X	X	
	Fish return conveyance systems	X	X	X	X
	Modular inclined screens	X	X	X	X
Vertical traveling screens	Standard through-flow vertical traveling screens		X	X	
	Fine-mesh modified traveling screens	X	X	X	X
	Other modified traveling screens		X	X	X
	Aquatic filter barriers			X	
Passive screening technologies	Barrier nets			X	X
	Light and acoustical deterrents	X	X	X	X
	Louvers			X	
	Narrow slot/wedge wire screens	X	X	X	X
	Porous dikes		X	X	
	Velocity caps	X			X
	Variable frequency drive (VFD) pump seasonal/ diurnal flow management	X	X	X	X

Table 9: Applicability of the various active and passive intake technologies to different seawater intake locations [Erin et al., 2011].

In our case, we used a stainless steel wedge wire screens with slot distanced by 2 cm for the following reasons:

- 4.1.5.1- The sea water examination almost showing the presence of only big fishes

- 4.1.5.2- The intake pipe open side is located in the midwater depths, no major particles or alga will be available at this sea level stage.
- 4.1.5.3- It was the quickest type to be fabricated and installed, easy to clean and maintained.

4.2- First installation of the open intake pipe.

Even that it was essential for the land to be the nearest to the shoreline, or it was totally forbidden due to the restriction of having any facility or plant near the coast inside the high security refinery, thus the land owner (ARAMCO) has provide the land near an existing and huge three storage tanks (22.000 m³ full capacity for each one), this option has reduced the distance between the SWRO plant and the storage tank to 40 meters, but in the other hand, we have been forced to install a long intake pipe line:

- From the back wash tank to the pumping room: 20 meters
- From the pumping room to the shoreline: 340 meters
- From the shoreline inside the sea: 95 meters (as per the design study).

At the first time, and due to the false information, the sub-contractor installing team has lie down the intake pipe line along with the sea bed ground level, from the shoreline to the inside of the sea, the available distance was around 13-15 meters only, the GRP intake pipe line was 30 cm above the ground sea level, it has 60 – 80 cm of water column above it, the opening side has been kept horizontal.

Even that it was not at all the perfect situation to run the intake or the plant, and even that the sub-contractor was ready to make the intake modification as per the design without any additional cost, or the stakeholder has insisted to run the plant with the actual situation due to the dead line approach and penalty to be taken in consideration (only 1 week remained for the dead line).

Once the coming water quality from the sea is stable and having the maximum possible clarity, and once the water quality at the outlet of the sand filter is stable, we started the plant running – step by step – until feeding the water throughout the membranes.

At this running condition, the SDI was between 7.16 – 8.12 (with an average of 7.5), the conductivity was between 42840 – 43356 $\mu\text{S}/\text{cm}$ (with an average of 43119 $\mu\text{S}/\text{cm}$), the pH was between 7.7 – 8.3 (with an average of 7.88), and the temperature was between 28.1 – 35.4 °C (with an average of 31.9 °C). Refer to table 10.

Note: each data mentioned in table 10 is the daily average of four measures (2 in the day and 2 in the night) taken for each parameter; for the conductivity, the average lag was 0.23% with maximum gap of 0.49%; for the pH, the average lag was 1.32% with maximum gap of 3.27% and for the temperature, the average lag was 4.68% with maximum gap of 10.65%.

Date	Sea Water				Feed Water			
	Conductivity	TDS	pH	Temp	Conductivity	SDI	pH	Temp
18-Sep-2012	55,975	34,055	7.95	32.0	43,206	7.56	7.83	33.3
19-Sep-2012	55,950	34,040	7.93	32.0	43,100	7.54	7.78	32.4
20-Sep-2012	55,850	33,979	7.90	30.1	43,039	7.41	7.80	31.4
21-Sep-2012	56,025	34,086	8.16	31.0	43,118	7.43	8.03	32.1
22-Sep-2012	56,075	34,116	8.08	32.5	43,193	7.98	7.95	33.5
23-Sep-2012	55,925	34,025	7.92	29.2	43,145	7.55	7.83	30.3
24-Sep-2012	56,000	34,070	8.03	30.2	43,156	7.44	8.03	31.3
25-Sep-2012	55,875	33,994	7.99	29.5	42,998	7.49	7.78	30.7
AVERAGE	55,959	34,046	7.99	30.80	43,119	7.55	7.88	31.87

Table 10: Daily average parameters for seawater and Feed water. Running period from 18-25 September 2012.

After the sand filter, the average SDI was 7.5 which is not the perfect value of water SDI going to the membrane (must be around 3 [Pankratz, 2006^B]). Even that the water will also be filtrated while passing throughout the cartridge filter, it means that the SDI will be also dropped by 2 degree at the best condition of the cartridge filter, the water SDI value will still above 5, which is also not suitable at all for the membranes, in addition that the cartridge filter replacement frequency will be increased. In fact, as much as the SDI level will be reduced, the best will be for the running condition, the best for the cartridge filters running life, and the best for the membranes performance.

The plant has been running from 18 – 25 September 2012, under this condition we were hoping that the SDI will be improved with time (stability period). But it was not the case, in fact the SDI, as the other parameters, was stable during all this period.

During the running period, the overall situation can be summarized as following:

- 4.2.1- We have GRP intake pipe line with opening diameter of 900mm, 12-15m are inside the sea lying down along the sea ground level.
- 4.2.2- The lower layer of the GRP intake pipe line is distanced from the sea ground level by 30 cm only.
- 4.2.3- No wet well sump has been installed before the intake pump room.

4.2.4- The feed water was not clear enough; it was directly affected by the power of the intake pumps which conduct sand, little stone from the sea ground level and floating particles from sea top water.

4.2.5- The presence of three huge storage tank ensure the possibility of important water storage, our production rate is (2*9600 m³/d), our delivery rate is between 6000 – 8000 m³/d (depending of the customers need, weather condition, site work and companies demands).

Based on this numbers, we have approximately 11 working days to stop the SWRO plant without affecting the delivery.

Reference to all the previous interesting points, we took the decision to change the intake pipe line and make it above the sea ground level (to stay away from the sand and particles of ground water) and prolong it far away in the sea in order to take the water from the middle of sea water.

4.3- First open intake modification

On 26 September 2012, we stopped the SWRO plant, and directly started the modification of the existing intake. Everything was prepared in priory in order to quickly finish the modification of the open intake. The cements base were prepared, treated and coated with specific material. The huge cranes were deployed at site and in sea, the GRP pipes were ready to be installed, and the divers' team was onsite with all the needed equipments.

During the transportation of the GRP pipes (twelve meters length each pipe), one steel cord of ground crane has been detached, and seven GRP pipes have been damaged. The technician team was able to repair two of them. We contacted Amiantit (the supplier of all GRP materials) in order to quickly supply and back up the damaged pipes, but they don't have any pieces like this in their stores.

Two options were available:

- To stop the modification plan and return back to the previous stage and wait until the arrival of the complete GRP pipes.
- To continue with the available GRP pipes and install them since all the needed equipment are available at site and already started the work, especially that we have all the needed permission from Industrial Security, from ARAMCO and from Petro Rabigh.

Finally we took the decision to continue the modification, based on five major points:

- the presence of all the team at site with all the equipment
- having the permission from all party, it will be easier to re-extend the permission either then cancel it and replace it with new one, specially that HUTA did not want to show any delay from her part to the land owner.
- The GRP supplier (Amiantit) may be able to supply us by the missing GRP pipe during the modification work.

- Maybe the modification of the existing intake with the available GRP pipe will be enough to reach the perfect position for the intake.
- In case this modification was not sufficient, the next modification will be easier since we will have more experience and some faced problems and difficulties could be avoided.

The modification has been completed, and the new situation of the intake was as following:

- The off-shore open intake point was situated at 40 meters from the shoreline
- We have 3 meters water column above the off-shore open intake point.
- The off-shore open intake pipe was 5 to 6 meters above the sea ground level.

In this running condition from 5 to 18 October 2012, the water quality at the feed was as following: the SDI was between 5.7 – 7.1 (with an average of 6.5), the conductivity was between 39000 – 42700 $\mu\text{S}/\text{cm}$ (with an average of 41459 $\mu\text{S}/\text{cm}$), the pH was between 7.5 – 8.7 (with an average of 7.96), and the temperature was between 26.8 – 33.8 $^{\circ}\text{C}$ (with an average of 30.9 $^{\circ}\text{C}$). Refer to table 11.

Note: each data mentioned in table 11 is the daily average of four measures (2 in the day and 2 in the night) taken for each parameter; for the conductivity, the average lag was 0.61% with maximum gap of 3.24%; for the pH, the average lag was 0.97% with maximum gap of 2.99% and for the temperature, the average lag was 3.16% with maximum gap of 9.24%.

Date	Sea Water				Feed Water			
	Conductivity	TDS	pH	Temp	Conductivity	SDI	pH	Temp
5-Oct-2012	53,200	32,175	8.36	30.3	40,300	6.45	7.98	30.9
6-Oct-2012	51,775	31,314	8.43	30.7	39,200	5.95	8.09	31.7
7-Oct-2012	52,275	31,616	8.41	30.5	39,600	6.15	8.06	31.3
8-Oct-2012	53,225	32,190	8.44	29.7	40,300	6.23	8.08	30.9
9-Oct-2012	55,350	33,476	8.32	30.5	41,925	6.74	7.91	31.7
10-Oct-2012	55,625	33,642	8.25	29.8	42,125	6.75	7.93	31.2
11-Oct-2012	55,350	33,476	8.35	29.5	41,925	6.53	8.11	31.4
12-Oct-2012	55,400	33,506	8.30	30.0	41,925	6.58	7.93	31.1
13-Oct-2012	55,600	33,627	8.34	30.3	42,125	6.63	7.98	30.8
14-Oct-2012	56,275	34,035	8.30	29.0	42,625	6.96	7.93	30.6
15-Oct-2012	55,300	33,445	8.36	29.2	41,875	6.94	8.04	30.3
16-Oct-2012	55,800	33,748	8.10	29.6	42,250	6.73	7.65	30.7
17-Oct-2012	55,850	33,778	8.26	30.5	42,300	6.54	7.94	31.3
18-Oct-2012	55,425	33,521	8.17	28.5	41,950	6.44	7.79	29.6
Average	54,746	33,111	8.31	29.85	41,459	6.54	7.96	31.0

Table 11: Daily average parameters for sea water and Feed water. Running period from 5-18 October 2012.

We noticed a decrease in the water Temperature (from an average of 31.9°C in the previous case to an average of 30.9°C in this case.

In addition, the water conductivity dropped from an average of 43119 $\mu\text{S}/\text{cm}$ to the new average of 41459 $\mu\text{S}/\text{cm}$.

Also, the SDI has been reduced from the previous average of 7.5 to the recent average of 6.5. While the pH still almost the same and have not been affected by the open intake modification.

4.4- Second open intake modification

On 15 October 2012, the five pieces of GRP pipes arrived at site, we discussed with our management and convince them to continue the previous modification and extend the off-shore open intake pipe line from the actual 40 meters to be at 95 m from the shoreline. We extended the previous modification work permission. Everything was prepared and ready in advance in order to quickly finish the modification of the open intake. The marine huge cranes were deployed at site and in sea. The cements base were prepared, treated and coated with specific material, the GRP pipes have arrived at site and ready to be connected, and the divers' team was onsite with all the needed equipments.

On 19 October 2012, we stopped the plant after completely fill the storage tank with produced potable water in order to be in the safe side. The modification has been completed, and the new situation of the intake was as following:

- The off-shore open intake point was situated at around 90 meters from the shoreline
- We have 8-9 meters water column above the off-shore open intake point.
- The off-shore open intake pipe was 12 to 15 meters above the sea ground level.

From 27 October 2012 till 27 November 2012, we enjoyed the perfect running condition, the great water quality at the feed was as following: the SDI was between 5.0 – 5.9 (with an average of 5.5), the conductivity was between 38900 – 41900 $\mu\text{S}/\text{cm}$ (with an average of 40502 $\mu\text{S}/\text{cm}$), the pH was between 7.6 – 8.9 (with an average of 8.1), and the temperature was between 24.4 – 32.1 $^{\circ}\text{C}$ (with an average of 29.1 $^{\circ}\text{C}$). Refer to table 12.

Note: each data mentioned in table 12 is the daily average of four measures (2 in the day and 2 in the night) taken for each parameter; for the conductivity, the average lag was 0.88% with maximum gap of 3.33%; for the pH, the average lag was 1.59% with maximum gap of 5.79% and for the temperature, the average lag was 3.26% with maximum gap of 13.77%.

Date	Sea Water				Feed Water			
	Conductivity	TDS	pH	Temp	Conductivity	SDI	pH	Temp
27-Oct-2012	54,050	32,689	8.28	28.0	39,525	5.43	8.02	28.8
28-Oct-2012	53,825	32,553	8.35	28.8	39,600	5.51	8.25	30.0
29-Oct-2012	54,175	32,765	8.05	26.6	39,625	5.46	7.90	28.0
30-Oct-2012	53,925	32,614	8.25	28.0	39,775	5.42	8.09	29.1
31-Oct-2012	54,025	32,674	8.00	26.2	39,775	5.29	7.83	27.0
1-Nov-2012	53,950	32,629	8.20	27.6	39,800	5.42	7.88	28.7
2-Nov-2012	55,025	33,279	8.00	25.7	40,525	5.65	8.01	26.4
3-Nov-2012	55,500	33,566	8.23	26.3	41,100	5.63	8.05	27.3
4-Nov-2012	54,825	33,158	8.30	27.3	40,875	5.53	8.20	28.2
5-Nov-2012	55,100	33,324	8.35	28.0	41,075	5.71	8.09	29.1
6-Nov-2012	54,925	33,219	8.23	28.3	40,750	5.56	7.93	29.3
7-Nov-2012	54,525	32,977	8.28	28.5	40,600	5.58	8.05	30.3
8-Nov-2012	55,000	33,264	8.30	28.3	40,400	5.51	7.91	29.9
9-Nov-2012	54,900	33,204	8.18	29.6	40,275	5.36	7.98	30.5
10-Nov-2012	55,550	33,597	8.30	29.1	40,450	5.35	8.05	30.4
11-Nov-2012	55,400	33,506	8.18	28.0	41,275	5.55	8.28	30.3
12-Nov-2012	55,050	33,294	8.10	29.2	41,675	5.50	8.25	30.2
13-Nov-2012	55,650	33,657	8.13	29.0	41,100	5.46	8.03	30.3
14-Nov-2012	55,750	33,718	8.33	29.2	41,450	5.49	8.16	30.5
15-Nov-2012	56,000	33,869	8.35	28.8	41,200	5.67	8.31	30.0
16-Nov-2012	55,375	33,491	8.10	28.3	40,850	5.59	8.30	29.8

17-Nov-2012	55,175	33,370	8.40	28.2	41,000	5.69	8.18	29.8
18-Nov-2012	54,600	33,022	8.28	28.2	40,525	5.38	8.23	29.6
19-Nov-2012	54,075	32,705	8.20	27.6	40,250	5.49	8.23	28.4
20-Nov-2012	54,625	33,037	8.05	28.5	40,225	5.37	8.18	29.2
21-Nov-2012	54,575	33,007	8.25	27.7	40,425	5.30	8.20	29.0
22-Nov-2012	54,100	32,720	8.18	26.9	40,200	5.29	8.31	27.8
23-Nov-2012	54,525	32,977	7.98	27.2	40,050	5.69	7.95	28.4
24-Nov-2012	54,650	33,052	8.18	27.6	40,275	5.58	8.00	29.6
25-Nov-2012	53,950	32,629	8.18	27.4	39,625	5.35	8.00	28.9
26-Nov-2012	54,775	33,128	8.28	27.5	40,100	5.33	8.20	29.4
27-Nov-2012	54,475	32,946	8.15	27.7	41,675	5.37	8.04	28.4
Average	54,752	33,114	8.20	27.90	40,502	5.48	8.10	29.14

Table 12: Daily average parameters for seawater and Feed water. Running period from 27 October 2012 till 27 November 2012.

While the pH still almost the same and have not been affected by the open intake modification. We noticed a decrease in the water Temperature (from an average of 30.9°C in the previous case to an average of 29.1°C in this case.

In addition, the SDI has been dropped from the previous average of 6.5 to the recent average of 5.5.

Also, the water conductivity has been slightly reduced from an average of 41459 $\mu\text{S}/\text{cm}$ to the new average of 40502 $\mu\text{S}/\text{cm}$. In fact we were expecting better Conductivity, but in global, the sea water intake was satisfying our demand.

4.5- Third open intake modification

On 25 November 2012, as schedules, our diver was making usual inspection on the protective screen of the intake when he get stopped and arrested by the Coast Guard police. The second day (on 26 November 2012), we received an urgent and important letter from the coast guard requesting HUTA to remove the intake pipe from the sea and replace it near the coast !!!!!

It was impossible to accept such request from technical and logical point of view; we diverted this request to the stakeholder and to the land owner who made their contact and try to convince the Coast Guard security Manager but without success; in fact, the security is the main and essential parameter in all the refinery working zone, and it was no question at all to keep the intake pipe inside the sea unless having approval from the higher coast guard management. Therefore, we received the official request to quickly remove the open intake pipe from the sea and relocate it near the coast (maximum allowed distance from the sea coast was 2 meters!!!!!!). All the previous cost and the future cost will be charged on the stakeholder.

As before, we waited until completely fill all the three water storage tanks, all the technicians, divers, cranes, equipment and labor team were present onsite. On 28 November 2012, we sadly stopped the SWRO plant to start the remove and relocation of the open intake pipe line.

All the GRP pipes have been removed and kept in our store, we tried to keep the cement base (in case we could have the permission in the future to install the intake again), but we have been forced to remove everything and keep the area as it was before our intervention.

With the only 2 meters allowed from the coast line, the maximum sea water depth that we could get is 0.5 to 1 meter; in fact, the GRP intake diameter is 90 cm, at 2 meters from the coast the maximum water column deep is around 0.8 – 1 meter; thus we could not get any deep in the sea water, the GRP intake pipe line was hardly covered by sea water level. With the 900 mm intake diameter, it was like impossible to cover all the open end of the pipe, the pipe looked like floating at the sea water top level; therefore many particles near the beach, sand, small stone and air were able to penetrate with the raw feed water, the intake raw water quality was so bad, especially we noted the elevation of temperature since we are taking the water from the top hot zone of the sea.

Despite the situation and working conditions were too bad, to run the SWRO plant, we have been forced to run the plant by the higher management and the stakeholder in order to avoid shortage penalty and respect his and our commitments and contracts , cover the customers need of potable water and avoid losing the customers.

From 5 to 17 December 2012, we suffered from the worst running condition, the awful water quality at the feed was as following: the SDI was between 7.7 – 11.7 (with an average of 10.37), the conductivity was between 41100 – 53700 $\mu\text{S}/\text{cm}$ (with an average of 47687 $\mu\text{S}/\text{cm}$), the pH was between 7.5 – 8.9 (with an average of 8.2), and the temperature was between 25.3 – 31.2 $^{\circ}\text{C}$ (with an average of 28.7 $^{\circ}\text{C}$). Refer to table 13.

Note: each data mentioned in table 13 is the daily average of four measures (2 in the day and 2 in the night) taken for each parameter; for the conductivity, the average lag was 0.70% with maximum gap of 2.81%; for the pH, the average lag was 1.10% with maximum gap of 2.73% and for the temperature, the average lag was 2.40% with maximum gap of 8.02%.

Date	Sea Water				Feed Water			
	Conductivity	TDS	pH	Temp	Conductivity	pH	Temp	SDI
5-Dec-2012	57,800	34,957	8.50	24.0	53,300	8.43	28.4	11.39
6-Dec-2012	57,725	34,912	8.35	24.2	53,325	8.41	28.0	11.33
7-Dec-2012	57,875	35,003	8.35	25.2	53,250	8.14	29.6	11.22
8-Dec-2012	58,050	35,109	8.33	24.5	53,425	8.17	28.9	11.49
9-Dec-2012	57,550	34,806	8.38	24.4	53,250	8.09	28.4	11.36
10-Dec-2012	57,517	34,786	8.43	25.9	41,525	8.18	30.2	8.00
11-Dec-2012	57,450	34,746	8.58	25.1	41,525	8.20	29.6	8.34
12-Dec-2012	57,775	34,942	8.40	25.1	41,175	8.21	29.5	8.08
13-Dec-2012	57,975	35,063	8.43	22.7	43,950	7.70	26.8	10.28
14-Dec-2012	57,775	34,942	8.40	23.7	45,400	7.95	27.6	10.63
15-Dec-2012	57,200	34,595	8.43	24.7	44,050	8.24	29.1	10.62
16-Dec-2012	56,825	34,368	8.48	24.7	44,375	8.20	28.9	10.65
17-Dec-2012	57,750	34,927	8.53	24.6	51,375	8.21	28.5	11.36
Average	57,636	34,858	8.43	24.5	47,687	8.16	28.7	10.37

Table 13: Daily average parameters for seawater and Feed water. Running period from 5 till 17 December 2012.

Also in this condition, the pH still almost the same and have not been affected by the open intake modification. On the contrary, we observed an immense increase in SDI values from the previous average of 5.5 to the recent average of 10.4.

In addition, and as expected, the water conductivity has been dramatically increased from an average of 40502 $\mu\text{S}/\text{cm}$ to the new average of 47687 $\mu\text{S}/\text{cm}$. In more details, from 5 to 9 December, the average was around 53300 $\mu\text{S}/\text{cm}$, but it has incredibly been improved to 41400 $\mu\text{S}/\text{cm}$ from 10 to 12 December, we were surprised and happy at the same time so have such a good results, but our happiness did not persist for a long time since from 13 to 16 December the conductivity has increased again to an average of 44444 $\mu\text{S}/\text{cm}$.

Or, despite the use of the top surface sea water (normally followed by temperature increase), we observed a decrease in the water Temperature (from an average of 29.1°C in the previous case to an average of 28.7°C in this case. But this decrease of the sea water temperature is basically due to the decrease of the weather temperature during the cold winter month of December.

4.6- Fourth open intake modification

Even at this level of high conductivity, we took the decision to keep it running in this bad condition, but on 17 December 2012 the conductivity reached again the 51400 $\mu\text{S}/\text{cm}$, therefore we directly stopped the SWRO Plant and started the prepared plan B for the intake modification.

The plan B principle consist to create a natural filtration system by using the natural stone from desert and sea; small stone (gravel) has been used to completely cover the intake open end, than it has been covered by the medium stone, finally huge stones have been installed at the opening side of the intake pipe line.

In this situation, and after running the intake pumps for more than 6 hours, we got better raw water quality, big part of sand and particles has been eliminated, and the quantity of sand and particles has been greatly reduced by 80 %. Or we were still facing the problem of the hot water which will affect the conductivity and TDS of the feed water.

From 23 December 2012 till 10 January 2013, we improved the previous worst running condition, the mended water quality at the feed was as following: the SDI was between 9.1 – 10.8 (with an average of 10), the conductivity was between 42000 – 47600 $\mu\text{S}/\text{cm}$ (with an average of 45286 $\mu\text{S}/\text{cm}$), the pH was between 7.5 – 8.1 (with an average of 7.8), and the temperature was between 20.2 – 29.2 °C (with an average of 26.2 °C). Refer to table 14.

Note: each data mentioned in table 14 is the daily average of four measures (2 in the day and 2 in the night) taken for each parameter; for the conductivity, the average lag was 0.60% with maximum gap of 2.20%; for the pH, the average lag was 1.00% with maximum gap of 4.53% and for the temperature, the average lag was 3.50% with maximum gap of 14.48%.

Date	Sea Water				Feed Water			
	Conductivity	TDS	pH	Temp	Conductivity	pH	Temp	SDI
23-Dec-2012	58,575	35,426	8.45	21.4	46,350	7.73	22.6	10.74
24-Dec-2012	57,363	34,693	8.43	21.6	43,888	7.75	27.0	9.83
25-Dec-2012	57,050	34,504	8.37	23.1	44,800	7.67	26.9	9.63
26-Dec-2012	58,080	35,127	8.38	22.5	46,900	7.75	27.3	10.46
27-Dec-2012	58,525	35,396	8.39	20.8	46,975	7.64	23.0	10.33
28-Dec-2012	58,575	35,426	8.41	20.4	46,375	7.90	23.9	10.59
29-Dec-2012	58,150	35,169	8.44	21.1	46,150	7.80	23.5	10.30
30-Dec-2012	57,525	34,791	8.47	23.4	45,625	7.83	26.5	10.25
31-Dec-2012	57,150	34,564	8.46	24.3	45,200	7.73	28.1	10.29
1-Jan-2013	57,000	34,474	8.50	25.5	45,225	7.92	28.6	10.32
2-Jan-2013	56,900	34,413	8.52	25.4	45,225	7.93	28.7	10.12
3-Jan-2013	56,900	34,413	8.43	25.1	45,175	7.78	28.1	9.97
4-Jan-2013	56,925	34,428	8.40	24.6	43,575	7.75	27.6	9.27
5-Jan-2013	56,825	34,368	8.44	24.6	43,375	7.73	27.2	9.56
6-Jan-2013	57,450	34,746	8.49	23.2	45,025	7.80	26.5	10.48
7-Jan-2013	56,825	34,368	8.38	22.9	45,125	7.72	25.7	9.95
8-Jan-2013	56,950	34,443	8.35	22.5	45,050	7.70	26.2	9.60
9-Jan-2013	57,375	34,700	8.49	21.6	45,450	7.86	24.9	9.66
10-Jan-2013	57,575	34,821	8.56	22.0	45,950	7.90	24.0	10.18
Average	57,459	34,751	8.44	22.9	45,339	7.78	26.1	10.08

Table 14: Daily average parameters for seawater and Feed water. Running period from 23 December 2012 till 10 January 2013.

As usual, the pH still almost the same and have not been affected by the open intake modification. On the contrary, we observed a light amelioration in SDI values from the previous average of 10.4 to the recent average of 10, which is still not enough to have the perfect working condition for the plant.

In the other hand, and as expected, the water conductivity has been greatly improved from an average of 47687 $\mu\text{S}/\text{cm}$ to the new average of 45286 $\mu\text{S}/\text{cm}$. The positive impact of this modification have been observed and felt in this amelioration of conductivity. Of course the applied modification is insufficient, but at least it was a step forward in the right direction in order to maximally improve the running condition for the intake and the whole trains of facilities.

As noticed previously, despite the use of the top surface sea water (normally followed by temperature increase), we observed a decrease in the water Temperature (from an average of 28.7°C in the previous case to an average of 26.2°C in this case. The same reason and lucidity used before, this reduce of the sea water temperature is typically due to the decrease of the weather temperature during the cold winter month of January.

4.7- Fifth open intake modification

Despite the little improve of the situation, we did not get upset, the initiated researches and site investigation continued in order to find better solution and try to find other possible modification that may improve the arrival sea water from the intake.

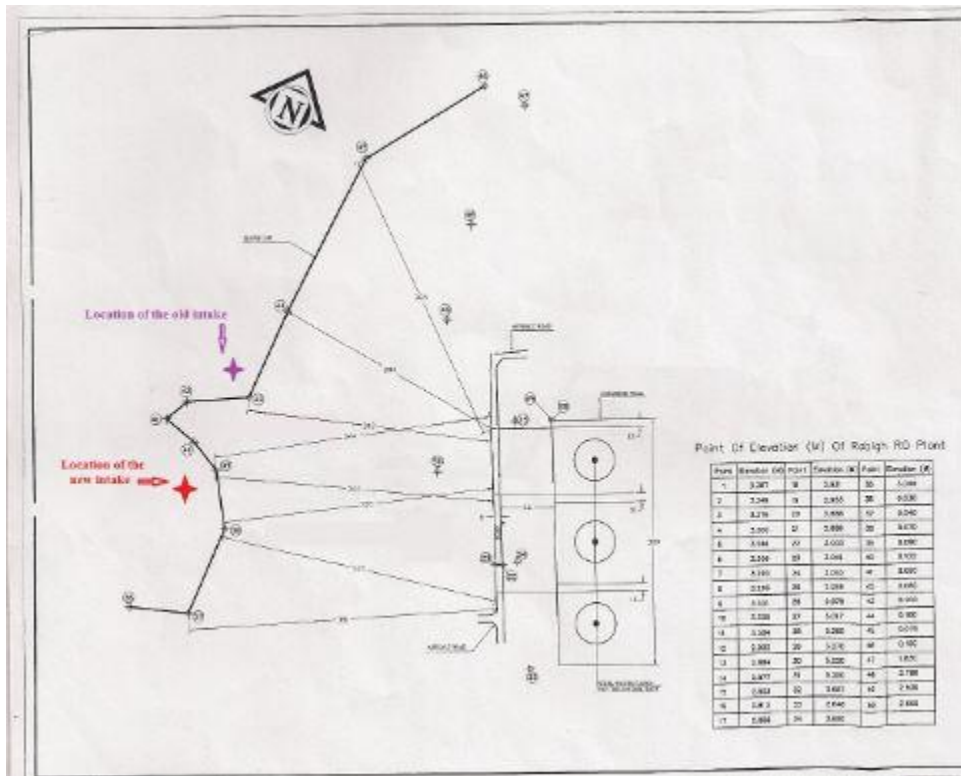
Since HUTA MARINE WORKS department have the biggest dredgers in Saudi Arabia, and since they have the perfect experience to accomplish their work with the best accuracy during the best time, and following our researches, we concluded the solution of modification of the sea ground level at the intake. Meaning that we planned to dredge the sea ground at the intake location in order to make it deeper at the shoreline; in this way we are going to create and copy the situation after the first modification and try to past it near the shoreline.

This decision is costly, but since all the equipment, dredgers, working personal are from HUTA, therefore no direct cost will be charged over the project, specially that the dredger was in Yanbu area (170 km away to the north from Rabigh) and it was planning to move to Dahban main workshop (situated at 150 km in the south of Rabigh), which mean that the dredger will pass by Rabigh.

On 25 December 2012, we prepared the study, with all the positive factors and circumstances, and presented it to the stakeholder and land owner (ARAMCO and Petro Rabigh) in order to get their approve, and later on the approve of the Coast Guard Security department. On 30 December 2012 we get approve from all parties and the work permission has been issued.

The main problem resides in the dredging effect on the marine coast. In fact, when the dredge work finished, the dredging will leave a huge milky water, and this milky water need long time to settle down and may affect wide zone of the coast, not only the dredging area, also the nearby area specially those located in the direction of the sea water currents. For this reason, we took the decision to avoid dredging in the actual zone of the intake, and to switch the dredging to other new zone which will be the new intake.

For our luck, the sea water current direction is south southeast, the shoreline include headland with 86 meters in the sea; our actual intake is located to the north of this headland, therefore if we dredged in the south zone of the headland (the new intake location), the actual intake will not be affected (refer to the drawing No.1), and the SWRO plant will be able to keep running while ensuring the dredging.

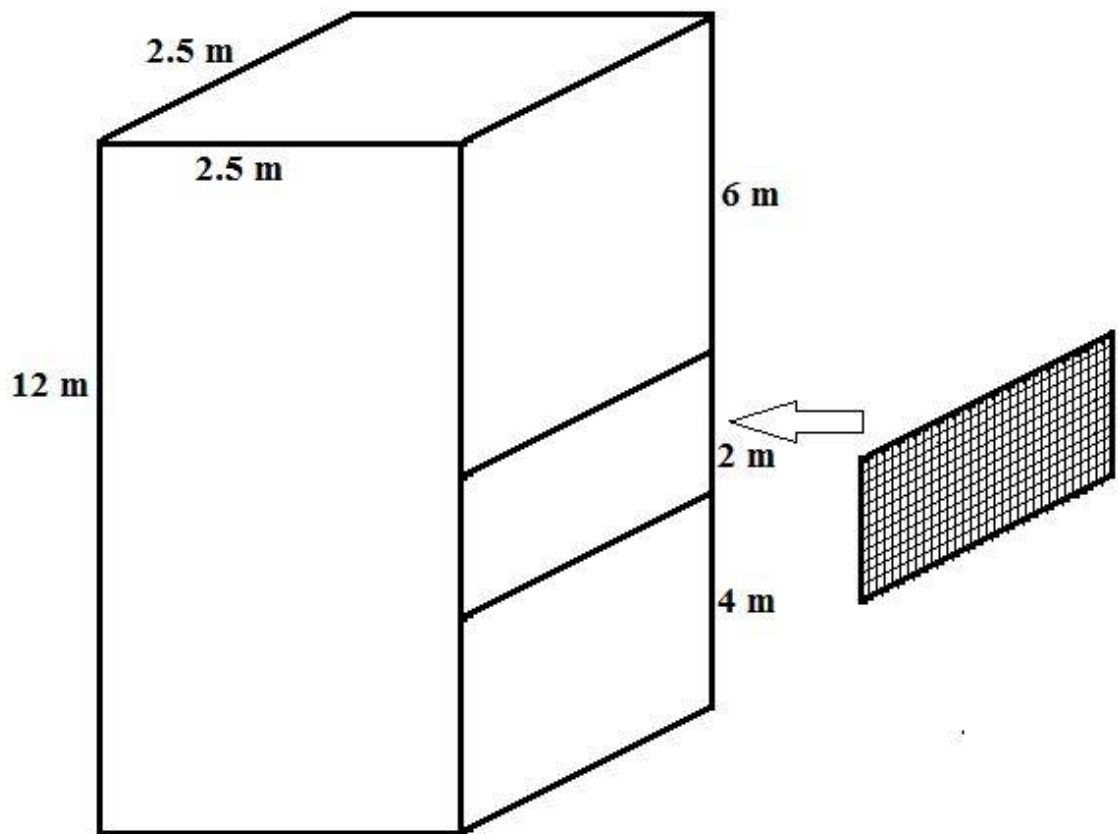


Drawing No. 1: Intake old and new location

The work strategy resides on the following steps:

- The dredger will directly start dredging on 31 December 2012, the area to be dredged is estimated to be a rectangle area, with average dimension around 20 meters * 10 meters. The deep to be reached is 12 meters. This works may take 4 days with the dredger.
- Once the dredging works is completed; we are going to install the 2 huge pumps in the dredging area (new intake area) in order to quickly remove the milky water.

- In order to respect the Coast Guard rules (keep the intake facilities within 2 meters from the coast) and avoid making any pipe structure far away in the sea, we innovated a specific manhole to be installed in the new intake dredged zone. The manhole specifications are: square base of 2.5m*2.5m, elevation of 12 meters, the side facing the sea has a mesh of 2.5m*2m starting from 4 meters at the bottom; the other three sides are totally closed. From the top to the bottom, the side facing the sea (west side) is divided into three sections: first section totally closed 6m*2.5m, second section composed of mesh screen 2m*2.5m (the mesh dimension are 2 cm), third section 4m*2.5m of cement totally closed to ensure enough distance (4 meters) between the sea ground level and the water entry point (Refer to drawing No. 2). The East side (facing the coast) has a circular opening diameter to connect the GRP pipe coming from the pumping room.



Drawing No. 2: The design of the intake new manhole.

- Connect the new manhole installed will be connected to the existing GRP pipes line feeding the intake pump room. ONLY during this step, the SWRO plant needs to be stopped.

On 11 January 2013, once the first three steps have been accomplish and the three storages tank are full, we stopped the SWRO plant, the forth step started, and we tested the new intake on 20 January 2013. We faced water leak at some pipe joints. On 28 January 2013, again we tested the new intake for two days before running the SWRO plant on 31 January 2013.

From 1 to 24 February 2013, we incredibly improve the running condition with the new intake design, the mended water quality at the feed was as following: the SDI was between 6 – 10.6 (with an average of 8.7), the conductivity was between 41700 – 48900 $\mu\text{S}/\text{cm}$ (with an average of 44979 $\mu\text{S}/\text{cm}$), the pH was between 7.7 – 8.4 (with an average of 8), and the temperature was between 20.1 – 28.3 $^{\circ}\text{C}$ (with an average of 25.5 $^{\circ}\text{C}$). Refer to table 15.

Note: each data mentioned in table 15 is the daily average of four measures (2 in the day and 2 in the night) taken for each parameter; for the conductivity, the average lag was 0.70% with maximum gap of 2.84%; for the pH, the average lag was 0.80% with maximum gap of 3.00% and for the temperature, the average lag was 2.30% with maximum gap of 15.90%.

Date	Sea Water				Feed Water			
	Conductivity	TDS	pH	Temp	Conductivity	pH	Temp	SDI
1-Feb-2013	57,000	34,474	8.19	20.4	45,475	7.88	21.6	9.42
2-Feb-2013	57,350	34,685	8.33	17.6	43,450	8.05	26.2	8.16
3-Feb-2013	56,825	34,368	8.24	19.2	43,125	7.98	27.1	7.86
4-Feb-2013	56,300	34,050	8.34	19.7	42,550	7.98	28.0	7.38
5-Feb-2013	56,375	34,096	8.32	20.0	41,925	8.08	27.6	6.69
6-Feb-2013	56,225	34,005	8.26	22.4	41,825	7.95	26.2	6.24
7-Feb-2013	56,175	33,975	8.45	23.3	42,075	8.11	27.3	6.20
8-Feb-2013	56,875	34,398	8.31	22.6	43,625	8.03	26.3	7.62
9-Feb-2013	56,950	34,443	8.22	24.5	43,450	7.93	25.1	8.16
10-Feb-2013	57,075	34,519	8.28	24.3	44,200	8.07	26.7	8.38
11-Feb-2013	57,500	34,776	8.21	24.4	44,350	8.00	26.2	9.04
12-Feb-2013	57,275	34,640	8.27	23.7	44,275	7.98	25.6	9.27
13-Feb-2013	57,875	35,003	8.35	24.1	44,750	8.09	26.8	8.90
14-Feb-2013	57,575	34,821	8.29	24.1	44,875	8.05	26.2	9.26
15-Feb-2013	57,275	34,640	8.24	24.0	44,650	8.03	24.9	9.60
16-Feb-2013	58,050	35,109	8.41	22.8	48,700	8.21	24.1	10.35
17-Feb-2013	57,750	34,927	8.21	21.8	48,450	8.01	21.8	10.15
18-Feb-2013	57,650	34,867	8.20	23.2	48,500	7.85	20.8	10.28
19-Feb-2013	57,100	34,534	8.35	22.7	47,700	8.16	25.3	9.87
20-Feb-2013	57,000	34,474	8.34	22.6	46,350	8.03	24.3	9.30
21-Feb-2013	56,100	33,929	8.31	21.4	46,400	8.08	24.9	9.41

22-Feb-2013	56,375	34,096	8.28	22.1	46,450	8.05	26.9	8.94
23-Feb-2013	55,900	33,808	8.19	22.4	46,550	7.95	25.2	9.07
24-Feb-2013	56,400	34,111	8.35	24.0	45,800	8.07	27.0	8.97
Average	56,957	34,448	8.29	22.4	44,979	8.03	25.5	8.69

Table 15: Daily average parameters for seawater and Feed water. Running period from 1 to 24 February 2013.

With this design, we were able to get the water from the depth sea water (7 to 8 meters) without being far away from the coast line and keeping our self under the rules of the Coast Guard. This has permitted for us to be happy with the great seen improvement; the water SDI has been greatly ameliorated from an average of 10 to the recent average of 8.7. The positive impact of this modification have been noted and felt in this amelioration of SDI. Of course the applied modification is insufficient, but in global it was a big step forward that extraordinary improved the running condition for the open intake.

As usual and since item is affecting the acidity of the water, the pH kept the same level and have not been affected by the open intake modification.

In the other hand, and as against our perspective, the water conductivity has lightly improved from an average of 45286 $\mu\text{S}/\text{cm}$ to the new average of 44979 $\mu\text{S}/\text{cm}$.

Despite the naturally weather temperature increased during February (in comparison with December and January) a decrease in the water Temperature (from an average of 26.2°C in the previous case to an average of 25.5°C) has been observed. This reflects the benefit of the water depth intake point that has been inaugurated.

4.8- Sixth open intake modification

Even that we have made huge progress in term of the water quality, and the parameters analysis showed acceptable results compared to the bad running conditions, but we have remarked that the conductivity did not improved as much as we desired.

Based on the fact that using the gravel and natural stone have greatly improved the conductivity in the forth modification (refer to the paragraph 4.6), we would like to test and try the addition of the gravel and natural stone to the existing manhole. For this purpose, many scenarios were available, but we preferred to use the easiest one which overmuch look like the situation of the forth modification.

Inside the manhole, and just behind the opening screen, we installed the huge stones which have been covered by the medium stones, finally small stones (gravel) have been used.

From 2 Mars to 4 May 2013, we successfully ameliorated the running condition with the new modified intake, the improved inlet water quality at the feed was as following: the SDI was between 6.5 – 7.7 (with an average of 7.3), the conductivity was between 39000 – 44600 $\mu\text{S}/\text{cm}$ (with an average of 43164 $\mu\text{S}/\text{cm}$), the pH was between 7.1 – 8.5 (with an average of 8.2), and the temperature was between 24.2 – 30.8 $^{\circ}\text{C}$ (with an average of 27.6 $^{\circ}\text{C}$). Refer to table 16.

Note: each data mentioned in table 16 is the daily average of four measures (2 in the day and 2 in the night) taken for each parameter; for the conductivity, the average lag was 0.50% with maximum gap of 2.79%; for the pH, the average lag was 0.70% with maximum gap of 2.62% and for the temperature, the average lag was 2.20% with maximum gap of 10.40%.

Date	Sea Water				Feed Water			
	Conductivity	TDS	pH	Temp	Conductivity	SDI	pH	Temp
20-Mar-2013	55,375	33,491	8.45	26.0	41,275	6.88	8.28	29.1
21-Mar-2013	54,925	33,219	8.55	26.1	39,750	6.75	8.32	28.6
22-Mar-2013	55,500	33,566	8.43	25.7	40,775	6.85	8.18	28.1
23-Mar-2013	56,175	33,975	8.55	26.4	39,725	6.78	8.30	28.6
24-Mar-2013	54,875	33,188	8.48	26.0	40,400	6.95	8.23	28.1
25-Mar-2013	55,700	33,687	8.50	25.9	41,175	7.15	8.25	27.7
26-Mar-2013	56,025	33,884	8.45	26.5	41,600	7.04	8.26	28.1
27-Mar-2013	56,275	34,035	8.53	26.4	41,875	6.97	8.26	28.8
28-Mar-2013	55,700	33,687	8.60	26.4	41,650	7.11	8.40	28.6
29-Mar-2013	55,750	33,718	8.55	26.6	41,625	7.01	8.40	29.3
30-Mar-2013	56,375	34,096	8.58	26.9	42,000	7.20	8.37	29.1
31-Mar-2013	56,757	34,327	8.53	26.3	42,550	7.35	8.32	28.6
1-Apr-2013	56,900	34,413	8.58	26.2	42,850	7.30	8.36	28.8
2-Apr-2013	57,025	34,489	8.43	25.1	43,075	7.48	8.22	26.9
3-Apr-2013	56,700	34,292	8.48	26.3	43,350	7.47	8.19	27.0

4-Apr-2013	56,350	34,080	8.35	24.2	43,500	7.46	7.93	26.8
5-Apr-2013	56,450	34,141	8.60	25.6	43,650	7.59	8.40	26.6
6-Apr-2013	56,225	34,005	8.48	25.1	43,775	7.51	8.27	27.2
7-Apr-2013	56,375	34,096	8.43	25.3	43,450	7.35	8.18	27.3
8-Apr-2013	56,725	34,307	8.43	25.7	43,550	7.38	8.13	27.8
9-Apr-2013	57,375	34,700	8.45	25.4	43,900	7.51	8.15	27.3
11-Apr-2013	56,650	34,262	8.40	25.6	44,050	7.57	8.10	27.6
12-Apr-2013	56,750	34,322	8.30	25.1	44,300	7.66	8.00	27.6
13-Apr-2013	56,550	34,201	8.53	26.1	44,100	7.54	8.29	28.3
14-Apr-2013	56,450	34,141	8.40	24.9	44,050	7.54	8.18	26.9
15-Apr-2013	56,425	34,126	8.48	25.3	43,700	7.37	8.18	27.6
16-Apr-2013	56,400	34,111	8.48	25.8	43,900	7.50	8.18	28.0
17-Apr-2013	56,125	33,944	8.45	25.8	43,650	7.55	8.15	27.9
18-Apr-2013	56,425	34,126	8.43	26.0	43,900	7.60	8.13	28.1
19-Apr-2013	56,425	34,126	8.38	26.7	43,950	7.47	8.08	28.5
20-Apr-2013	57,125	34,549	8.43	26.6	44,275	7.57	8.13	28.7
21-Apr-2013	57,150	34,564	8.50	27.2	44,025	7.55	8.20	29.6
22-Apr-2013	56,975	34,458	8.43	27.3	44,150	7.49	8.13	29.2
23-Apr-2013	56,875	34,398	8.33	27.4	44,325	7.42	8.08	28.2
24-Apr-2013	56,725	34,307	8.20	25.8	44,175	7.48	7.98	26.4
25-Apr-2013	56,525	34,186	8.30	24.9	44,025	7.48	8.06	26.8
26-Apr-2013	56,550	34,201	8.30	24.4	44,100	7.54	8.08	26.5
27-Apr-2013	56,400	34,111	8.15	24.1	44,000	7.42	7.90	24.5
28-Apr-2013	56,350	34,080	8.33	24.0	44,000	7.54	8.07	25.0

29-Apr-2013	56,550	34,201	8.35	24.1	44,125	7.38	8.15	26.4
30-Apr-2013	56,550	34,201	8.33	24.0	44,125	7.50	8.08	25.5
1-May-2013	56,650	34,262	8.45	26.4	44,050	7.53	8.10	27.6
2-May-2013	56,400	34,111	8.40	26.9	43,975	7.35	8.10	27.4
3-May-2013	56,450	34,141	8.38	25.0	44,025	7.47	8.01	25.3
4-May-2013	56,230	34,008	8.43	24.6	43,925	7.46	8.10	27.0
Average	56,384	34,101	8.44	25.74	43,164	7.36	8.17	27.6

Table 16: Daily average parameters for sea water and Feed water. Running period from 20 March to 4 May 2013.

As expected, this modification has especially improved the conductivity; with the use of gravel and natural stone inside the manhole, the water conductivity has brightly been ameliorated from an average of 44979 $\mu\text{S}/\text{cm}$ to the new average of 43164 $\mu\text{S}/\text{cm}$.

In parallel, the water SDI has been slightly decreased from an average of 8.7 to the recent average of 7.3.

As expected, the pH kept the same level and have not been affected by the open intake modification.

Finally, the water Temperature has been increased (from an average of 25.5°C in the previous case to an average of 27.6°C). This is generally due to the elevation of weather temperature during the spring season.

Conclusion

This study proved that with the off-shore open intake and respecting the sea water depth intake point, we could get clean water with high quality and almost free from pathogen leading to the best running condition of the SWRO plant, therefore we have smooth running of the whole systems, the recovery rate was around 35%, and we noticed a long life working period of the cartridge filter.

Period	Situation of intake	Point depth	Far from coast	Cond. $\mu\text{S/cm}$	SDI	pH	T $^{\circ}\text{C}$
18-25/09	near coast along with seabed	0.8 m	14 m	43119	7.5	7.9	32
5-18/10	In the depth sea water/6m seabed	3 m	40 m	41459	6.5	7.9	31
27/10-27/11	In the depth sea water/12m seabed	9m	90 m	40502	5.5	8.1	29
5-17/12	Near the coast (30 cm from seabed	0 m	2 m	47687	10.4	8.2	29
23/12 – 10/1	Near coast + gravel and stone	0m	2 m	45286	10	7.8	26
1-24/02	Near coast + manhole	8 m	2 m	44979	8.7	8	25
4/3 – 4/5	Near coast+manhole+gravel+stone	8 m	2 m	43164	7.3	8.2	28

Table 17: recapitulative table for the different situation and modification.

As shown in the recapitulative table 17, the best ever water quality has been taken from the depth water, at a low stable level of 9 meters and as far as possible from the shoreline (in our case 90 meters).

In the other hand, the best water temperature are taken from the depth water, the more we go in the depth sea water, the better is the temperature; we have to pay attention to leave a security distance from the intake point and the sea ground otherwise sand and small particles risk to be sucked.

Finally, the open intake proves one of his great advantages: we are able to interfere and quickly implement solutions for any problem that may occur. In fact, in our case, we have been forced to make six different types of intervention, some include huge work, other include small modification, or, with the positive presence of huge storage tank, the delivery has never been stopped or interrupted.

CHAPTER 2 : THE PRE-TREATMENT

The Pre-Treatment

1- Introduction

1.1- Definition

The need for appropriate pre-treatment to ensure optimum performance of SWRO systems is well documented. The main role of the pre-treatment system is to ameliorate the raw water quality and the requested water volume for the SWRO plant while maintaining stable performance of the whole system. All SWRO desalination units need minimum degree of pre-treatment, but the type and level differ from site to site depending on origin of water, the type of intake and the selected desalination technology. For source water of poor quality, pre-treatment can be a very significant portion of the overall plant infrastructure [WHO, 2007].

In principle, pre-treatment is a form of different degree of filtration – typically, multimedia filters are used to effectively remove solids; additional physical-chemical procedure are applied in order to eliminate the suspended solids (particles, silt, organics, algae ...) and oil/grease available in the raw feed water when membranes are utilized at the end of the desalination process[WHO, 2007].

The configuration of RO membranes makes them very susceptible to a wide variety of organic and inorganic foulants; membrane fouling is the biggest issue and cause problem for most seawater reverse osmosis (SWRO) plants, which reduces operational performance and the expected life of the membranes [Vrouwenvelder et al., 1998]. To mitigate membrane fouling, seawater must be treated before it reaches the RO unit to remove dissolved solids [Meyer S., 2000]; therefore, sufficient, reliable, complex and relatively priced treatment processes are requested at the pre-treatment phase to reduce the rate of biofouling and the frequency of membrane cleaning and to produce superior quality RO feed water that will ensure stable, long-term performance of RO membrane elements regardless of the turbidity variations of the raw water.

No matter what is the level of filtration to be applied, pre-treatment will never be able to totally remove all the danger parameters affecting the SWRO performance, that is why the main objective of this stage is centered to provide the lowest concentration possible of constituents in the raw water that cause decreasing in SWRO performance and loss of production.

1.2 Role of Pre-treatment

Ensuring good operation condition at high level of performance for the SWRO equipment impels the application of expensive pre-treatment; or on the long term study, the additional cost for that will never exceed the capital cost to be paid if such pre-treatment has not been provided.

For membrane desalination facilities the major pre-treatment goals considered in RO plant process design must address: [MEDRC, 2006]

- Control of plugging and colloidal Membrane fouling and scaling
- Control of metal oxide and sulphide Membrane fouling and scaling
- Control of mineral (inorganic salts) scale
- Control of biological activity and fouling: Biofouling by organic materials
- Control of silica precipitation
- Chemical oxidation and halogenation by residual chlorine;
- Chemical reduction of chlorine
- Effects of other constituents such as oil, aquatic organisms and heavy metals.

1.3 General description of common Pre-treatment

As mentioned before, for SWRO plants, the essential is treating the raw water to protect the main two expensive items: the High Pressure Pump (the main heart of the plant) and the Membranes (the highest filtration technology); the latest is safeguarded by the elimination of contaminants and the control of biofouling on membrane superficies. The first filtration ensure the elimination of suspended solids, lessen the pH help sheltering the membrane and controlling salts precipitation, finally and most important, dosing the anti-scalant inhibitors to stop any membrane fouling. Sterilizer (derivatives of chlorine, UV or Ozone) is introduced to kill microorganisms, bacteria and algae before causing microbial growth, the residual sterilizer must be neutralized before reaching and damaging the sensible membranes.

1.4 Type of Pre-treatment

Most of the applied SWRO pre-treatment are an assembly of the sequence: dosed chemicals (disinfecting agents, coagulator, acid ...) + sand filters + cartridge filters. Or recently, many of plants start substituting the conventional pre-treatment of low efficiency by the new priced technologies of membrane based pre-treatment in order to ameliorate the feed water quality and reduce the deterioration of the costly membrane (figure 4).

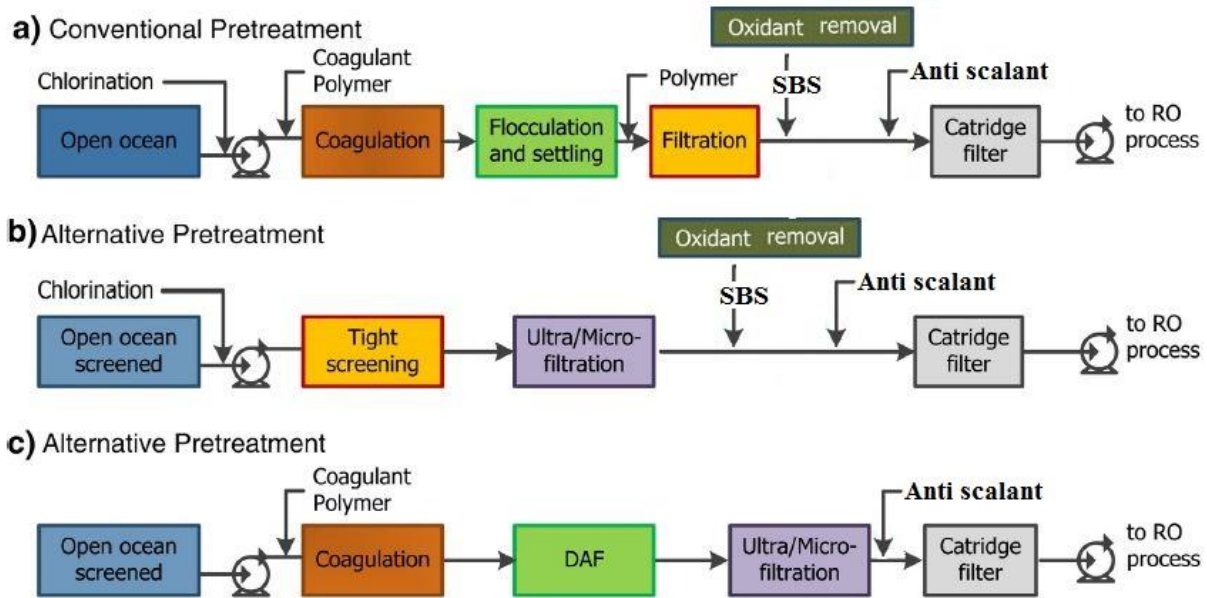


Figure 4: Type of Pre-treatment [Missimer et al., 2013].

The type of pre-treatment determine the size of particles allowed to pass through out; figure 5a and 5b shows the size and the type of bacteria, Virus, Colloids, Suspended solids and others that could be blocked using each type of filtration.

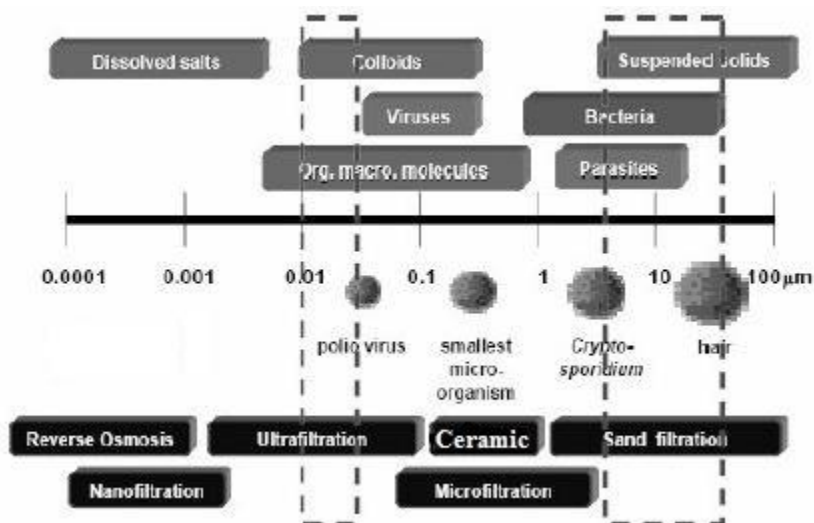


Figure 5a: Type of pre-treatment and particles sizes [Wolf & Siverns, 2005].

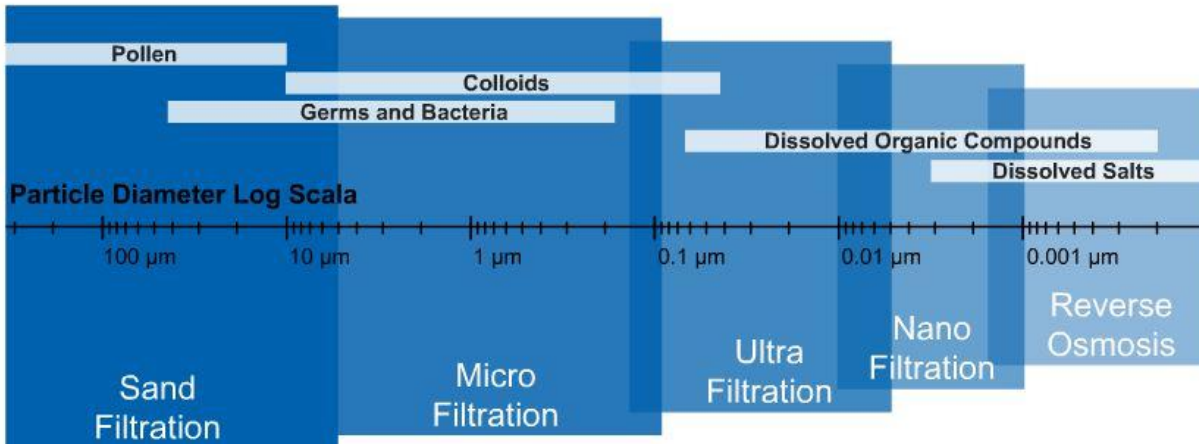


Figure 5b: Type of pre-treatment and allowed particles.

1.5 The SDI

Generally the pre-treatment processes coupled with the use of chemicals target to ensure that filterable materials are eliminated to reach low quantity of suspended solids and silt in the feed water, which is tested via silt density index (SDI) parameter. SDI rates of the feed raw water are indicative of future membrane fouling tendency. Generally suppliers of RO membranes usually require feed water with an SDI-15 (15 minute Silt Density Index) of the feed to the RO to be less than 5, and generally recommend the SDI-15 should be less than 3 in order to maintain steady and predictable performance. These reduce troubles raised by suspended solids plugging the brine spacers in the RO membrane unit.

Procedure for Measuring Silt Density Index (SDI)

The SDI rate is the wide used method for detecting raw water quality in SWRO facilities. His principle is based on needed time to filter a volume of feed water through a 0.45 mm filter pad at a feed pressure of 30 psig.

1.5.1- Test Equipment Set Up

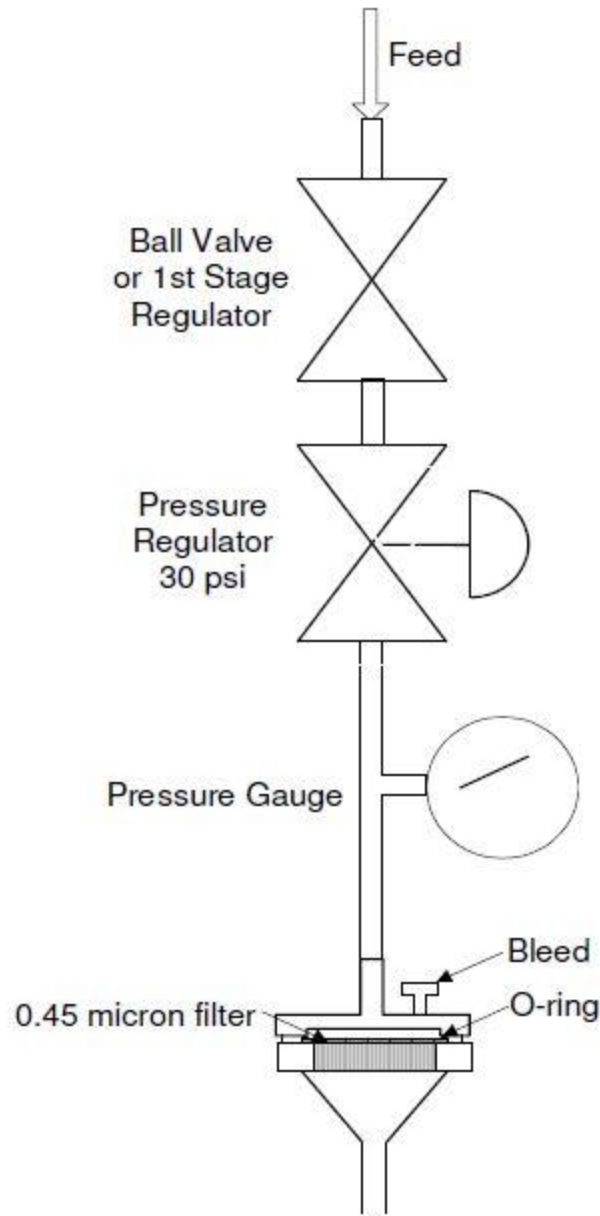


Figure 6: SDI kit details [www.membranes.com 2013].

1. Assemble the test equipment as per figure 6.
2. Locate a sample tap on the feed water piping and install the test equipment.
3. Adjust the pressure regulator to 30 PSI with a filter pad installed. Use a fresh filter for the actual test.

Note: For best results:

- Use dull tweezers when positioning the filter to prevent puncturing the filter.
- Ensure that the O-ring is clean and in good condition, and is properly positioned.

- Avoid touching the filter with fingers.
- Flush the apparatus to remove any contaminants that may be held within it.

1.5.2- Test Procedure

1. Take the temperature of the feed water. The temperature should not vary more than + 1 °C between the start and end of the test.
2. Bleed any entrained air in the filter holder. Depending on the model of the filter holder, either open the bleed valve, or loosen the filter holder while cracking the ball valve. Then close the bleed valve or filter holder.
3. Place a 500 ml graduated cylinder under the filter to measure the amount of water that passes through the filter.
4. Open the ball valve fully, and measure the time required to collect 100 ml and 500 ml* from the time the ball valve is opened. Record these times, leaving the valve open and letting the flow continue.
5. After 5 minutes, repeat the time measurement required to collect 100 ml and 500 ml samples. Repeat again after 10 and 15 minutes of elapsed time.
6. If the time required to obtain a 100 ml sample is greater than about 60 seconds, pluggage will be about 90%, and it is not necessary to continue the test.
7. Measure the water temperature again to ensure that it did not vary by more than 1 °C from the initial temperature.
8. After completing the test and disconnecting the apparatus, the filter paper may be saved in a plastic bag for future reference; in fact it may help to determine the type of suspended items present in the feed water (figure 7).

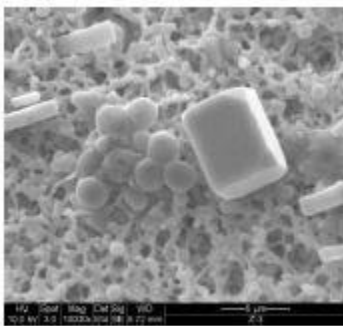


Figure 7: Bacteria, Mineral, Salts and Shell fragment on SDI filter paper [Wolf & Siverns, 2005]

1.5.3- Calculations

$$SDI = P30 / T_t = 100 * (1 - T_i / T_f) / T_t$$

where SDI = Silt Density Index

P30 = % pluggage at 30 psig feed pressure**

Tt = Total test time in minutes (usually 15 minutes, but may be less if 75% pluggage** occurs in less than 15 minutes).

Ti = initial time in seconds required to obtain sample.

Tf = time required to obtain sample after 15 minutes (or less).

NOTES

* Time to collect 500 ml should be approximately 5 times greater than the time to collect 100 ml. If 500 ml collection time is much greater than 5X, SDI should be calculated using 100 ml collection times.

** For accurate SDI measurements, P30 should not exceed 75%. If P30 exceeds this value, re-run test and obtain Tf at a shorter time, (T).

Most of SWRO desalination plants operate successfully with well designed, maintained and operated conventional pre-treatment systems [Galloway M. A. and Minnery J. G., 2001]. For example, IONICS Company owns and operates a plant in California that has run for eight years without the RO membranes needing to be cleaned [Prato et al., 2000].

Other SWRO pre-treatment designs have been applied in many circumstances. Using very well established subsurface intakes, cartridge filters alone are appropriate to conserve the membranes. For other open intakes having high suspended solids (example: estuaries into the seawater or in a port), supplemental pre-treatment steps, such as clarification, should be applied.

1.6 Bad effect of pre-treatment

All previous experiences and most of operational SWRO plants confirm the high importance of upstream pre-treatment of feed sea water, the most this step is reliable, the best efficiencies in operating the RO and the better water volume is produced on long term.

It is substantial to keep high performance of the pre-treatment process to produce satisfactory water quality for the service intended. Most of desalination frustrations are due to inappropriate and unreliable pre-treatment process that negatively affect the SWRO performance; in fact, the failure source maybe in design or in ineffective performance of the pre-treatment. Experiences prove that bad fluctuations in the performance of a pre-treatment process lead to solids causing more brine spacer fouling including elevated rates of membrane plugging, additional frequency of membrane cleanings, reducing the recovery ratio, increased pressure drop on the concentrate side of the membrane, high operating pressure, poor product quality, reduced membrane life and reduced plant productivity [WHO, 2007]..

From chemical point of view, if the inadequate or overdose / low dose of chemicals have been injected into the conveyor pipes feeding the membranes, irreversible elevation in the Trans membrane pressure (TMP) may occurs that cause increase in electric consumption, additional frequency of membrane cleanings, decrease the membrane life, and overall elevation in the SWRO operating and maintenance costs.

Finally, the necessity injection of chemical (Chlorine derivation, coagulants, flocculants, antiscalants, Lime ...) during the pre-treatment process imposes the precipitation of residuals

formed after chemical reaction. These residuals have a potential effect on the marine environment and maybe on public health.

1.7 Water Quality sustainable maintain

In order to maintain the sustainability of the water source quality, the choose and preservation of the source are the key items to evade pollution of raw feed water by certain organics, surface runoff, ship discharges, and chemical and sanitary waste outfalls near the intake to the desalination plant [WHO, 2007]. When contaminations take place, further costly pre-treatments should be adopted.

In some special cases, source raw water is affected by periodic or seasonal surges producing high turbidity and conductivity, it may be necessary to adopt other filtration technique; for example adding settling basin before the filtration train.

2 Major Type of pre-treatment

Since the start of the RO desalination technology, the most used pre-treatment filtration technique was the conventional pre-treatment filtration that include the use of media filtration (from 1st stage to multi-stage media); with times, regarding the faced problem of water quality during operation, and to adapt with the different type of the raw water, more filtration technologies has been introduced and were commercially available for use as RO pre-treatment [MEDRC, 2006]:

- Mixed or Dual Media filtration
- Precoat filtration
- Bag filtration
- Microstraining
- Microfiltration (MF)
- Ultrafiltration (UF)

2.1 Conventional Pre-treatment

Usually Sea water RO desalination plants with conventional pre-treatment mainly consist of: a sea water intake system, break-point chlorination, acid addition, followed by a single- or double-stage sand filtration [Wolf and Siverns, 2005]. The sand filtration could be done in steel vessels under pressure or via gravity inside big concrete or steel tank(s), this filtration is done by different types sand derivations. The sodium bisulfite (SBS) is dosed before the HPP to ensure the removal of the oxidant elements remaining in the water feed, antiscalants are also dosed to forbid any precipitation or scale formation on the membrane superficies. The last stage of the pre-treatment consist of using very fine filtration via cartridge filter (some designer prefer the use of bag type guard filter) equipped with mesh size staring from one up to ten microns (generally 5 microns are the most used) to protect the main RO system (HPP and membranes).

Reference to raw water chemical and/or physical quality, another techniques maybe used like: rotating screens for coarse pre-filtration, inline coagulation, and addition of a flocculation aid [Wolf and Siverns, 2005].

During operation, the sand filters ensure the removal of most coagulated particles (organic or inorganic base) in addition to the huge sized colloidal material, thus after hours of operation spaces between the sand derivations particles may be plugged, resulting in pressure drop. For this reason, the sand filter media should be backwashed periodically at least once a day or when a preset differential pressure across the filter is reached. The back wash process uses filtered water (stored in different back-washing tank(s)) and air, water are pushed by back-washing pump(s) and air by blower.

For the Cartridge filters, the recurrence of replacement of cartridges relays on the feed water quality and the performance of the pre-treatment previous sections and extends from every ten days to ten weeks.

2.1.1- Advantage of Conventional pre-treatment

Most of the conventional pre-treatment systems, accompanied with chemical addition, produce feed water of an acceptable quality when properly tuned, operate and controlled, and with good raw seawater quality.

The major advantages are briefly listed below:

- Low construction cost ; if compared to the other techniques
- Long life of the filter body and the media used for filtration: if well maintained, the conventional filtration may be in service for around 20-30 years
- High temperature resistance; due to it inorganic material (mainly from sand), the conventional filtration is able to work under the high temperature and also can handle the different variation of temperature.
- Robust; the sand is generally well known to handle the pressure therefore it is robustness
- Chemical resistance; with the addition of different kind of chemical mentioned above, the filtration system must resist to the added chemical, not all material could handle the chemical and stay inert, or the sand is well known as inert to most of the used chemical during pre-treatment phase.
- Easy cleaning operation (back wash) and no need for chemical during back wash

2.1.2- Disadvantage of Conventional pre-treatment

The key success of the conventional pre-treatment is the balanced adjustment of the chemical addition depending on the raw water quality. As long as the raw water quality is stable, the conventional pre-treatment will ensure positive treated water quality for the membranes. However, the raw water quality is vulnerable, changes in water quality may occur leading to upset results that are detrimental to the operation of the RO. Accordingly, it is not constantly sure that well-tuned conventional pre-treatment assembly will be able to meet the 15-minute silt

density index levels (SDI-15) recommended by the RO membrane manufacturers; generally between three and five.

There are several major disadvantages of a conventional pre-treatment which contribute to higher rates of RO membrane fouling and shorter RO membrane expected life including [Wolf Peter H. and Siverns Steve, 2005]:

- The environment condition could cause changing of raw water quality which gives rise to significant fluctuations of the quality of RO feed.
- Difficult to achieve a constant SDI-15 < 3.0 especially during high turbidity feed water conditions.
- Low removal efficiency of particles smaller than 10-15 microns: suspended solids, germs and bacteria remain in the effluent.
- The possibility of breakthrough during filter backwash
- Carryover of high concentrations of colloidal particles immediately following a filter backwash.
- Coagulant impact on RO membranes
- Moderate regeneration rate; in fact, even after the back wash, it shows limited removal of iron and manganese resulting in accumulation inside the filter body.

2.2 Polymer Membrane Filtration

Over the last twelve years, hollow fiber membrane technologies have been worldwide adopted in water pre-treatment process for potable/drinking water production. By 1999, over 200 mgd (million gallons per day) of installed capacity was in operation [AWWA, 1999]. As a result they are being forecasted for future SWRO desalination facilities and for adjusting upgrades to operating conventional RO pre-treatment facilities. Recently, membrane filtration started to be selected for pre-treatment to SWRO, especially in sites where sea open intake feed water contain high turbidity and are difficult to be treated and for the treatment of the much polluted industrial liquids.

Hollow fiber membranes for water treatment may either be Microfiltration (MF) or Ultrafiltration (UF) membranes. The fibers are typically 0.5 - 1 mm diameter [Galloway and Minnery, 2001]. The Pore Size is 0.05-0.5 micron for the MF membranes and 0.001-0.1 micron for the UF membranes. Thousands of hollow fibers are roped into a membrane element. At either one or both ends of the membrane element, the fibers are potted in epoxy. Typical membrane materials include polysulfone, PVDF, Cellulose acetate, polypropylene, polyacrylonitrile, polyethylene and polyethersulfone [Galloway and Minnery, 2001].

At present the following types of Membrane filtration devices are commercially available in several common geometries [Wolf and Siverns, 2005]:

- immersed hollow fiber;
- immersed plate membranes;

- pressure-driven capillary;
- pressure-driven spiral wound membranes.

Of these, the most commonly used in water treatment are the capillary, hollow fiber and spiral wound [MEDREC, 2006]. Generally the applied pressure are below 2.4 bar (35 psi) with typical transmembrane pressures of 0.7-1.9 bar (10-28 psi). The applied pressures for spiral wound slope to high range.

The manufacture delivers the membrane filtration units with full or semi-automatic controls devices; also the follow fiber racks are equipped with on-line testing modules.

2.2.1- Advantage of Membrane Filtration

Most probably, Membrane Filtration is adopted in areas being subject of huge variations in the feed raw water quality imposing difficult to handle bad effect on conventional pre-treatment; counter to conventional pre-treatment, Membrane Filtration technologies benefit from its particularity and act as physical barrier to particles and colloidal material; under this operation condition, SWRO plants operate with good water quality and constant flows. This will be translated in the high performance of the desalination plant, raising in water productivity and lowering the life time costs.

The major benefits are briefly listed below:

- Small size: Membrane Filtration assembly uses less than 50 % of the spaces used for conventional pre-treatment; this considerably helps reducing the installation cost. It means that these technologies are more favorable where area is restricted or where civil works are costly.
- Low Power consumption: These new membrane technologies need low electrical load and consume less electricity; in the other hand, working with high water quality, the RO will be more relaxed, biofouling will be radically decreased the same as membrane cleaning .In general, SWRO electrical consumption will be reduced.
- Low chemical usage: conventional pre-treatment assembly consume huge quantities of chemicals: Chlorine derivatives for disinfection, acids to reduce pH, Lime to minimize the turbidity, specific additives for coagulation or flocculation; although, depending on the circumstance, more chemical may be imposed for the SWRO. Conversely, chemical dosing is eliminated or significantly reduced for Membrane filtration systems, which help avoiding the risk of overdosing.
- High and stable filtrated water: During storm calamities and algae blooms, the feed water quality will dramatically deteriorated including extremely increase in suspended solids and turbidity. Or Membrane filtration pre-treatment excises most of suspended solids, precludes fouling and plugging of the brine spacer and maintains feed water quality regardless of inlet water turbidity and quality fluctuations (figure 8). Once large variations in raw water quality occur, the sophisticated membrane automatic systems will offset by increasing frequency of backwashing.

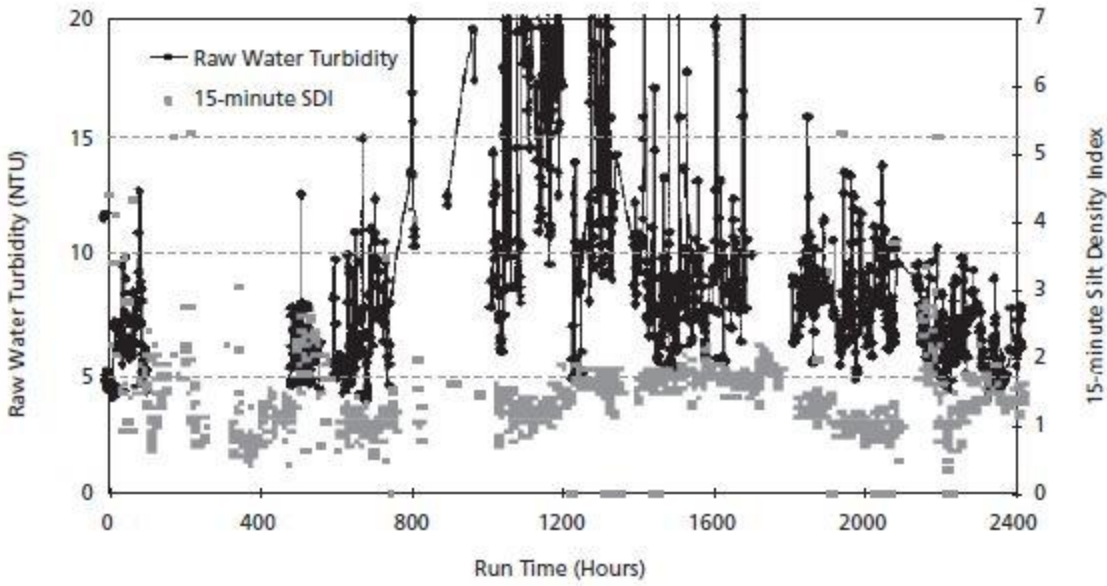


Figure 8: Feed Water Turbidity v/s filtrate water quality for membrane filtration [Galloway and Minnery, 2001]

- Operator: reduce the demand of operators; in fact, during storm calamities, a conventional pre-treatment will impose operators to test the feed water quality and adjust chemical dosing accordingly every few hours, while Membrane Filtration automatic systems only require operator presence for a few hours per day.
- Lowering the needed membranes in RO system: higher filtrated water quality induct higher SWRO operating flow, thus the needed number of membrane will be reduced, including fewer pressure vessels and manifolds, and finally resulting in lower total water cost.
- Removal of bacteria: For potable water applications, hollow fiber membrane systems can guarantee removal of bacteria such as *giardia* cysts and *cryptosporidium* oocysts [Wang et al., 2010] because the safety of the system has been tested, which reduce biofouling and blockage of the RO brine spacer.

2.2.2- Disadvantage of Membrane Filtration

Even the huge advantage of the Membrane Filtration and the world wide growing use, many weak points are present and have been registered during operation as listed below:

- Temperature limit: the Membrane Filtration are limited to 30°C, other techniques are limited to 40°C; or in the arid and high temperature area (like Saudi Arabia and most of Gulf country), the temperature may reach 50 or 55°C in some places. This maybe the major problem for the application of the Membrane Filtration technique in such area.
- Limited resistance: each cleaning of the Membrane results in reducing of lifetime of the membrane and reducing in the effluent quality. Therefore the Membrane filtration is not able to realize long term stable operation process.
- Sensitive material: the used materials (general type of polymer) are sensitive against sunlight, drying-out and high pressure back flashing; therefore, it requires high maintenance effort. In Saudi Arabia, a SWRO plant was designed to have the Membrane Filtration technique at the pre-treatment, the UF membrane were purchased on July 2008, due to their high sensitivity, a special protection against the sunlight, higher temperature (more than 40°C) and from drying-out (figure 9).



Figure 9: Protection of UF membrane.

After six months (January 2009), intensive ex-situ cleaning took place, disconnection of membrane units has been done using truck crane (figure 10) to lift the modules into external cleaning tanks.



Figure 10: Membrane removal for external cleaning.

On June 2009, after one year of operation, due to high fouled and blocked membranes (figure11) and no possibilities of membrane regeneration (figure 12 and 13), the membranes have been replaced.



Figure 11: Damaged membrane to be replaced.



Figure 12: accumulation of sludge and hairs between fiber bundles due to faulty pre-treatment in the Hollow fiber membrane.



Figure 13: Sludge blocking between the plates due to faulty aeration system in the Flat sheet membrane.

- Despite the fact that Membrane Filtration systems have higher principal price with comparison to conventional pre-treatment technologies, but on long operation term, membrane technologies are less costly and more reliable, with the exception suffers of the extremely unplanned high operation cost. However, when circumstances occur, traditional pre-treatment are forced to adopt additional treatment steps (additional clarifiers, flocculation basin ...) including additional pre-treatment cost for the conventional pre-treatment, in this case, the cost difference between the two technologies is almost trivial [Van Hoof et al., 1999]. In the other hand, extensive application of hollow fiber membrane filtration for potable water production has led to the costs of this technology coming down to the point where it is sufficiently cost competitive to be evaluated for SWRO pre-treatment [Murrer and Rosberg, 1998].

2.2.3- UF advantage over MF

UF has been found to have as many benefits as pre-treatment to RO systems [Von Gottberg and Persechino , 2000]. Moreover, in some zone characterized by very bad raw water till a point that SWRO is counted as impracticable, UF pre-treatment reverses the situation and permits the employment of SWRO desalination plants, and has been assured in environments of much more difficult raw water; for all previous reasons, UF membrane technologies are being widely selected in the design of new SWRO desalination plants and for retrofit upgrades to existing conventional RO pre-treatment systems [Glueckstern et al., 2002].

Due to the presence of very fine colloidal silica in many seawater sources [Van Hoof, 2000], UF is likely to be a better choice than MF for SWRO pre-treatment. In fact, given appropriate pore size selection UF is considered to be the best choice for pre-treatment of seawater that contains colloidal silica [Pearce et al., 2003].

Finally, the UF membranes technologies typically generate excellent water quality with an SDI-15 less than 2 (and often below 1).

2.3 The Ceramic Filter Technology

The Ceramic Flat Membrane (CFM) systems combine the advantage of an inorganic filter and submerged flat membrane filtration [Juffali, 2009].

The CFM system can be used for drinking water application, waste water treatment, as beverage filter and for the separation of oil and water.

The CFM contains ceramic coating slurry based on nanoparticles (α -Al₂O₃ / TiO₂ / ZrO₂) with specific separation characteristics.

The outside layer of this asymmetric membrane is a filter active layer (figure 14); many numbers of membranes are arranged together to form the filtration module, the filtration module will be a part of the filtration unit (Figure 15).

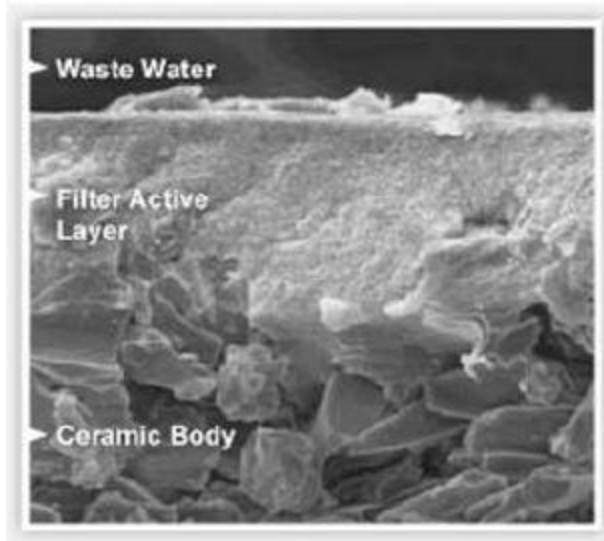


Figure 14: Layer of the CFM [Juffali, 2009].

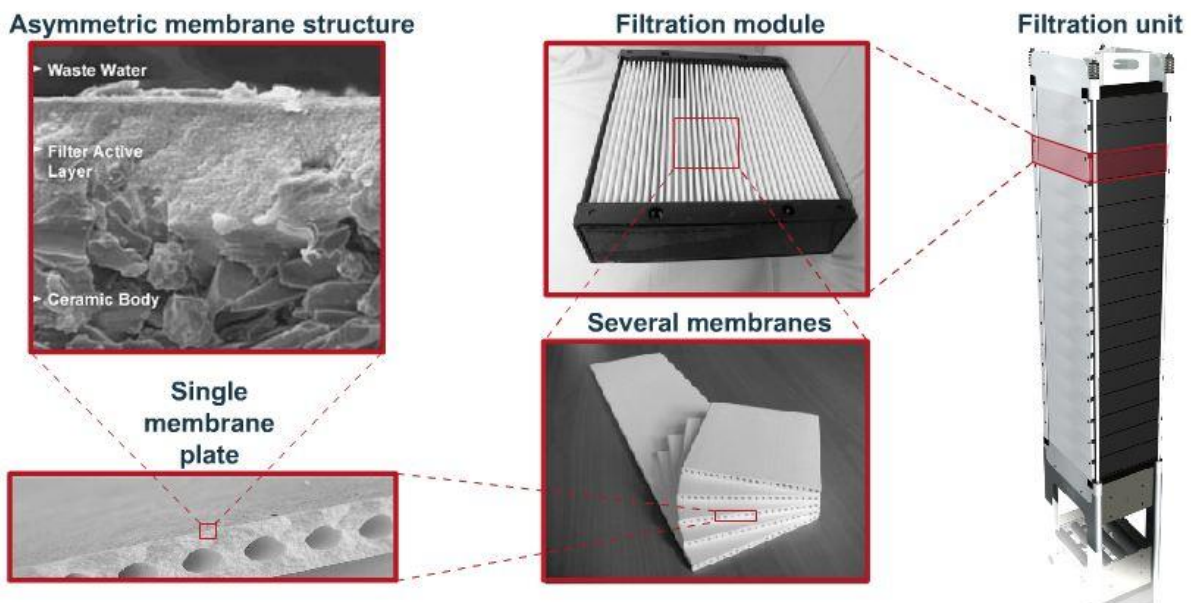


Figure 15: Construction and Module design of CFM [Juffali, 2009].

The filtration mode process: the sea water and its particles will be in direct contact with the outside active layer of the CFM, due to the small pore diameter, only the water molecules will be able to migrate and penetrate through the Filter active layer to reach the permeate channel (Figure 16).

Fouling during filtration mode

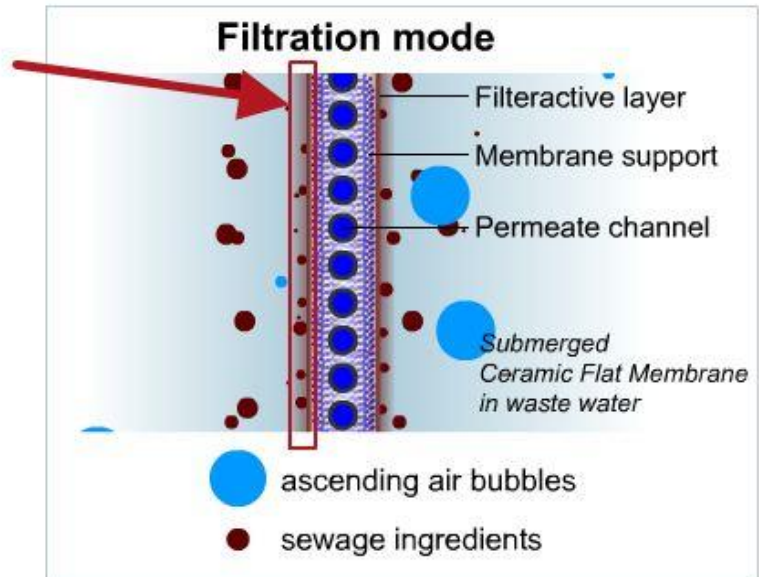


Figure 16: Filtration mode of CFM

During the filtration process, fouling of small particles will start to occur on the outside active layer, that is why the CFM are equipped with Automatic Detergent Assisted Back flushing which will ensure the flaking of the fouling particles using subsequent high pressure back flushing (Figure 17 & 18).

Fouling during filtration mode

Start ADAB - Automatic Detergent Assisted Backflushing

Specific flaking of fouling with subsequent high pressure backflushing

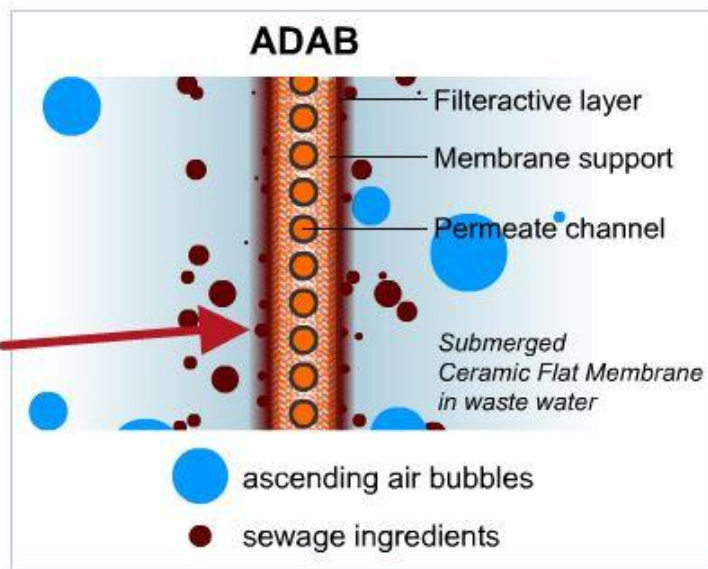


Figure 17: Automatic Detergent Assisted Back flushing of CFM

Fouling during filtration mode

Start **ADAB** - Automatic Detergent Assisted Backflushing

Specific flaking of fouling with subsequent high pressure backflushing

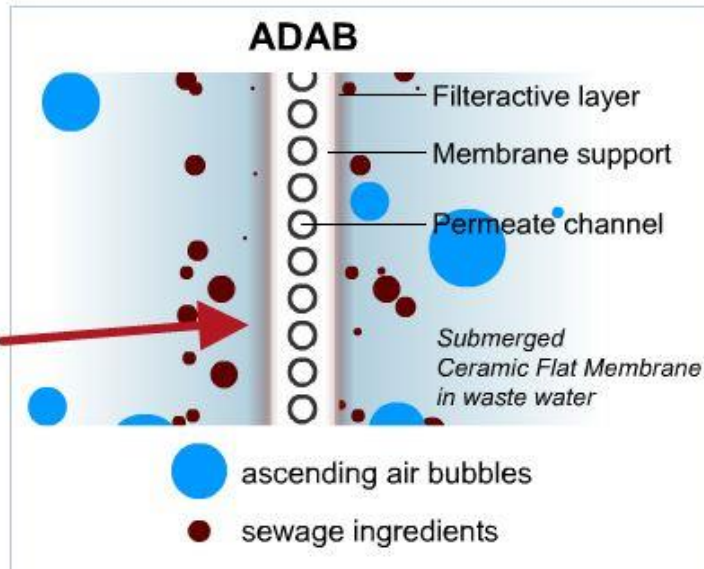


Figure 18: Automatic Detergent Assisted Back flushing of CFM – cleaning phase

In addition to the previous system, the CFM is equipped with an Automatic Mechanical Cleaning: during this process the outside active layer will be continuously cleaned by plastic particles (Figure 19).

AMC - Automatic Mechanical Cleaning

Continuous surface cleaning during filtration by plastic particles

Permanent prevention of surface fouling

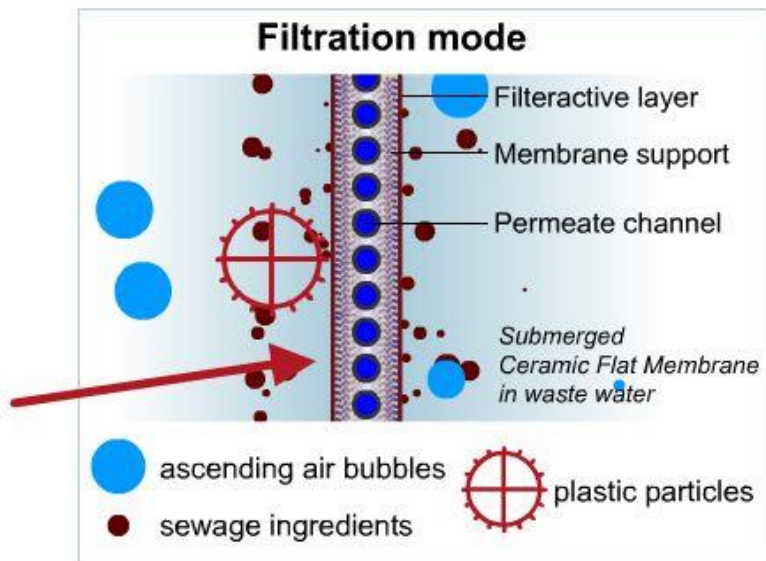


Figure 19: Automatic Mechanical Cleaning mode of CFM

Process description of CFM pre-treatment for the RO Plant:

The CFM systems use the ozone (highly efficient oxidant) filtration solution in order to oxidize and remove all inorganic and organic constituents of water. In fact, before the water

enters the filtration tank, an air ozone mixture is injected into the piping system by a venture nozzle. A circulation pump generates an optimal mixing inside the tank and realizes maximum ozone utilization (Figure 20). Due to ozonation, all organic and inorganic dissolved ingredients existing in the water will be oxidized into particular solids.

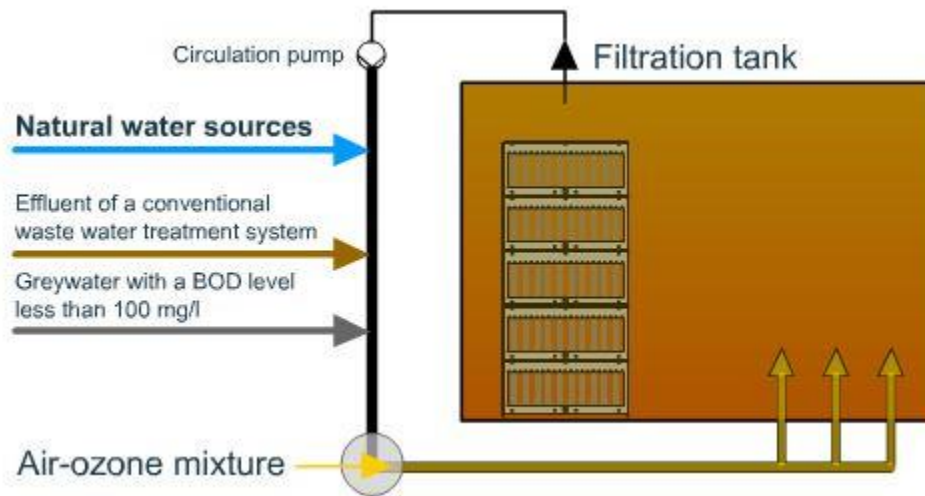


Figure 20: Ozonation Process for CFM

The CFM completely separates germs, bacteria, algae and suspended solids (particles) from the treated water. Therefore the effluent is characterized by an extremely low concentration of organics and minimized level of inorganic solids, leading to rarely blocking, biofouling and scaling potential for the subsequent reverse osmosis plant.

Due to the superiority of the new membrane generation, the Ceramic Filter Membrane offer the following advantages:

- Resistance against high temperature, stable operation up to 40-60°C
- Extremely Robust filtration material that could handle the high oxidation level of ozone.
- High effluent quality due to high separation efficiency: free of iron and manganese, free of Suspended Solids, real physical barrier for germs and bacteria
- High resistance against chemicals and aggressive media like the plastic particles used for the Automatic Mechanical Cleaning.
- Easy to clean due to high pressure backflush options combined with fully automatic membrane regeneration strategies; the CFM show no irreversible fouling or scaling effects due to combination with the ozonation step. Merely some cake layers could be observed on the membrane surfacesm but this cake layer could be easily removed by short high pressure back flushing cycles.
- Reduction of operation cost due to the reduce of chemical.
- Increasing of capacity and efficiency while maintaining the sustainable water quality

The major disadvantage of the CFM systems is the high price of the module and the need of ozonation and chamber for the ozone reaction.

2.4 Pre-treatment technologies comparison

The following tables 18 provide a comparison of the major differences, water quality, cost ... and the impact of the three different types of pre-treatment technologies on an RO based sea water desalination plant.

	Conventional Pre-treatment	Polymer Membrane Filtration	CFM filtration
Material	Sand filter Media	Polymer	Ceramic
Turbidity	0.5 NTU	< 0.1 NTU	< 0.1 NTU
SDI-15	3-6	< 3 (MF) and < 2 (UF)	< 2
Water Quality	Fluctuating quality	Consistent, reliable	Consistent
suspended solids	Not removed	Removed	Removed
Bacteria	Not removed	>5 log removed	>5 removed
Giardia	Not removed	>4 log removed	>4 removed
Virus	Not removed	>4 log removed	>4 removed
Life time	25 – 30 years	3 – 8 years	9 – 20 years
Cartridge filter	replaced after 2-8 week	Often no needed	No needed
average RO flux	14 lmh	18 lmh	50 – 70 lmh
SWRO replacement rate	14% per year	10 % per year	8 % per year
SWRO cleaning	4-12 times/year	1-2 times/ year	0.5 – 1 / year

Table 18: Process and water quality comparison for pre-treatment.

Life cycle cost comparison

Technical superiority of the pre-treatment capabilities of CFM and UF/MF membranes over conventional coagulation and sand filtration is clear [Glueckstern P.and Priel M., 2003]. The economic comparison of the two technologies depends on a large number of parameters

including, most significantly, raw seawater quality, membrane replacement rates and utility costs.

Costs for three comparable systems are presented based on the following assumptions:

Sea Water TDS = 41000 ppm

Raw Water quality : poor, variable turbidity

SDI-15 of raw water: immeasurable

Power Cost: 0.013 SR/KWH

Interest rate: 5%

Plant life = 20 years

For conventional pre-treatment, in-line coagulation + 3 types of media filtration

	Conventional Pre-treatment	Polymer Membrane Filtration	CFM filtration
Investment Cost (figured numbers in SR/m ³ /day)			
Price per m ²	140-350 SR	200-500 SR	600-700 SR
Required area	200%	100%	25-30%
Installation cost	54 SR	55 SR	25 - 35 SR
Operation cost (figures in SR/m ³)			
Process & cleaning	0.013 SR	0.011 SR	0.007 SR
Maintenance/media/CF	0.0007 SR	0.0062 SR	0.003 SR r
Membrane replacement	0.007 SR	0.0043 SR	0.0038 SR
Power consumption	0.046 SR	0.047 SR	0.042 SR

Table 19: Cost comparison of pre-treatment technologies

2.5 Our case

Starting from the economical point of view on the long term, it is clear that using the CFM pre-treatment technology is the right and wise decision. In the other hand, this technologies help reducing the chemical use therefore help protecting the environment, which is an important key in taking the right decision. Or, for the reason mentioned in the intake section, paragraph 3-2 ; 3-3 and 3-4 (especially the short duration 5 years) of the contract), HUTA has been directed to use the conventional pre-treatment.

3 Chemical Dosing and Control System

3.1- General water quality

On long operation period, the performance of the whole SWRO desalination plant basically depends on the raw water quality aspects.

The main constituents of the natural water are the organic and the non-organics (or inorganic). Generally, non-organic compounds are under dissolved or suspended forms, they are formed from various combinations of metallic cation (example calcium, magnesium, sodium, iron) and non-metallic anion (e.g., carbon, nitrogen, oxygen, sulfur, chlorine) elements, while the organic compounds are generally more complex structures always containing the element carbon [MEDRC, 2006].

In general, natural water contains the following chemical elements but at different concentration depending on the water source, location, ground soil and water interaction with environment [UNEP, 2002]:

Aluminum, Barium, Boron, Bromine, Calcium, Carbone, Chlorine, Chromium, Copper, Fluorine, Hydrogen, Iron, Lead, Magnesium, Nitrogen, Oxygen, Phosphorus, Potassium, Silicon, Sodium, Strontium, Sulfur [WHO, 2004].

The major components of an average water analysis generally include only a limited number of these elements or of their combinations [Kusky Timothy M., 2005]. These major components usually add up to almost the entire dissolved solids content of the water [Zeebe Richard, Gattuso Jean-Pierre, 2011] and are listed in Table 20.

Cations ; Metallic Elements			Anions ; Non-Metallic Elements		
Name	Chemical Symbol	Concentration in our Sea Water	Name	Chemical Symbol	Concentration in our Sea Water
Calcium	Ca ²⁺	480-490 mg/l	Carbonate	CO ₃ ²⁻	25 – 30 mg/l
Magnesium	Mg ²⁺	1520 – 1550 mg/l	Bicarbonate	HCO ₃ ⁻	140 – 150 mg/l
Sodium	Na ⁺	12200 – 13000 mg/l	Sulfate	SO ₄ ²⁻	3100 – 3200 mg/l
Potassium	K ⁺	410 – 460 mg/l	Chloride	Cl ⁻	22300 – 23200 mg/l

Table 20: Major Components of Natural Waters [MEDRC, 2006].

During the study and examination phase, not all the chemical elements in the sea water have to be analyzed; only the major chemical mineral elements in addition to other specific mineral elements should be analyzed:

Calcium, Total Iron (Fe^{2+} and Fe^{3+}), Magnesium, Potassium, Total Manganese (Mn^{2+} and Mn^{3+}) Sodium, Strontium, Chlorine, Bicarbonate, Sulfate, phosphate, Fluoride, Nitrate, Silica (as SiO_2 ; Silica should be reported as total and reactive).

In fact, even that Silica, Strontium, Total Iron and Total Manganese maybe present in small concentration, but they have important effect on membrane scaling and fouling, that is why they should be analyzed in order to prepare the adequate pre-treatment and preserve the RO membrane.

3.2 Our water quality

The chemical composition of Red Sea water, at Rabigh has been analyzed in our laboratory; during the first 3 months, the bacteriology tests have been done in outside laboratory.

Rabigh Seawater has higher TDS (more than 41000 ppm) than the oceans water. During normal operation condition with the intake point from the deep sea, the average SDI of treated Red seawater at Rabigh is $5.5 + 0.26$ with a range of 5 to 5.9. Or from the shoreline intake point (after amelioration of intake point condition- refer to intake case study), the average SDI of treated Red seawater at Rabigh is $7.5 + 0.46$ with a range of 6.5 to 8.2.

Total suspended solids (TSS) - normally responsible for the spotted elevation in SDI of feed water - has an averages of 18 mg/liter with a range of about 12 to 23 mg/L, due to the use of coagulant at the feed, we succeed to reduce it by only 1 mg/liter or less after filtration pre-treatment process. The analysis using Energy dispersive X-ray (EDX) technology shows that the TSS components basically are: Ca, Si, Mg, O and Carbon. Other elements found are Fe, and Na but at a much lower concentration [Hassan A. M. et al., 1995].

In microbiology, a colony-forming unit (CFU) is a unit used to estimate the number of viable bacteria or fungal cells in a sample, it is determined as number of colony forming units per ml (CFU/ML), it ranges between 60 to 20×10^3 CFU/ML, but it is variable from one season to another. Bacteria count minimum values are during November till February and increase gradually during hot months reaching maximum value during the month of July.

The pH (potential of Hydrogen) is generally stable, with average value of 8; the turbidity is relatively low and have never exceed the 0.2 NTU.

For the chemical elements concentration in our Red Sea Water at Rabigh SWRO desalination plant, refer to table 21.

3.3 Introduction to chemical dosing

3.3.1 General important definition

Total Dissolved Solids, (TDS), represent the aggregate of all the dissolved elements in the water, either inorganic or organic. The unit of this measure could be expressed in milligrams per liter (mg/l) or part per million (ppm).

- Total Suspended Solids, (TSS), represent and reflect the amount of particles in a water sample that are not dissociated. This includes colloids, such as non-reactive silica (SiO_2). The unit of this measure is expressed in milligrams per liter (mg/l).

- Conductivity. This measurement is related to TDS. Usually measured as micro-siemens (μS), it reflects the resistance of the water.

3.3.2 Membrane Feed Water Quality

From environment point of view, the selection of the type of membrane is essential, in fact, based on its configuration and material composition will depend the type of the pre-treatment process to be used and the chemical dosing system to be applied to the raw water. The reverse osmosis membranes discard metals and suspended solids colloids with an eventual hazard of plugging and fouling; thus it is indispensable to remove these substances before it pass to the membranes, and globally a comprehensive adequate pre-treatment process is applied upstream to ensure the best water quality [Morton et al., 1996].

In our case, we used XXX Membrane, as per the membrane manufacture the minimum feed water quality should respect the following (Table 21):

Element / item	Spiral Cellulose Acetate	Spiral Polyamide	Our Spiral Polyamide
Turbidity NTU	Less than 1	Less than 1	0.5/0.6
SDI	≤ 4	< 4	< 5
Iron mg/l	< 2	< 2	< 2
Manganese mg/l	< 0.5	< 0.5	< 0.5
Silica mg/l	< 160	< 160	< 150
Chlorine mg/l	< 1	0	0
Scale inhibitor mg/l	12 – 18	12 – 18	10 – 18
pH	5.5 – 6	4 – 10	2 – 11
Maximum T°C	40	45	45
Dust, oil, grease	0	0	0
SBS	> 5	> 5	> 5
ORP	< 300	< 300	< 300
Feed Pressure Bar			60-70

Table 21: Membrane Feed Water Required Quality [Membrane manufacture manual].

3.3.3 General description of our pre-treatment

Based on our Red Sea water quality and in order to meet the specified water quality, the best system to be used consists of: chlorine is continuously injected at the discharge of the seawater pump to remove the bacteria and germs and the seawater is then acidified and treated with alum or ferric chloride to lower the pH and coagulate any colloidal matter. A baffled retention tank is provided to allow time for floc growth and for the sterilizing action of chlorine to be completed, and if necessary a polyelectrolyte is added before the multimedia filtration stage. Sodium metabisulphite is injected downstream of the filters to de-chlorinate the treated seawater and antiscalant is injected prior to membrane to help protecting the membrane from fouling and scaling opportunity. Cartridge filters are normally used ahead of the high pressure pumps and membrane to ensure particulate removal.

3.3.4 Pre-treatment selected chemicals

In general, the pre-treatment process utilize many kind of chemicals to ensure the best feed water quality prior to rack of membranes. The used chemicals are not stable and vary from plants to plants depending on the selected intake and the environment conditions. Table 22 shows different types of chemicals commonly applied, part of these chemicals are permanently injected whilst other parts are dosed occasionally during particular environment conditions or for specific purpose.

Commercial name	Chemical Type	Role	Dosage	Application
Scale inhibitors	polyelectrolyte polymer blends	Increase solubility of sparingly soluble salts such as calcium and magnesium carbonates and sulfates. Additional chemicals may be used to target specific species, such as silica.	≈1-5 mg/liter	Primarily in brackish water and sea water RO desalination
Acid	Sulfuric Acid or Chloridric Acid	Reduction of pH for inhibition of scaling and for improved coagulation.	40-50 mg/liter To reduce pH to ≈6-7	Primarily in seawater RO applications. Not used in all applications.
Coagulant	Ferric chloride or ferric sulphate	Improvement of suspended solids removal.	5-15 mg/liter	Primarily in open intake seawater RO and surface water RO systems.
Flocculant	cationic polymer	Improvement of suspended solids removal	1-5 mg/liter	used intermittently when feed SDI is unusually high.
Oxidizing Agent	all form of chlorine, biocides	To control bio-fouling and aquatic organism growth in the intake and pre-treatment facilities.	Site specific may be 2-7 mg/liter	Used for large surface and sea water intakes. Small systems and those using wells,
Reducing agent	Sulfate BiSulfite	To eliminate oxidizing impacts on the RO membrane	2 to 4 times higher than oxidizing agent dose	In all membrane processes using polyamide RO Membranes

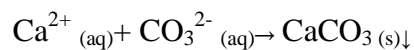
Table 22: most common chemical used during pre-treatment in RO [WHO, 2007].

Note: Dose rates are only indicative and are shown as milligrams of chemical per liter of feed water.

4 Salt in water

In sciences definition, the salt is a chemical compound resulting from the combination of metallic element and non-metallic element or radical; the most famous examples are: Calcium Carbonate (CaCO_3), Magnesium Carbonate (MgCO_3), Ferric Hydroxide ($\text{Fe}(\text{OH})_3$), Magnesium Sulfate (MgSO_4), and Sodium Chloride (NaCl).

Most of salt combination are dissolved in water at different level (especially NaCl) in form of ions (Na^+ as cation and Cl^- as anion), while others are dissolved up to certain concentration limit (example CaCO_3). Once the solubility limit of a salt combination is override, the salt starts to precipitate in the solvent liquid (Water). Equation describing the precipitation phenomenon of CaCO_3 is written as follows [Chen-Tung Arthur Chen, 2007]:



The solubility of the salt is not fixed, it is affected by many parameters like the Temperature, the pH, the solvent characteristics, other ions dissolved in the solvent... During the selecting of membrane type of SWRO plant, it is so importance to know the limited solubility of some salts, because as the feed stream is concentrated in its progress along the membrane array, some salts which were below the solubility limit in the feed may become supersaturated when water start to migrate through the membrane [MEDRC, 2006].

Salts of importance in RO operations include the following [Donald et al., 2000; Bruins Jantinus et al., 2014]:

Calcium Sulphate CaSO_4	Strontium Sulphate SrSO_4
Barium Sulphate BaSO_4	Calcium Carbonate CaCO_3
Calcium Fluoride CaF_2	Calcium Phosphate $\text{Ca}_3(\text{PO}_4)_2$
Ferric Hydroxide $\text{Fe}(\text{OH})_3$	Manganese Oxide MnO and Mn_2O_3

In order to prevent the precipitation possibility near the membrane, we have to control the oxidation products especially the oxides of metals which are considerably insoluble; in the SWRO desalination technology, the main attention should be focused on the oxides of ferric iron (Fe^{3+}) and manganic manganese (Mn^{3+}). To avoid the irreversible precipitation, it is preferable to define the concentration of irons in the raw water not to exceed 3 mg/l, and manganese concentration at maximum level 0.1 mg/l. Many experiences at different SWRO plants have proved that concentration of irons and manganese exceeding the previous doses causes problems of co-precipitation with other constituents such as silica [MEDRC, 2006].

In the other hand, the high concentration of irons reaching the membranes zone could negatively affects the performance of the anti-scalant (refer to the next paragraph # 5); some cases have reported the presence of precocious deposition of scale-forming compounds.

5 Antiscalant

5.1 Introduction

For SWRO plants fed by raw water having TDS concentration around 35,000 mg/l, membrane scaling is not considered a major problem as in brackish water plants (recovery could reach 90%); in fact, the recovery ratio of SWRO desalination facilities is defined by the osmotic pressure of the concentrate stream to 30-45%. Recently most of membrane manufactures recommend dosing scale inhibitor when operating above a recovery of 35% [Filmtec, 2011].

As per normalization and local law, the antiscalant (scale inhibitors) dosed in drinking water process must have National Sanitation Foundation (NSF) certification under NSF Standard 60, Drinking Water Additives [MEDRC, 2006].

5.2 Historic and type of antiscalant

During the past, seawater reverse osmosis desalination facilities used low recovery ratio between 25 and 30% during operation, designer and operators dosed complex of acid (mostly sulphuric) with sodium hexametaphosphate (SHMP) in order to reduce fouling. However this procedure failed a lot due to the introduction of phosphate element that is considered as source of food for bacteria and was subject to hydrolyze with production of calcium phosphate precipitation near the membrane superficies [Chesters et al., 2011].

In the other hand, the dosing using the Sulphuric acid resulted in high corrosive trend and in increase of Sulphate concentration which cause precipitation of calcium sulphate.

Due to the previous reason and negative results, SHMP has been substituted by additional antiscalants (polymeric based), however reducing the pH by dosing acid was still required acid and were found to contribute a nutrient which increased microbial activity. Twenty years before, new series of antiscalants (phosphonate based) have been invented and successfully tested, resulting in decreasing the dosing of acid [Chesters et al., 2011].

We conclude from the above that monitoring the membrane scale was a challenge to find the balance between the feed water quantity, the dosed antiscalant and the use of acid. Even that the antiscalant based on polymeric phosphates was injected at threshold doses, but propagation of bacteria has been noted, researches proved that it was due to the hydrolysis of orthophosphates accompanied with contamination starting from the dosing unit and progressing through the SWRO plants; in the other hand, also the reject was affected by the presence of phosphates used as food for biological growth and causing eutrophication in the zone of discharge. The uses of polymeric additives based on maleic anhydride have now eliminated this possibility [Morton et al., 1996].

5.3 Role and function

The antiscalant main role is to prevent the precipitation of the metal compounds (salts) and preserve the RO membrane from the scale formation, example: scales combination of Sulfate with polyvalent cations like calcium, strontium and barium are important scale factors in SWRO.

Preventing the fouling and precipitation is achieved by allowing the super saturation (up to certain limit) of the main salts affecting the membranes. Previously, operators paid attention to control the calcium sulfate saturation under 100%, or after the introduction of synthetic antiscalant, the concentration of double saturation is controllable with the injection of the exact quantity of antiscalant and in the right location, that will allow reaching the following approximate super saturation levels [MEDRC, 2006]:

CaSO₄ : 2 x saturation

BaSO₄ : 60 x saturation

CaCO₃ : LSI < 2.4

SrSO₄ : 8 x saturation

The fouling caused by carbonate and sulfate scales are the most dominating scales which occur frequently, but experiences and theory highlighted other sparingly soluble salts (like the Calcium Fluoride and Calcium Phosphate) to precipitate and impose fouling problems at the membrane superficies in SWRO desalination plants. For these reasons, the good design should control most of the potential scaling salts to ensure the long term facility performance.

In our case, we used the different types of antiscalant, starting from the one advised by the membrane manufactures (which cost is relatively high) to the one available in the market, we did not notice any big different between or bad results on the membrane scale or fouling, in fact most of the local antiscalant has relatively similar prices, and in our case, any product that we want to use must be approved from ARAMCO; therefore any product must have the well known reputation, analysis, tests and good function.

6 Suspended Solids

Generally the suspended solids don't generate problem when using duly installed and maintained well (or ground) water or subsurface intake from ocean/sea; suspended solids are considered as master problem when dealing with direct water. Generally, for SWRO desalination plants, suspended solids in raw water consist of fine inorganic materials, such as clays; insoluble metal oxides; and organic substances such as colloidal color [MEDRC, 2006].

The suspended solids are fine and light particles that are enable to precipitate; their size range varies from 2 to 100 micron, therefore they are able to traverse the Sand filter media filtration and in case of the extremely fine material they are even able to traverse the cartridge filter.

The suspended solid are generally measured by the SDI, the RO membrane process will suffer with the elevated value of SDI, while it will operate smoothly with the low level of SDI.

The suspended solids particles are discarded from the inlet feed inside the materials of filtration using conventional water treatment practices and a series of techniques including straining, interception, impaction, sedimentation, flocculation, and adsorption [Galloway and Minnery, 2001] (Table 23). A majority of the suspended material in the raw sea water is removed during this first filtration step leading to decrease the suspended solids in membrane process at different levels of success.

System	Operation Technique	Note
Physical Straining	Screening	Little efficiency
	Precoat Filters	Limited to small plants
	Cartridge Filter	1 to 10 micron, for big plant
	Polymer Membrane Filtration	High cost of MF and UF
Gravity Separation	Sedimentation	Need of reservoir
	Clarification	Generally after flocculation
Granular Filtration	Single or Multimedia Sand filter	Could be pressurized
Other	Dissolved air flotation	Usage is limited
	Cyclone Separators	For small plant

Table 23: Most used technique to remove the suspended solids [MEDRC, 2006].

7 Coagulant

Coagulant is used to help removing the suspended solids, the organics, the inorganic and the colloidal particles from feed water; therefore it help reducing the SDI. There are many techniques for the application of the coagulant within the intake feed water, the most two applied methods are the direct injection and the coupled of powdered activated carbon with a sedimentation basin.

After being in contact with water, coagulants compose hydroxide molecules which coagulate suspended solids into flocs and thus can be removed by the filter media [Hamidi et al., 2007]. In fact, the molecules having charge (+) will react with particles having (-) charge to support the charge accumulation.

In more details, in the presence of adequate pH and under suitable temperature, the injected coagulants interact with water to compose hydroxides combination; during precipitation, these hydroxides will connect together to form long chains or meshes, physically trapping small particles into the larger floc [Stolarski, 2013]. *Van Der Waals* forces and using polymeric flocculants complete the process, forming larger aggregates which can be flocculated and separated from the waste stream [Chesters et al., 2011].

The most used coagulant are those based on aluminium and iron cations, the frequent coagulant used worldwide are: Ferric chloride (FeCl_3), Ferrous chloride (FeCl_2), Ferric sulphate ($\text{Fe}_2(\text{SO}_4)_3$), Ferrous sulphate (FeSO_4), Aluminium chloride (AlCl_3), Aluminium sulphate (alum, $\text{Al}_2(\text{SO}_4)_3$), Polyaluminium chloride (PAC). In our case, we used two type of coagulant: The

Ferric Chloride and the Magnafloc LT. The coagulant has been added in the feed ahead of dual media filter within the following concentration: for Ferric Chloride (0.8 ; 1.0 ; 1.2 ; 1.4 and 1.6 ppm); the Magnafloc LT has been using within the following concentration (1.4 ; 1.6 ; 1.8 ; 2.0 and 2.2 ppm).

The results show that the Ferric Chloride – even more expensive – has ensured better SDI drop, and as long as we increase the dosing of the Ferric Chloride, more the SDI drops. But in or case, we do not have stable working condition and the feed water quality has been changed many times during operation (due to the intake modification), therefore the SDI drop was not stable during time and it was difficult to judge and fix the best dosage to be used. Or at Ferric Chloride concentration of 1.2, the SDI drops by an average of 2.4 +/- 0.4 and the % of drop was around 31%; this equivalence has been found the best to select in our case, since injecting more coagulant did not significantly reduce the SDI to the expected range: for example, at 1.6 ppm, we are injecting 33.3 % more coagulant, but the SDI drop is only 2% more.

We changed the operation condition by acidifying the Feed to pH =6.5 by injecting the Ferric Chloride as coagulant at 1.2 ppm and by injecting coagulant-aid (Polyelectrolyte) at 0.8 ppm). The SDI drops to significant value of 2 +/- 0.3. This condition has not been admitted, since it is adding more cost on the pre-treatment operation while the obtained SDI using Ferric Chloride at 1.2 ppm look satisfied.

8 Organic in water and Biofouling

In addition to the mineral composition of the water, the presence of biological, organic, and other inorganic materials such as clay must be identified to prevent membrane fouling.

8.1 Origin of biofouling

The SWRO membranes are great efficient barriers and stop biological constituents in the inlet feed to pass through, producing great biologically inert water. In this situation, the biological components will be present near the membrane superficies which may cause dangerous fouling; the most frequent identified problem is biofouling in the divers forms of bacteria and associated biofilm but can include fungi, algae and even nematode worms [Chesters Stephen P. et al., 2011], biofouling is a special case of particulate fouling in that it involves living organisms.

Not all the existing bacteria are harmful, conversely the most frequent bacteria, such as coliform and sulphate reducing bacteria are generally not involved in fouling issues during normal operations; in the other hand, the dangerous types, particularly slime producing bacteria, are the most popular motive of membrane fouling. With the introduction of GRP piping – like our case – application shows an increased in algal growth which could be successfully stopped when the GRP is painted to prevent light.

8.2 How it occurs

The initial fouling is similar to other particulate foulants. SWRO membranes can handle a viable biofilm; in general, as long as the biofilm is not exuding a protective polysaccharide film then it will be stable and will not adversely affect system performance [Darton Ted et al., 2004], but once the organism has impacted on the surface of the membrane, it has the ability to grow and proliferate. Small amounts of biological materials present in desalination systems may rapidly grow and deposit on equipment surfaces [Amjad, 1996].

Biofouling of membrane surfaces is invariably accompanied by other fouling. Scaling is common; however the types and the concentrations of mineral salts may vary greatly, depending on the specific chemical and microbiological characteristics of the feed water [Ridgeway, 1988]. Particulate matter is also often trapped in a bacterial glycocalyx.

8.3 Results of Biofouling

The biomass proliferation on the membrane superficies causing biofouling has negative effect on the performance of the membrane and therefore of the desalination unit; in fact the damage start from loosing product water flow till the physical degradation of membranes.

The disposal of this biological organism by killing them near the membrane is not a practical solution as it appears, in fact, A dead biomass will adhere as well as, and sometimes better than, a living one.

8.4 What to do

Biological fouling is a serious problem if not properly controlled, therefore, the type and details of bacteria which are present in the feed water should be identified in order to know the best type of pre-treatment that eliminates the bacteria, and to identify the type of membrane biofouling when happened.

Off course the best way to prevent biological biofouling is to eliminate the causative of contamination from the water source, this could be accomplish by killing the causative and disposing from their bodies. But one of the best strategies is to restrict the nutrient and food, blocking the proliferation possibility of the bacteria. This strategy could be done via good performed pre-treatment in conjunction with the dosing of biocide. Chlorination is the worldwide used technique known to be forceful in killing the bacteria present in flowed water, but unfortunately it wasn't able to remove and eliminate the established colonies in the inlet pipes or on installed equipment superficies. In order to eliminate this colonies, the injected dose must reach 1000 – 1500 times as high as the dose used to kill free bacteria in water due to protection from extracellular polymeric structures excreted by the bacteria [Chesters et al., 2011]. Bacteria grow back very quickly when free chlorine is lost [Saeed et al., 1999]. Because the survived bacteria will feed on the new nutrients from the chlorine degraded organic material [Winters H., 1994] (refer the next paragraph #9). To be noted that the efficiency of the injected chlorine is proportional to the concentration of undissociated hypochlorous acid (HOCl), in fact chemical prove that (HOCl) is 100 times more effective than the hypochlorite ion OCl^- , and dissociation of HOCl to OCl^- increases with pH [Chesters et al., 2011]:

At pH <5 HOCl = 100%

At pH 6.5 HOCl = 90%

At pH 7.5 HOCl = 50%

At pH >10 HOCl = 0 %

Most SWRO inlet feed waters have pH between 7.6 and 8.5 which mean that the chlorination is not effective as it supposed to be; for this reason, the inlet pH should be decreased to less than 7.4. Recently, designers tend to use intermittent chlorination that differs from site to site on daily or weekly basis. Some SWRO facilities are running without the dosing of chlorination which reduce nutrient to reach near the membranes.

9 Chlorine

The inlet sea water of SWRO desalination plants using open intake directly could implicate pathogenic microorganisms including bacteria, protozoa and viruses [WHO, 2007]. The chlorine dosing point should be located before the sand filter media during the pre-treatment stage, the important question centers on the suitable dose of chlorination to protect the process (specially the membrane) without causing any risk or damage for the system

Traditionally during pre-treatment a disinfectant, often chlorine compounds, will be used and injected to disinfect seawater intake systems and the associated downstream plant, to minimize biofouling and to save the sensitive membrane: some organisms or microorganisms may proliferate through the membrane imposing degradation.

The objective of the chlorination stage is to prohibit biofouling. As seen before, the best technique resides by killing the pathogenic microorganisms and by rescission the ambiance of their proliferation.

To be noted, disinfection of inlet feed using chlorine may convert natural organic material (NOM) to assimilable organic carbon (AOC) which becomes a food source for bacteria. NOM in the water can cause membrane fouling and loss of performance [MEDRC, 2006].

That is why in some desalination plants, ensuring disinfection is accomplish without reliance on Chlorine derivatives that have been replaced by copper sulfate (CuSO_4); well known as an effective algaecide in controlling algae and planktons [Light W.G. et al., 1988]. In this way, the problem of membrane damage is surpassed and the operation cost is reduced by reducing the injection of SBS. In general, the CuSO_4 is used as disinfectant by dosing between 0.3 to 0.8 ppm

During the first days of testing the pre-treatment, the inlet feed sea water has been driven to the sand filter and then to the brine line. We made disinfection of the whole intake line and fitting; after the feed pumps, we injected the Chlorine in high concentration (5 ppm), we made the test of chlorine after the sand filter and we founded total absence of residual Chlorine. We increased the dosing of Chlorine to 7 ppm, to 8 ppm and finally to 10 ppm. After this

concentration we started having residual chlorine after the sand filter. (For details comments and explanation, refer to paragraph 13.2).

Once the system has been properly working, and following the difficult that we face during disinfecting the system with chlorine, we took the decision to use the chlorine as disinfection at the pre-treatment for our SWRO desalination plant.

The chlorine (NaOCl) exists in three different physical type in the market: the solid form, the liquid form and the gas form.

From quality and finance point of view, the solid form is the best choice. However in our case, using the solid impose using preparation tank equipped with agitator, transfer pump and specific tools to handle and maniple the solid chlorine.

From the easiest use and efficiency point of view, the gas chlorine in the best choice, or in our case using of any toxic gas is totally forbidden inside the refinery of Petro Rabigh.

That is why the liquid form was the final choice. Generally the Sodium Hypochlorite liquid form came with 25L per Barrel, the commercial mentioned concentration is 10%, but due to the high temperature, long and sometime bad transportation, old stock in the market and bad stock in the storage are, the maximum concentration of Sodium Hypochlorite-liquid form is 8%.

After the stabilization of the pre-treatment process, the dosed chlorine was adjusted daily depending on the raw feed water quality; in fact, the dosage of chlorine is adjusted in a way to keep minimum concentration of 1 ppm in the line after the sand filter.

With this concept, the dosage of chlorine was between 1-3 ppm; rare is the time where we used concentration of free chlorine above 3 ppm.

10 Acid and SBS

The residual chlorine is an oxidant agent; if they reach the membrane, all oxidant compounds are harmful and cause huge damage to the membrane and especially to the Spiral polyamide, the Spiral Cellulose Acetate could handle the chlorine concentration in feed water up to 1 ppm. Therefore all oxidant including the residual chlorine must be totally removed from the water stream before reaching the membrane.

In general, the chlorine is removed from the pretreated feed by Sodium metabisulfite (SBS or SmBS).

Sodium Bisulfite [SBS] is the typical chlorine reducing agent of choice for larger RO systems. A SBS solution is made by dissolving solid sodium metabisulfite into water and has a pH of 4.6 at 1.0 % (by weight) solution strength. The sodium metabisulfite is commercially available at 97.5 to 99 % purity and can be stored safely up to six months in a dry storage area. The SBS solution is not stable to air and reacts with oxygen as well as chlorine

Theoretically, 1.47 ppm of SBS (or 0.70 ppm of sodium metabisulfite) will stoichiometrically neutralize 1.0 ppm of chlorine. Designers have been known to use a dosing rate of 1.8 to 3.0 ppm of SBS per 1.0 ppm chlorine. For safety reason, some engineer prefer to use SBS at 4 ppm.

The acid (generally Sulfuric acid or Chloridric acid) is used to reduce the pH of the feed water for the following reasons:

- It helps and prevents scale formation (especially of CaCO_3 , alkaline scale formation, polymeric scale) on the membrane surfaces due to sea water concentration.
- During the coagulant use, lowering the pH help the coagulation phenomena and reduce the SDI.
- Lowering the pH help getting the best chlorine form (HClO), best choice for killing and removing the bacteria from the sea water.

11 Silica

Silica is a natural common component in water that caused operational problems, membrane fouling and damage to the desalination facility. Silica is present in different concentrations level in all natural waters and figures in different forms [MEDRC, 2006]:

- Monomer silica, or silicic acid, Si(OH)_4 : soluble or reactive silica.
- Polymerized silicic acid: colloidal or un-reactive silica.
- Particulate silica.

The disadvantage of the presence of silica in the inlet feed water reside in its ability to interact with the -if existing- heavy metals (even at low concentration) and produce polymerization of complex silica-heavy metal.

Most of operational SWRO desalination plants defined the concentration of silica in the feed water to 150 mg/l. Even that, some plants managed to operate as higher concentration up to 250 mg/l. The highest level of 120 mg/l is advised for hollow find fiber membranes [MEDRC, 2006].

Right now, antiscalant and some specific inhibitors are in market, and allow running the RO desalination plant at silica level of 220 mg/l in the feed water. Like all operating parameters, it is better to test and analyze the silica level in the feed water using pilot testing unit.

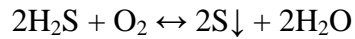
In our SWRO desalination plant, the concentration level of SiO_2 is very low and we didn't face any problem with silica during the operation.

12 Hydrogen Sulfide

In locations known to previously being as wetland (like the ground water), the sulfate reducing bacteria used to be frequently present; the life period of this bacteria produce Hydrogen Sulfide (H_2S) as by-product.

Benefitting from the gas properties, H_2S could traverse the membrane, therefore H_2S could be present in both product water and brine.

Removing H₂S from the feed water during the pre-treatment stage is not recommended because it is costly and may be involved in the virtually irreversible membrane fouling with colloidal sulfur as follow [MEDRC, 2006]:



Generally, once detected, the H₂S is effectively treated and eliminated from the produced water via air stripping with pH reading range from 5.5 to 5.8

13 Sand Filter

The Sand Filter is the most important part of the conventional pre-treatment with variable size based on the design and the desalination production quantity. Two types of working conditions are normally followed: the first one follow the gravity rules, in this case most of the Sand filters are concrete; the second one use the pressure to drive the water through the Sand Filters, in this type most of the Sand filters are made from rubber lined steel.

During the normal working operation, the inlet pipe is used to flow the raw feed water inside the sand filter, and the outlet pipe is used to direct the filtrated feed raw water to the cartridge filter. During the backwash, using back wash pumps, the outlet pipe is used to drive the filtered water (stored in separate Back Wash tank) to the sand filter in opposite direction of the normal working flow, and the inlet pipe is used to throughout the black backwash water to the brine channel.

13.1 Media of Sand Filter

The Sand filter media has huge rang; in fact, it starts by the easy single media (using one type of filtration media) till the ideal 5 layers media (from the bottom to the top):

- ❖ Small gravel particles
- ❖ Sand having medium particles size
- ❖ Fine Sand small particles size
- ❖ Extra fine sand small particles size
- ❖ Anthracite

Each plant designer can make numerous layers combination from the previous type of media depending on the raw water quality, the type of pre-treatment and the membrane specification. The media general size and media layer thickness are listed in table 24.

Media type	Particle diameter (mm)	Layer Thickness (mm)
Anthracite	0.8 – 3	200 – 600
Fine Sand	0.5 – 1.5	200 – 900
Extra Fine Sand	0.3 – 0.5	250 - 600

Table 24: Sand filter media dimension.

Our sand filter media consisted of three coarse layers: Small gravel, Fine Sand particles (diameter between 0.5-0.7mm) topped with anthracite (diameter between 0.8-1.2 mm). In our pilot test, we made several experience, we changed the thickness of the layer and we took the SDI measurement. The results are summarized in the table 25.

Thickness (mm)	Gravel	Fine Sand	Anthracite	Average SDI drop
Experience 1	350	250	400	1.3
Experience 2	300	450	450	1.6
Experience 3	200	500	400	1.8
Experience 4	200	600	400	1.9

Table 25: SDI drop with Media Thickness layer.

The difference in the SDI of the pre-treated feed during the various experiences may be explained in terms of the difference in the plant’s filtration system: when the thickness of the sand layers is quite small (250 mm) at the first experience, the SDI drops by an average of 1.3; when compared to the sand layers thickness (500 and 600 mm), the SDI drops by 1.8 and 1.9 respectively. Our desalination units have been in operation for three years without negative effect on performance. Moreover, no membrane fouling has been observed.

13.2 Operation

As mentioned in paragraph 9, during the first days of testing the pre-treatment, the inlet feed sea water has been driven to the sand filter and then to the brine line. Disinfection has made using high concentration of chlorine (starting from 5 up to 10 ppm). At the first low concentration, we could not detect the presence of residual chlorine after the sand filter, until reaching the 10 ppm concentration of injected chlorine.

This is probably due to the presence of high bacteria concentration inside the media. In fact, after filling the media inside the sand filter, and once the inlet pipes has been installed, the installation team made mistake and connected the GRP pipes to the sand filters and proceed with the hydro-test of the GRP pipe. This impose the direct entry of non-treated raw sea water to the sand filter (no chlorine has been injected, no coagulant) and after that the media layers have been kept inside for minimum 3 months until completing the installation of the feed pumps, back wash pumps and the electrical control panel which is connected to the main PLC of the plant.

During this long period stop, bacteria have taken place, get well installed inside the media of the sand filter and have been multiplied and reproduced. When injecting the chlorine at 5-10 ppm (which is normally high values), it has been all consumed to kill the huge number of bacteria colonies. Once most of the bacteria colonies have been killed, we started detect the residual chlorine after the sand filter.

After complete installation of the sand filter system: 5 sand filters, all GRP inlet pipes, all GRP outlet pipe, the butterfly valves, the pneumatic air control system of the valves, the air blower, the back wash tank, the back wash pumps, the chemical dosing injection points and the air release valves; the sand filters have been put in cleaning and stabilization period of 72 hours, during this period, multiple operation and back washing has been done to each sand filter.

Once filtration via sand filter started, the media of filters block, capture and accumulate suspended solids, formed coagulate and particles. This lead to blockage and is generally supervised by the increase in pressure loss across the sand filters. The cleaning philosophy of the sand filter is as following: one cleaning procedure is automatically programmed to take place periodically (once per day), also, when the differential pressure across the sand filter drop radically. In backwashing, clean water at a high flow rate is introduced at the bottom of the filter, expanding the media and washing collected solids out the top [Galloway Merrilee A.and Minnery John G., 2001].

13.3 Back wash strategy

The back wash ensures the regeneration of the sand filter media, as per the philosophy, the back wash should be automatically done when the differential pressure across the sand filter dramatically drops and/or at least one time per day. Also it could be done manually when needed.

The following point should be taken in consideration during the back wash:

- ❖ Back washing will be initiated through the selector switches provided on each sand filter
- ❖ Each sand filter is provided with Auto/Manual selector switch, for selecting the filter back wash mode
- ❖ In back wash cycle, back wash pumps will be activated automatically through the PLC
- ❖ To execute Manual back wash for individual filter, the system should be in OFF mode by turning the system selector switch (OFF/ON) to OFF position and the selection mode (Manual/Auto) to Manual.
- ❖ Before operating any back wash, the back wash tanks level should be checked

- ❖ The air compressor regulator should be adjusted to the required pressure to operate the butterfly valves actuators.
- ❖ The air blower must be checked to be ready to work properly.
- ❖ The following will be the sequence for auto backwashing, system (OFF/ON) in ON position, sand filter (AUTA/MANUAL) in AUTO:

Time in min	Cumulative time	Back Wash Process Description
00	00	Initiation to start the back wash cycle
2-3	2-3	Open the air release valve to ensure no air is trapped inside the SF
3-5	6-8	Open the drain/rinse valve to partially drain the water
-	6-8	After completing the drainage, close the air release & drain valve
-	6-8	The service inlet & outlet valve must remain closed
-	6-8	Open the suction valve & discharge valves of the backwash pump
-	6-8	Open the inlet backwash valve & backwash outlet valve
4-5	11-13	Run the back wash pump, the water start to cross the SF in the opposite direction of normal service.
-	11-13	Open the air scouring valve & the air blower discharge valve
3-5	16-18	Start the air blower & monitor the discharge pressure & current
-	16-18	After completing the air scouring, stop the air blower & close the air scouring valve; the back wash outlet valve should keep closed
3-4	20-22	Keep the back wash pump running.
-	20-22	Stop the back wash pumps, close the suction valve & discharge valves of the backwash pump, close the inlet cleaning valve & backwash outlet valve.
2-3	23-25	For 3 min open the air release valve, than closed back
-	23-25	Open the service inlet & drain/rinse valve
12	35-37	Start the sea water intake feed pump to rinse the SF

Table 26: Back wash sequence Process

This sequence could be modified, in fact during the air scouring process, the back wash pump could be in stopped mode, but in our case, we founded more efficient having them working together.

14 Cartridge Filter

At the last sequence of the pre-treatment, the cartridge filters succeed the multi-media filters (Sand Filters). Once pass through the Sand Filters, the filtered water will be the subject of the last filtration and finest barrier before being into the suction pipe of the high pressure pump. At this stage, the remaining finest suspended matter (typically down to 5 microns in size) are retained and eliminated by the fine cartridge filters.

Depending on the pore size diameter of the filter element (could be between 1 and 10 microns), the smallest particles size (1 to 20 microns) which escaped from the Sand filters are captured inside the cartridge filters; cartridge filters must eliminate 85–95 % of all particles greater than the “Filtering Particles” size. In summary, the essential role of the cartridge filters is to prevent the SWRO membranes from damage.

Our cartridge filters comprise the following: housing/casing, filter element, tube support and inlet and outlet opening. During working operation, water flow inside the housing through the filter elements; the small particles and the suspended solids and are jailed in the fine fibers of the element. The filter element of the cartridge could not be re-used; therefore they should be all replaced periodically in order to keep the high performance of the plant.

Cartridges elements shall be of the depth wound type, of polypropylene thread wound on or polypropylene core [MEDRC, 2006].

Different housing materials are used in the cartridge filter; approved for use in potable water, RTR, FRP & FDA materials are generally used, or some cartridge has stainless steel housing.

In our case, we used the traditional 5 micron element filter, during normal operation, the cartridge filter element are replaced one time each 40 days and ensuring very good water quality with SDI result range between 3-4.

15 Online meter and dosing pump

In order to persist to the different types of used chemical, the chemical dosing pumps bodies should be made from glass reinforced polypropylene and avoid using any metallic element. They shall be electronically-operated and permitting the manual adjust of stroke/speed.

Use of On-line and Laboratory Analytical Tools

In modern professional designed SWRO facilities, it is familiar to periodically control the water chemistry of the inlet and permeate water using an on-line analysis accompanied with laboratory analysis. These analyses shall be examined and treated by the unit team in order to watch, control and preserve the soundness of the membranes. Finally, it is very important for the operation team to detect any variation in the inlet feed water quality in order to reply, adapt and adjust the chemical dosing system.

Therefore a Feed water Panel is generally established have the connection to most of the following online instrument:

1. Turbidimeter; turbidity Indicator-Transmitter
2. Turbidimeter Flow Rotameter
3. pH Cell; pH Indicator-Transmitter
4. pH Flow Rotameter
5. Temperature Indicator-Transmitter
6. Conductivity Cell; Conductivity Indicator-Transmitter
7. Conductivity Flow Rotameter
8. Cartridge Filter Inlet Pressure Differential Indicator-Transmitter
9. ORP Apparatus

CHAPTER 3: THE MEMBRANE

THE MEMBRANE

1- Introduction

Most of scientific consider the membrane as the heart in the SWRO desalination plant, and it is the last and important barricade that ensured the separation of the dissociated salts; in fact, during the reverse osmosis process and as the name reflect, water volume is forced to transfer from the high concentrated solution to a lower one. To complete this technology, we should apply high pressure greater than the osmotic pressure of the saline solution.

2- Type of membrane

In general, the membranes are classified based on the process performance which reflects the removal capacity of each membrane and the major domain of application; table 27 resumes the four main categories of commercial membrane and provides some generalized performance and major applications.

Membrane type	Nominal pore size (μm)	Removed items
Microfiltration	0.1 – 1	Particles, bacteria, protozoa
Ultrafiltration	0.001 – 0.1	Virus, large MW organics
Nanofiltration	0.001	Multivalent ions and organics
Reverse Osmosis	0.0001 – 0.001	Seawater & brackish water desalination

Table 27: Different types of membranes and theirs performance [Water Treatment Guide, 2014].

Due to their large nominal pore size, the Microfiltration and Ultrafiltration membranes are generally used to remove bacteria and bigger particulate contaminants at home application, and recently, they have been introduced and used in the pre-treatment stage prior to the main membrane to help decreasing the load on the restrictive RO membranes and prolonging their performance and operation time.

Also, there are numerous compositions of membranes within each system category; for example, in the RO application, membranes are situated in a module and they can be configured as hollow fiber, spiral, tubular and plate. Selecting the type of membrane to be installed and used

in RO depend on their own characteristics and the specific cases of the project, but the most widely used configurations are the Hollow fiber and spiral benefiting from their positive operating process efficiency relative to cost (Operating pressures are in the range of 250 – 1000 psi (17 to 68 bars, 1724 kPa to 6896 kPa)). Many things intervene in choosing the type of membranes basically we listed the following: general cost, mechanical solidity, operating life, working pressure, pH constancy, and performance for removal of salts [WHO, 2007].

3- Material of fabrication

In general, most membrane factories follow the same fabrication procedure and the membranes are made of prolonged organic series called polymers (having supreme molecular weight). These polymers have an affinity for water and are distinguished by their hydrophilic characteristic that permits water small molecules to migrate, or permeate via the body of membrane, whilst blocking the migration of other molecules.

As mentioned before, the common SWRO membranes generated worldwide are fabricated in an asymmetric type structure or as a thin film composite; the asymmetric type structure is made of cellulose triacetate or more likely polyamides and polysulfones, they are assembled into Hollow Fine Fiber (HFF) configuration. Conversely the thin film composite structures are generally made of polyamide composition, and they are assembled into a Spiral Wounded (SW) configuration [Hassan A. M. et al., 1995]. The main membranes factories are located in U.S.A., Japan and recently in China.

Actually, the international standard of reverse osmosis membranes fabrication consists of perforated conduit and two sheets of membranes which are generally layered or thin film composites polyamide material; the membrane sheet are united together and spirally coiled around the conduit through which the produced permeate water are collected and forced to leave the membranes. The first membrane sheet or the surface contact layer (rejection layer) has microscopic pores that can retain compounds of size smaller than 200 Daltons [WHO, 2007], this help stopping most of minerals existing in the source water on the membrane superficies. This first sheet is very thin (even less than 0.2 microns) thus it is sensitive fragile and may not resist to the applied high pressure needed to ensure the desalination; therefore it is generally adhered to a porous support produced from the same material as the surface, normally this support consist of another (but thicker) membrane sheet fabricated from higher-porosity polysulfones material but having wide sized pores. Membrane thickness is on the order of 0.05 mm.

The international standards are followed in the fabrication of reverse osmosis membrane. For the huge potable water production plants, the standard element dimensions are: 40 inches (101.6 cm) length, 8 inches (20.3 cm) diameter and it is able to ensure 99.5 % TDS rejection rate. In common, to define membrane performance three traits are admitted as reference: flow, rejection, and recovery rate. For the small potable water production plants, smaller and specialized element are used, the dimensions are: 40 or 21 inches (101.6 or 53.34 cm) length, 4 inches (10.16 cm) diameter [Water Treatment Guide, 2014].

4- Mode of filtration

Profited from the produced pressure of the HPP as driving force, Sea Water Reverse Osmosis Plants take advantage of the desalination processes technology to divide by two the high salinity inlet water: product water or permeate with low salinity and brine (concentrate or reject) water with very high salinity. The desalination process counts on the capability of small and light water unit to diffuse through the membrane structure better than the bigger and heavy compounds of the dissociated salts. From mechanical and chemical point of view, SWRO mode of desalination is not truly a filtration process that remove salts because of their huge volume, but a diffusion process leading to filtration.

When feed saline water is located near a semi-permeable membrane, and once the applied pressure exceeds the natural osmotic pressure, water from the concentrate will diffuse via the membrane as a result of the reverse osmosis process. Experience and application manifest that acetate membranes are more successful to be used for this purpose [Ghaffour N. et al., 2013].

Although the membranes are the most essential item in the RO technology, but without the needed pressure, this desalination process could not be achieved. Here resides the importance of the HPP which ensures the needed high pressure to conquer the naturally existing forces of the osmosis process, water flow will continue till the pressure created by the high pressure pumps equals the osmotic pressure of the salt solution. When the applied pressure stopped, the normal osmosis will take place and drive back the water through the membrane to the high saline water.

During the desalination process, most of source water minerals are blocked by the membranes therefore they become more concentrated with time. Membranes are not totally semi-permeable, in reality they let certain dissolved salts to pass [Technical Aspects of Desalination Plant, 2010]. The concentration of salts in the produced permeate is monitored by decreasing the membrane inlet pressure or by rising the filtration units; to be noted that membrane inlet pressure, rate of permeate and membrane fouling are proportional.

The philosophy of desalination technology resides in the use of separation membrane to eliminate the dissociated ions from the water, but the restrained ions may block the membranes pores that mean closing the passage of filterable materials. Generally produced membranes are not designed to operate under high quantity of suspended solids in the feed, the occurrence of filterable solid materials will decrease the permeate quality and quantity and may cause the reduction of the membrane performance and life.

Generally RO membranes ensure total rejection for the algal toxins (like saxitoxin and domoic acid), for the human pollutants (such as pharmaceuticals, cosmetic products) and they can remove 4 logs of *Giardia*, *Cryptosporidium*, viruses and other pathogens presents in the source water [WHO, 2007]; therefore this technology is more efficient in rejecting pathogens than the traditional treatment.

With the advanced research and techniques, recent membranes are now able to restrain up to 99% of all ions and are able to stop all organic chemicals molecules having weight between 100 to 300 Daltons.

The unified atomic mass unit (symbol: u or uma) or dalton (symbol: Da) is the standard unit used for indicating mass of atomic or molecule. One unified atomic mass unit is

approximately the mass of a nucleon and is equivalent to 1 g/mol.[Stryer Lubert et al., 2007] It has a value of $1.660538921(73)\times 10^{-27}$ kg [NIST, 2014].

5- Membrane performance

In the long operation, the membrane performance represents the best indicator concerning the pre-treated water quality, it is even more critical than the SDI reading. Many studies [Hassan A. M. et al., 1995] focused on disposition and appraisal of the performance of different commercial SWRO membranes of spiral wound and hollow fine fiber; the studies concluded that – like pre-treatment – performance is affected by divers parameters: type of coagulant, coagulant-aid (if applied), chemicals concentration; disinfection procedure; inlet pH and flow rate and – if used – Ultrafiltration.

Membrane performance is generally expressed using the permeate flux, the salt rejection rate and the recovery; these indicators are briefly described below.

The permeate flux is defined as the quantity of water that pass through membrane superficies during a specific time. [MEDRC, 2003] stated that is affected by the thickness and porosity of membrane and by the running circumstances like salinity, inlet pressure, temperature and pH. Depending on manufactures, it is generally expressed in LMH (liter/sq. meter/hour) or in GPD/FT² (gallon/day/square foot). The same definition is applied to the salt flux to express the salt quantity that diffuse via the membrane; the salt flux is related to the disparity between the inlet and the permeate concentration.

Salt rejection is related and based on the membrane efficacy to eliminate salinity from the water source. It is not stable but varies from ions to ions and generally multivalent ions are better eliminated than monovalent ions. Salt rejection is influenced by diverse parameters (pH, T° ...). The designer should pay high attention to all ions concentration in the source feed water because some ions (like boron), even at low concentration in the feed, may exist in the produced water at unaccepted concentration as per norms. Salt rejection is measured by the following formula: $\frac{\{(\text{salt concentration})_{\text{feed}} - (\text{salt concentration})_{\text{permeate}}\}}{(\text{salt concentration})_{\text{feed}}}$

The permeate recovery or conversion is expressed as the produced (recovered) water volume compared to the main source water. The recovery rate, the brine salinity concentration and the osmotic pressure are proportional. The recovery is calculated by the following formula: $100 \times (\text{water flow})_{\text{permeate}} / (\text{water flow})_{\text{feed}}$.

Experiences noted decline in the produced water quantity after stopping the SWRO desalination facility for long period, this may be explained by the occurred membrane preservation and the changes in the membrane physical structure once the applied pressure stress has been removed. From conductivity point of view, some membranes were not affected while others suffer from low to high rising in permeate conductivity; in global, the average membrane life is between 3-5 years, it is normal to note drop in membrane performance and retro-gradation of the salt rejection over time; therefore it is wise to design the facility based on membrane performance at the end life.

Finally, some parameters or feed water characteristics may dramatically affect typical membrane and present limitations, for example: feed water temperature (45°C); pH (minimum of

2 and maximum of 10); silt density index (less than 4); chlorine content (not tolerant to chlorine in measurable amounts); and feed water pressure (maximum of 80 to 100 bars) [WHO, 2007].

6- Membrane failure

Over the last 30 years, a trend exists to elevate the recovery rates from 30% to 40 and sometime 50%. This imposes the use of higher feed pressure, and it is followed by higher concentration of ions at the surface of membrane and probability of scale precipitation in last position elements [Chesters et al., 2011].

The main problem facing the membrane is the fouling that could be caused by suspended solids and/or micro-organisms in the inlet saline water. Trend to avoid or radically minimize this problem is successful by sequence of chlorination (generally sodium hypochlorite), acidification (mainly by sulphuric or chloridric acid), and coagulating (principally with the iron derivatives). During the pre-treatment stage, injecting these chemicals is helpful when right levels are dosed, but if not, harmful damages could occur and membranes could be lost.

All kind of membrane fouling (biological or inorganic origin) and the minerals scaling can cause irreversible damage of the membranes. In some case, especially when using low quality material, fabrication blemish or mechanical failure (most often O-ring connectors) lead to salts crossing through the membrane to join the produced permeate. Therefore it is so important to keep controlling the membrane inlet water and the produced permeate in order to reveal and degradation in water quality reflecting the loss of integrity

In global, for membrane processes, [MEDRC, 2006] listed the following concerns:

- Membrane fouling and scaling
- Biological fouling or attack
- Fouling by metal oxides or sulphides
- Membrane degradation by oxidation or other means
- Suspended solids plugging

In his case study of 99 SWRO Plants [Chesters et al., 2011] show that 40% of autopsies reflected the existence of iron, 33% clay and 21% calcium and magnesium. The main cause for membrane deficiency showed that 27% was due to microbiological fouling, 19% were abraded, 18% oxidized, 12% of the samples showed metal oxide present as iron, manganese and aluminium, mineral scale formation from calcium carbonate, calcium sulphate and silica scale was identified as the major cause of membrane failure for 8% (refer to figure 21). Only 10% of the membranes were described as clean.

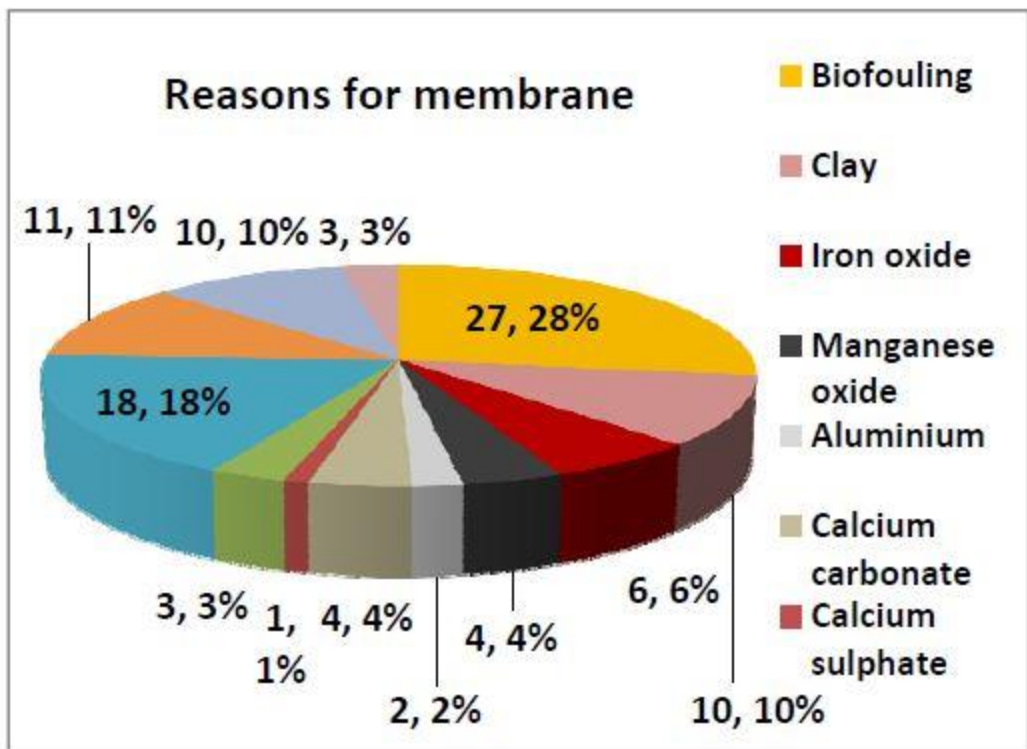


Figure 21: Reason of membrane failure [Chesters Stephen P. et al., 2011].

6.1- Scaling (Mineral Scale)

The membranes autopsy of mineral scale reflect the presence of calcium and/or magnesium residue in most of the case; the analysis of sediments show that it mostly contains calcium carbonate (CaCO₃), then calcium sulphate (CaSO₄) and finally silica (SiO₂). It has been noted that the deposit of calcium carbonate (CaCO₃) is generally located in the last train of membrane. The precipitation of CaCO₃ has been studied and predicted by multiple index, the most used one is the Langelier Saturation Index (LSI) [Daviil et al., 2009]:

$$LSI = pH - pHs$$

pHs = pH of solution if it were in equilibrium with CaCO₃

$$pHs = pCa + pAlk + C$$

pCa = log of Calcium cation concentration

$pAlk$ = log of MO Alkalinity

C = Constant related to temperature (T) and TDS

However, Stiff and Davis Index are preferred to be used when water solution has elevated ionic strengths since this index is more accurate in predicting the possible future scale.

$$SD = pH - pHSD$$

$$pHSD = pCa + pAlk + K$$

Where K = constant related to temperature and ionic strength.

To understand these indexes, we have to compare the pH of the inlet water:

- If $pH > pH_s$ (or $pHSD$), that mean if LSI and SD value are positive, then the inlet water is considered to be saturated in calcium carbonate and high trend for sedimentation, but with the advanced technology and the introduction of high efficacy anti-scalant, the positive index up to 2 are readily monitored and re-dissociated by reducing the inlet pH water or by circulating a muriatic acid solution.
- If $pH < pH_s$ (or $pHSD$), that mean if LSI and SD value are negative, then the inlet water is considered to be unsaturated in calcium carbonate and precipitation risk is neglected.

To recapitulate, in most of RO desalination plant, the mineral scale formation contributes to only 6 – 9 % of membrane fouling; this low percentage is due to the injection of acid and advanced anti-scalant.

6.2- Biological Fouling

6.2.1- introduction:

Natural water includes vast amplitude of biological life that could cause biofouling; even when operating using clear brackish water known to have low agglomeration of microorganisms, the possibility of biofouling persists. In general, nutrients concentrations and microorganisms are proportional and site dependant: they plentiful exist near the seashore and the sea ground, however they decrease as long as we go far from land to open sea. Raw sea water from an open intake has more microorganisms than those obtained from subsurface intake (well).

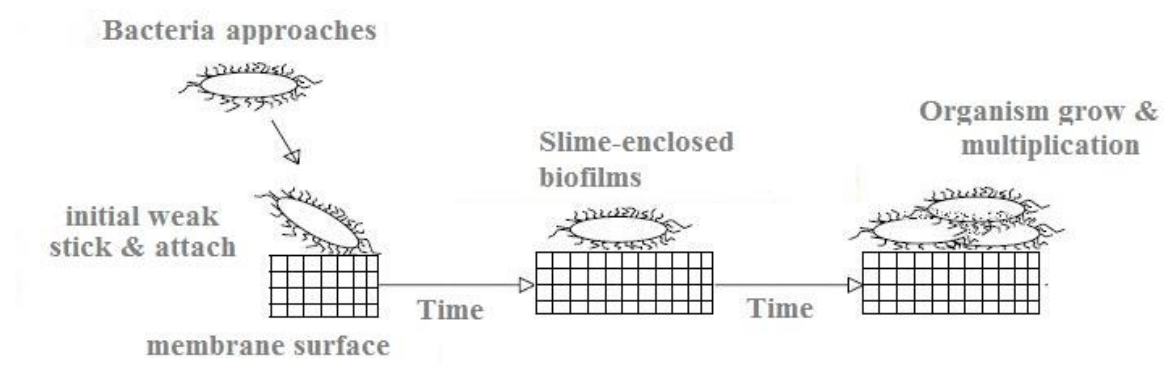
That explains the fact why biofouling is the major membrane problem which basically implicates bacteria and associated biofilm but can include fungi, algae and even nematode worms [Chesters et al., 2011]. These microorganisms could cause operational problems if not controlled, so that attention must be taken if any microorganisms exist in the raw feed water, and it is wise decision to look for the nature of the biological life, to ensure the full disinfection of all the inlet system (piping, pumps, vessels ...) till the membrane, and if necessary to disinfect even the membrane using special biocide advised by the manufacturer.

6.2.2- Formation of biofouling:

Because pre-treatment process cannot eliminate all the microorganisms existing in the raw water, the remaining traverse the sand filters to reach the cartridge filter where some of them are caught and the lasting one reach the membrane superficies. The injection of SBS imposes the absence of disinfectant near the membrane, thus biofouling (accumulation of slime and biomass) takes place on the membrane superficies from the attachment of microorganisms that start the proliferation procedure [Voutchkov, 2011].

These microorganisms mostly prosper in slime-enclosed biofilms tied to membrane superficies (drawing 3). Most of the new membranes are able to handle a viable biofilm. Experiences prove that since the biofilm is not exuding a protective polysaccharide film, then

membrane operation remains stable and the system performance is not affected [Darton et al., 2004]. The introduction of GRP piping has resulted in increased algal growth which is only stopped when the GRP is painted to prevent light.



Drawing 3: How bacteria stick to the membrane [MEDRC, 2006].

Once microorganisms occur, biofilms quickly start agglomeration, the formation of this biofilms on the membrane superficies of SWRO desalination units delimit the water volume passing via the membranes imposing a huge decreasing of water flow; this phenomenon is called Biofouling. Generally, biofilm agglomeration is a precursor to biofouling; it could be present on the membrane superficies and being stable in the absence of detectable biofouling [MEDRC, 2006]. See step of biofouling in table 28.

Event	Time to onset	Description/Explanation
Primary organic film	Seconds/minutes	Typically referred to as the <i>conditioning</i> film; defined as the rapid adsorption of dissolved organic macromolecules and inorganic substances at the membrane/liquid interface.
Primary cell adhesion	Seconds/minutes	Refers to pioneer bacterial attachment; dependent on nature of cell surface, membrane type, feed water chemistry, and system hydrodynamics; provides major contribution to early biofilm accumulation.
Cellular detachment	Seconds/minutes	Influences biofilm accumulation rate; detachment is sometimes enhanced by micro-biocidal agents, dispersants, etc.
Cell growth	Minutes/hours	Occurs at expense of soluble and sorbs feed water nutrients; may provide greatest contribution to biofilm formation where biocides are not present.
Biopolymer synthesis	Minutes/hours	Provides for greater biofilm structural integrity; acts as a reactive transport barrier to chemical biocides; promotes nutrient concentration/storage.
Particle/colloid Entrainment	Seconds/minutes	Secondary effects, where suspended particles and colloidal material are passively entrained in the biopolymer matrix or within biofilm void spaces.
Secondary cell adhesion	Days/weeks	Commences after primary biofilm formation by pioneer cells; probably strongly influenced by surface properties and physiology of primary biofilm and leads to greater species diversity.
Biofilm sloughing	Days/weeks	Refers to cell and biomass detachment; occurs in response to changes in hydrodynamic shear or turbulence forces, or introduction of biocides, dispersants, etc.
Biofilm senescence	Weeks/months	Refers to accelerated cell die-off in old biofilms; cell death is in equilibrium with biofilm growth in continuous flow systems; may result in release of soluble nutrients via cell lysis.

Table 28: Step of Biofouling [MEDRC, 2006].

The majority of the microorganisms existing in the inlet sea water aren't pathogens, but it is question of facility performance rather than health and hygiene; in fact, once redundant development of aquatic organisms began and biofouling took place, the passive influence on

desalination process started with water flow decrease accompanied with higher reading of pressure drop across the feed brine spacer, followed by loss of salt rejection efficiency, in result the overall SWRO facility performance is dramatically reduced succeed by raising in water cost.

It is so hard to take off biofilms when settlement occurs and cause fouling of membranes, the best way is to keep the high quality of feed water, maintain the good performance, and applying multiple cleaning to avert membrane damage.

6.2.3- Nutrients for microorganisms:

The best way to avoid proliferation of microorganisms is to make them starving by eliminating their source of food. Normally aquatic organisms nourish on existing nutrient in the inlet raw water which remains even after the pre-treatment stage. The mainly nutrients are: dissolved organic compounds, generally humic materials consisting of a mixture of humic and fulvic acid plus other neutral and basic compounds produced by decaying vegetation [Hassan et al., 1991].

Marine vegetable (algae and phytoplankton) create most of the humic acids, under their natural forms, these acids don't contain the valuable carbon source for the microorganisms, but once being in solution with the presence of oxidant like chlorine, they may be assimilated by the marine life [Hassan and Malik , 1989].

Furthermore, the biological activity depends on temperature, pH of solution, dissolved oxygen and sunlight. Activity tends to rise with an increase of temperature in presence of sunlight [Hassan et al., 1991].

6.2.4- effect of membrane type:

In addition to what have been detailed before, membrane biofouling is not only affected by the type of microorganisms, agglomeration and abundance of food, but it depends also on the biological attraction of the constructive and composing materials of the membrane.

The first used membranes in the past were made of cellulose acetate; during operation, the membranes were on rushed by different feed water microorganisms, emerging different dimension of holes on the superficies, and raising the product water flow and the salt quantity in the produced water. At some different cases, membranes biofouling occur accompanied with decrease in the product water flow, increasing the needed power and the adjacent cost.

Or cellulose acetate membranes can handle the oxidant disinfected Chlorine up to light dose, therefore disinfection of the whole feed line up to membrane was the adapted solution.

After the introduction of the new innovation of polyamide and non- cellulosic substances of membrane fabrication, it became impossible to allow powerful oxidants elements to reach the membranes otherwise materials degradation took place at the body of membranes. But this disadvantage was recompensed by the ability to stand and faced the microorganisms' onrush [Light et al., 1988] due to the specific properties of the membrane components. The studies inducted by [Light et al., 1988] showed withstand of UOP TFC SW membranes to biofouling caused by some kind of bacteria. Others discovers that attachment of bacteria (and later than biofouling) to superficies is related to the components of fabrication. [Flemming and Schaule,

1988] stated that the use of Polyether-urea membrane succeed to greatly reduce microorganisms ability to stick on the superficies compared to the polyamide, polysulfone and polyether sulfone type of membranes. With the intromission and the wind use of these types of membranes, the main goal now resides to monitor the consistence of biofilms.

6.2.5- How to protect the membrane:

In order to eliminate the microorganisms and avoid their multiplication and to overcome the biological fouling, the best strategy involves killing the microorganisms coupled with the restriction of nutrient supplies. This strategy is accomplished by the alternative of filtration and disinfection injection.

In general, the SWRO plants using traditional direct intakes (pre-treatment) monitor the biological fouling by the dosing of oxidants elements or biocides.

Chlorination is the worldwide used technique known to be forceful in killing the bacteria present in flowed water, but unfortunately it wasn't able to remove and eliminate the established colonies in the inlet pipes or on installed equipment superficies. In order to eliminate this colonies, the injected dose must reach 1000 – 1500 times as high as the dose used to kill free bacteria in water due to protection from extracellular polymeric structures excreted by the bacteria [Chesters et al., 2011]. Bacteria grow back very quickly when free chlorine is lost [Saeed et al., 1999]. Because the survived bacteria will feed on the new nutrients from the chlorine degraded organic material [Winters, 1994]. To be noted that the efficiency of the injected chlorine is proportional to the concentration of undissociated hypochlorous acid (HOCl), in fact chemical prove that (HOCl) is 100 times more effective than the hypochlorite ion OCl^- , and dissociation of HOCl to OCl^- increases with pH [Chesters et al., 2011]:

At pH <5 HOCl = 100%

At pH 6.5 HOCl = 90%

At pH 7.5 HOCl = 50%

At pH >10 HOCl = 0 %

Most SWRO inlet feed waters have pH between 7.6 and 8.5 which mean that the chlorination is not effective as it supposed to be; for this reason, the inlet pH should be decreased to less than 7.4. Recently, designers tend to use intermittent chlorination that differs from site to site on daily or weekly basis. Some SWRO facilities are running without the dosing of chlorination which reduce nutrient to reach near the membranes.

In their study, [Applegat et al, 1989] reported that Du Pont executed multiples experiences and tested the injection of Chloramine instead of the traditional Chlorine, they detected the advantage of Chloramine by avoiding the chlorine degradation of humic and other organic elements therefore avoiding the production of food in the raw water. As describe before, without the food sources, no assimilation by bacteria will be noted, microorganisms will get starved, they will not be able to reproduce, and in final result no biofouling will take place on the membrane superficies.

6.3- Metal Oxides

As mentioned before, twelve percent of reasons for membranes failure reveal the appearance of metal oxides. Multiple types of oxide were available, but experiences commonly reveal the existence of iron / manganese / and aluminium oxides, with the domination (40%) of iron oxide. The iron and aluminium element are not frequent in sea water, they are injected during the pre-treatment stage in form of coagulant; this last is generally a multivalent cations (iron cation under the two form ferric and ferrous, and aluminium) [Hamidi Abdul Aziz et al., 2007]. The most selected coagulant are: Ferric chloride [FeCl_3], Ferrous chloride [FeCl_2], Ferric sulphate [$\text{Fe}_2(\text{SO}_4)_3$], Ferrous sulphate [FeSO_4], Aluminium chloride [AlCl_3], Aluminium sulphate [alum, $\text{Al}_2(\text{SO}_4)_3$], Poly Aluminium Chloride [$\text{Al}_n(\text{OH})_m\text{Cl}_{(3n-m)}$].

The focus on the iron element reside in his bad fouling and damaging result on both cartridge filters and membranes as shown in Figure 22 & Figure 23.



Figure 22: Cartridge Filter fouled by iron.



Figure 23: Membrane fouled by iron.

Selecting the antiscalant is critical and essential in desalination process, the polymer form of antiscalant interact with ferrous cations to produce iron acrylate that induces irrecoverable damage to the membrane as seen in Figure 24. To avoid the presence of high concentration of iron and prevent the oxide precipitation on the membrane superficies, a lot of recent desalination plants prefer the dosage of phosphonate based antiscalants due to their biggest advantage of sequestering iron.



Figure 24: Membrane Fouling caused by iron acrylate [Chesters et al., 2011].

In their studies report, [Chesters et al., 2011] stated that membrane autopsy deposit analysis reveals little precipitation of transition metals such as titanium, vanadium, chromium, manganese, cobalt, nickel, copper and molybdenum. [Murphy, 1991] indicated that de-acetylation (of CA membranes) occurs at different level in the presence of salts: it is more efficient with cobalt and ruthenium, middling with iron, nickel, rhodium, palladium and silver, and lightly with copper and gold salts.

Most of these metals don't exist in raw sea water at important level; their presence in the feed water is mainly due to corrosion of inlet facilities and from impurities available in the injected coagulants (iron based). Operation experience report conducted by SWCC showed an increased likelihood of membrane oxidation when injecting low quality coagulant of ferric chloride due to the existence of transition metals which catalyzed the oxidation reaction [Abdulgader et al., 2001] and [Nada, 1984].

6.4- Membrane degradation

6.4.1- Oxidation

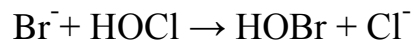
Most of SWRO desalination plants disinfect their facilities and the feed water by the injection of free chlorine; that is why membrane oxidation is the second faced problem in these plants. The recent generations of polyamide membranes impose the absence of free chlorine in the inlet water otherwise this kind of membrane will be dramatically oxidized and deteriorated; membrane oxidation is manifested by the elevation of salt passage. For example, studies on Dow FILMTEC™ RO polyamide membranes shows that deterioration took place after 200-1,000 hours of operation in the presence of 0.8 – 1.1 mg/L of free chlorine [Chesters et al., 2011]. However, all oxidant elements including chlorine could be eliminated from the feed water by the dosing of sodium metabisulphite (SBS).

Generally oxidant parameters may reach the membrane area because of: defeat in chemical dosing pumps, personal mistakes and false analysis of remaining free chlorine. The old generation membrane based on Cellulose acetate (CA) and tri-cellulose acetate (TCA) could handle to moderate concentration of free chlorine, but they are fragile regarding the microorganisms that feed on the body of membrane. Although the domination of the polyamide

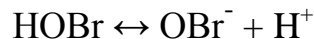
generation, the CA / TCA membrane have been preferred and selected in specific location; for example, the Red sea coastal of Saudi Arabia is famous for red and green algal blooms, thus the chlorine must be injected at high concentration; for this reason the TCA membranes have been preferred and selected to be adopted in the desalination plants of Shokaik, Rabegh and Yanbo'u. The injection of SBS was stopped from time to time, allowing free chlorine to reach the membrane area and supporting the monitor of microorganisms' proliferation.

After facilities construction or following a specific and occasionally environment condition, the piping inlet may require disinfection, if the disinfectant was not removed by SBS and arrive to membrane superficies, and oxidation started. The oxidation phenomen could be catalyzed by certain elements of aluminium and transition metal ions like Cu^+ , Cu^{2+} , Zn^{2+}

To be noted that the water chemical analysis between sea source and brackish source is the existence of bromide in concentration between 58 and 70 mg/L; therefore attention should be taken in consideration when operating with sea water, since bromide interact with hypochlorous acid to form hypobromous acid as following:



For this reason, when seawater is pumped as feed, some designers prefer to go for HOBr as selected biocide; hypobromous acid is dissolved to hypobromite ion as shown in the following chemical reaction:



However HOCl is more dissolved than HOBr, for example at pH 8, HOCl and HOBr dissociation are about 72% and 17% respectively [Chesters Stephen P. et al., 2011]; thus disinfection could be accomplish at higher pH in brackish desalination plants.

6.4.2- Abrasion

For seawater desalination plants, the HPP ensure the essential high pressure (generally between 55 and 68 bars) needed to accomplish the reverse osmosis phenomena. Working under this pressure increases the rate of abrasion failure on the membrane superficies, in fact the inlet spacer is compressed into the body of membrane following surplus pressure resulted from scaling or fouling. The traces and signs caused by the spacer could be distinctively noted as shown in Figure 25.

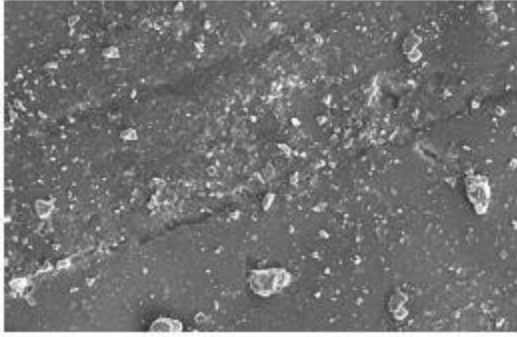


Figure 25: identification of spacer [Chesters et al., 2011].

Abrasion failure affects the membrane performance over operation, the negative effects are high salinity in the permeate and an increase in the produced water flow.

Another cause of abrasion failure is the pulling of particles along the membrane superficies, these particles could be:

- Metallic particles: the pumping or piping networks may be the subject of corrosion that delivers damaging particles into the system.
- Welding particles: during the installation of the inlet piping, any welding work may through particles.
- Algae: those having size under 5 micron are able to cross the element cartridge.
- Other particles resulting from the bad and improper cleaning and flashing.
- Cleaning particles that result from membrane cleaning procedure especially if improper filtration was adopted.
- Calcite or silicon particles: generally generated from the cartridge body.
- Filtering media particles: during commissioning the traditional sand filter could inadvertently deliver sand and anthracite into the system and damage the membrane as shown in Figure 26.

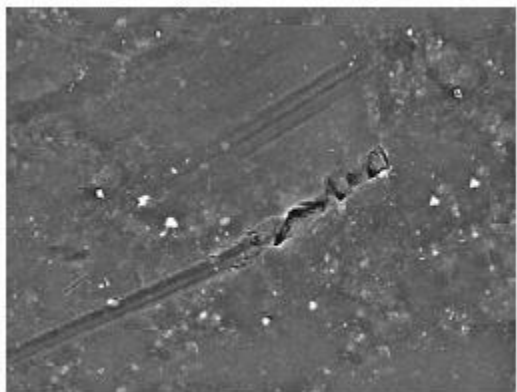


Figure 26: Abrasion caused by sand particles from media [Chesters et al., 2011].

6.5- Clay (Alumino-silicates – Al_2SiO_5)

This kind of fouling exists in 35% of SWRO membranes, mud precipitation represents one-eighths of whole membranes fouling (Figure 27). Clay or grit naturally exists in water resulting from the chemical reaction between the natural rocks and weather. From chemical point of view, they are formed by tetrahedron rings connected via common oxygen atoms to additional rings in a two dimensional plane composing a crystal flat structure looking like plate sheet (Figure 28); multiples sheets are attached together by binding stratum of positive ions. The smooth compressible characteristics are scientifically due to the encumbered water and neutral molecules between the sheets. [Swaddle, 1990] refers them as aluminosilicates when some Si^{4+} cations in the silicates structure are substituted by Al^{3+} cations; this substitute unbalances the charge equilibrium which is rectified by the presence of other cations like iron, magnesium, alkali metals, alkaline earths and other cations.

Due to the constitutional features of clay, [Armstrong et al., 2009] stated that during operation, the augmentation in applied pressure will press the precipitated clay, imposing loose in permeate flow and membrane performance. It has been proved that clay precipitation on membranes causes unrepaired damage due to abrasion. Experiences show that it is impossible to totally eliminate clay from the raw water during the pre-treatment stage although the huge amelioration in pre-treatment technologies, in fact, fine particulates/colloidal (less than $2\ \mu\text{m}$) cannot be removed from the inlet water, but clay fouling maybe reduced by using micro-filters, by dosing adequate flocculants and by adopting habitual cleaning with particular clay cleaners.



Figure 27: Membrane failure by Clay fouling [Chesters et al., 2011].

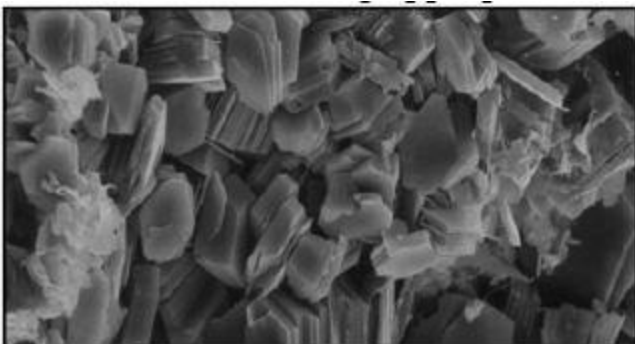


Figure 28: Clay structure [Chesters et al., 2011].

7- Pilot study: use of different types of membrane

The most expensive items in the SWRO Plant are the High Pressure Pump and the membrane. The High Pressure Pump will be bought one time, then it will be matter of maintenance (oil change, barring, alignment, heating, electrical load ...) and spare parts. In the other hand, the membranes life cycle is generally between 3 to 5 years, before membrane replacement took place, which imposing the payment of big amount of money.

Therefore the membranes to be selected are essential in order to select the appropriate type that ensures the maximum operation time and reducing the membrane replacing period and the cost. For this reason, the performance of the membrane itself in the long run is a more sensitive and accurate indicator than the SDI measurement.

7.1- Description of the Pilot study

For this purpose, we bestowed a small pilot unit to study 4 types of membranes from two membrane's manufactures (XXX and YYY) (two types for each one). Following the advice of the membrane's manufacture, from XXX we selected the XXX-H and XXX-C; from YYY we selected the YYY-4 and YYY-5.

Receiving sea water flowing through traditional pre-treatment: Chlorine disinfection, addition of FeCl_3 as coagulant and SBS to remove all oxidant element from water, our pilot unit consisted of one small Sand filter, three small cartridge filter (5 μm) and high pressure pump feeding two small 8 inches vessels; each vessel could hold two membranes (figure 29 and 30); the pilot system is equipped with chemical dosing system to ensure accurate simulation of the real SWRO Plant.



Figure 29: The sand filter and the cartridge filter of the pilot unit



Figure 30: The membrane and chemical of the pilot unit

This pilot test is designed to compare the performance of two identical sets of membranes and to evaluate the performance of various commercial SWRO membranes of spiral wound (SW) configuration on the quality of produced water and the long term stability.

7.2- Test Conditions

During all experiments, the testing conditions could be summarized as following:

- The Chlorine dose was fixed between 1-3 ppm
- The Coagulant (Ferric Chloride) dose was 1.2 ppm
- The SBS dose was around the double of the Chlorine dose.
- The pH of sea water feed was used at 2 doses: the normal sea water dose at 8 – 8.2 and at 6.5 by adding the Chloridric Acid.
- The working pressure applied to the membrane was 58 - 60 bars
- Anti-scalant dose was fixed by the manufactures for each type of the membrane
- The test Duration was 5800 Hours for each 2 sets of membranes.

The seawater (Conductivity = 43.742 $\mu\text{S}/\text{cm}$) is supplied to the pilot unit by the feed pipeline at a flow rate of about 120 to 150 m^3/d . The sea water is stored in storage tank of 30 m^3 capacity, where the chlorine (and acid when pH need to be reduced) and coagulant are dosed. Under low pressure 3 – 4 bars (40-60 psi), the feed water reaches the dual media filter from which the filtrate flows into the cartridge filter. Antiscalant and sodium bisulfite (SBS) are introduced as required after the 5 μ cartridge filter to condition the feed and remove the chlorine from it prior to the feed entry into the HPP which raises the pressure and supplies it to the membranes.

7.3- Tests details

In the first test, we introduced 2 XXX membranes XXX-H in one vessel and 2 XXX membranes XXX-C in the other vessel at pH = 6.5.

In the second test, we introduced 2 XXX membranes XXX-H in one vessel and 2 XXX membranes XXX-C in the other vessel at the normal pH 8 – 8.2 of sea water.

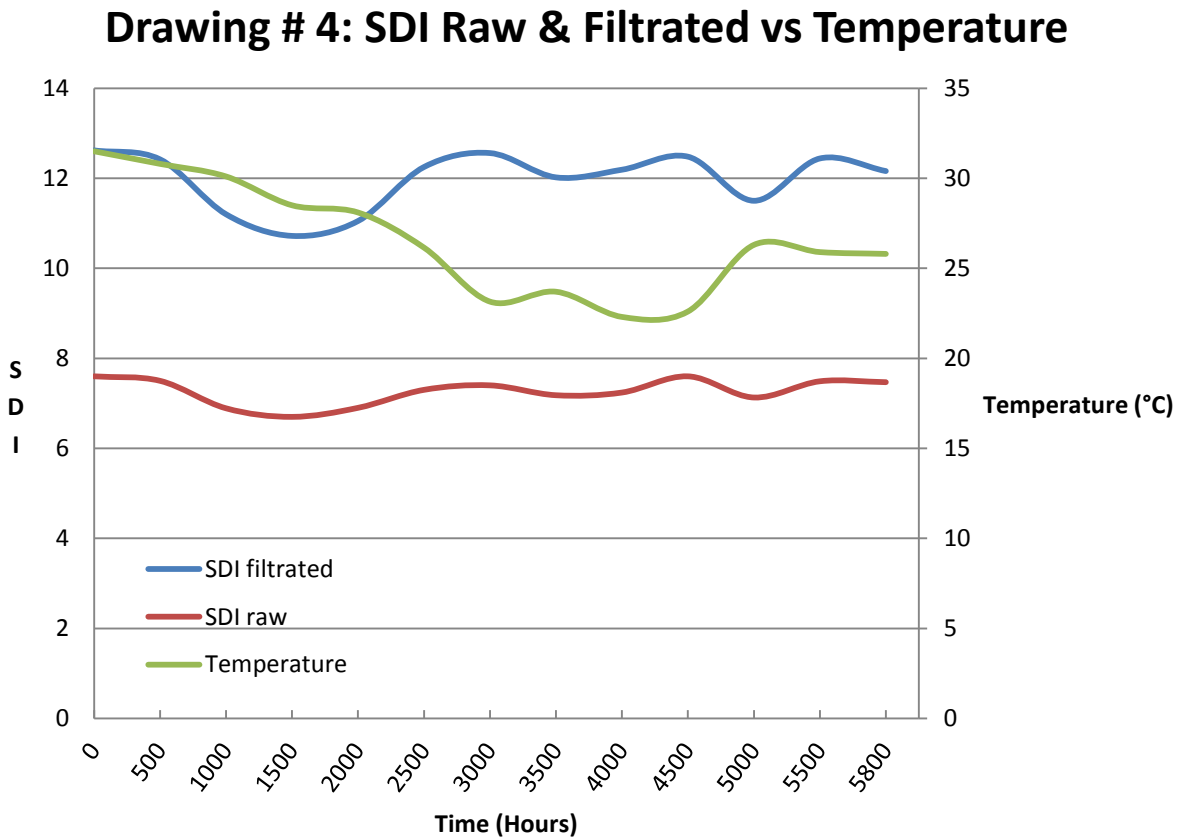
In the third test, we introduced 2 YYY membranes YYY-4 in one vessel and 2 YYY membranes YYY-5 in the other vessel at pH = 6.5.

In the fourth test, we introduced 2 YYY membranes YYY-4 in one vessel and 2 YYY membranes YYY-5 in the other vessel at the normal pH 8 – 8.2 of sea water.

All type of membrane having the same physical characteristics: same membrane surface active area (37 m^2), same configuration (spiral wound), same membrane polymer (Polyamide), almost same salt rejection (99.7 – 99.8%), same production flow and almost same operation input feed condition, and working under the same weather and temperature in special closed room.

7.4- Results and Discussions

AS mentioned before, the sea water was treated with Ferric Chloride (at 1.2 ppm) as coagulant prior to enter the pre-treatment stage. Drawing # 4 shows the SDI of sea raw water, SDI of filtrated water after the sand filter and the temperature values during the 5800 hours test period.



The TDS of sea raw water average is about 7.3 ± 0.5 ; the TDS of filtrated feed water after the sand filter is about 4.7 ± 0.6 ; the study has hold from September till May, having sea water temperature fluctuation between 22°C and 32°C with 26°C as average. This situation is considered as the standard to which all other cases studies have been done.

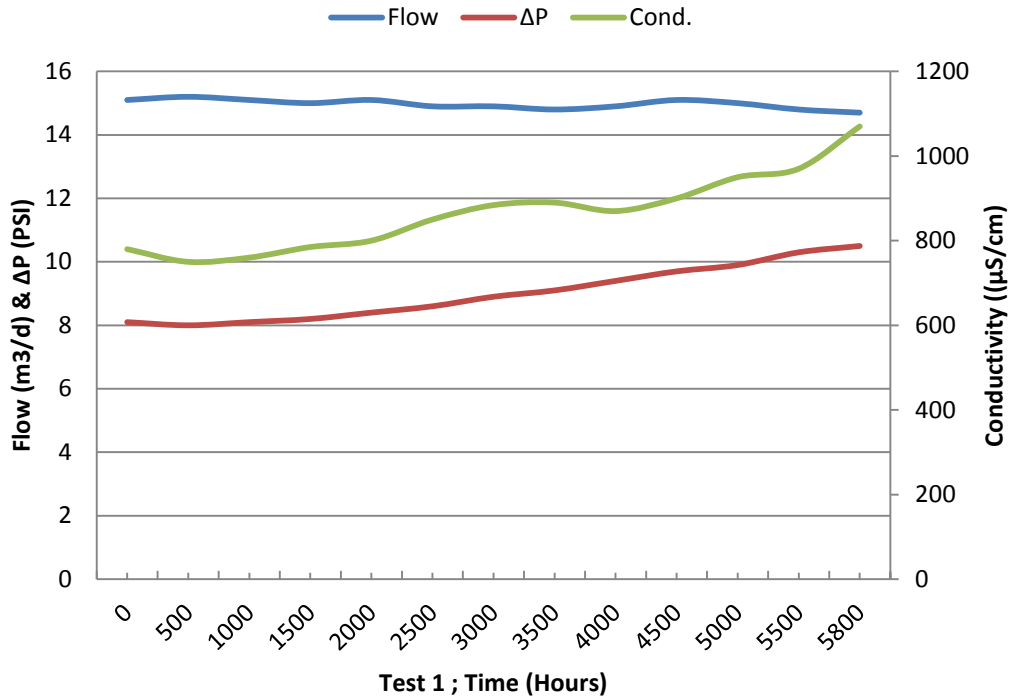
The following Table 29 resumes the summary of the performance results obtained for the four types of membranes during the 4 pilot tests study. In this table start and end values for permeate conductivity, permeate flow and pressure drop (ΔP), were computed as the average for the first and last 120 hours of operations. The average value is calculated for all results obtained during the entire operation. The Pressure drop amelioration reflects the effect of cleaning on lowering of ΔP .

Test # & membrane	Operation hours	Permeate Conductivity ($\mu\text{S}/\text{cm}$)			Permeate Flow (m^3/d)			Pressure drop (psi)			Pressure drop amelioration
		Start	End	Average	Start	End	Average	Start	End	Average	
1 ; XXX-H	5800	780	1070	866	15.1	14.7	15	8.1	10.5	9.1	4.2 psi
1 ; XXX-C	5800	850	2050	1270	17.1	16.3	16.5	9.3	12.2	10.7	2.3 psi
2 ; XXX-H	5800	770	959	847	15	13.5	14.4	8.1	12	10	3.9 psi
2 ; XXX-C	5800	820	1900	1200	16.4	13.4	14.9	9.3	13.4	11.4	2.4 psi
3 ; YYY-4	5800	740	970	856	13.7	12.3	12.9	5.1	7.4	6	2.8 psi
3 ; YYY-5	5800	705	1100	880	13.6	11.4	12.3	5	8.9	7.2	3.9 psi
4 ; YYY-4	5800	714	940	815	13.5	12	12.9	5.1	7.9	6.8	3.1 psi
4 ; YYY-5	5800	690	1060	833	13.8	11.7	12.5	5	8.7	7.4	3.8 psi

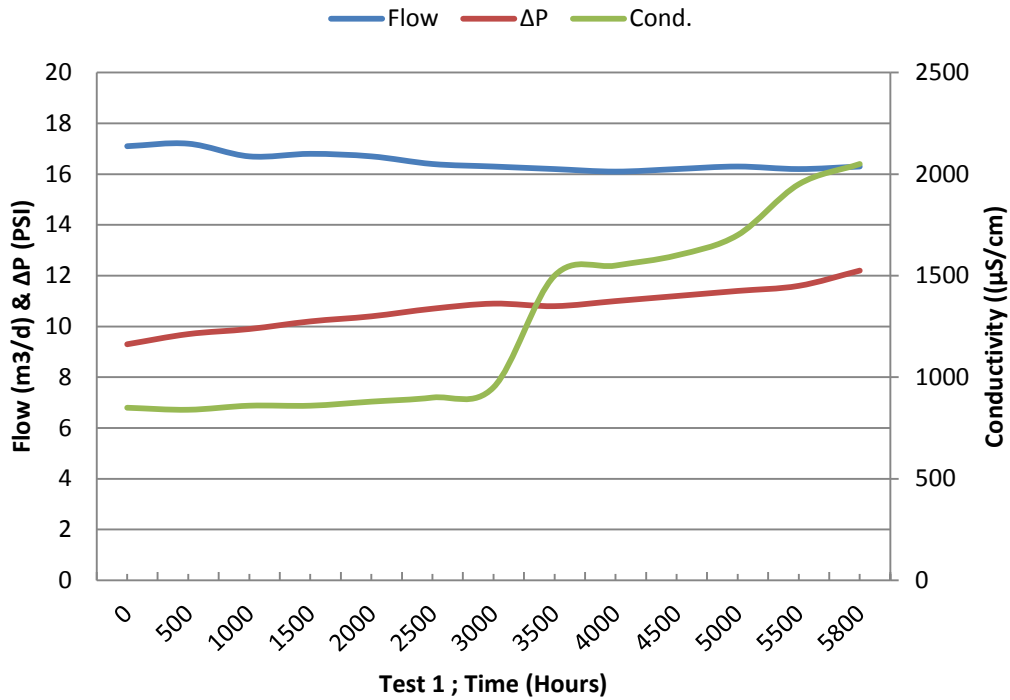
Table 29: Results summary of the pilot Study.

Table 29 and Drawing #5 to 12, show the permeate conductivity in ($\mu\text{S}/\text{cm}$), the production flow in m^3/d and the pressure drop (ΔP in PSI) v/s operation time in hours for all membranes with and without acid treatment.

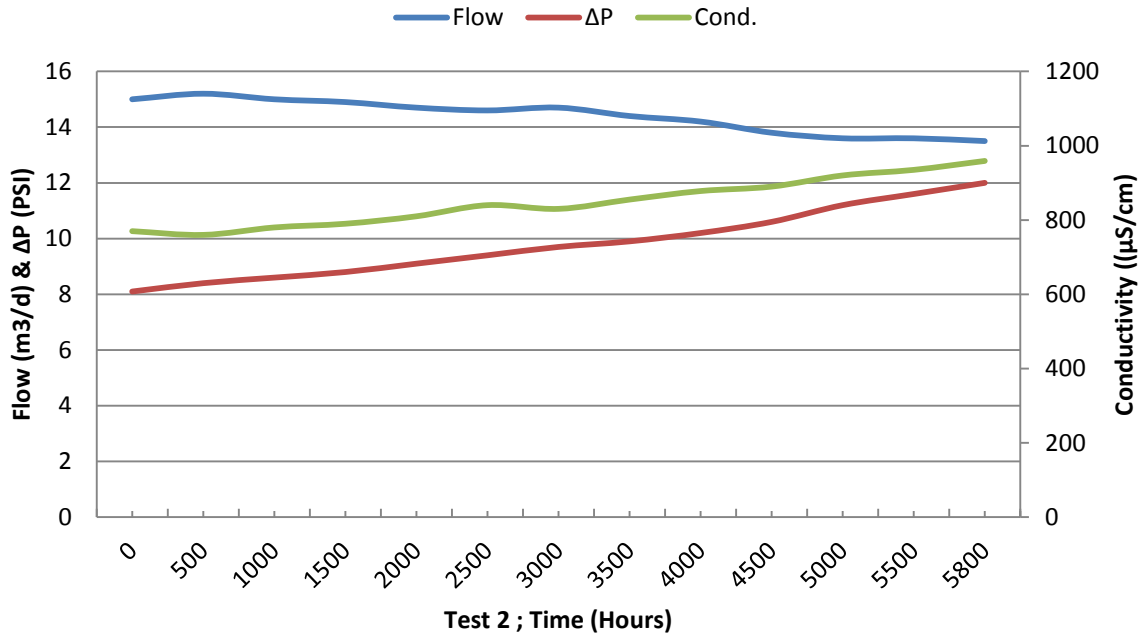
Drawing #5: XXX-H performance



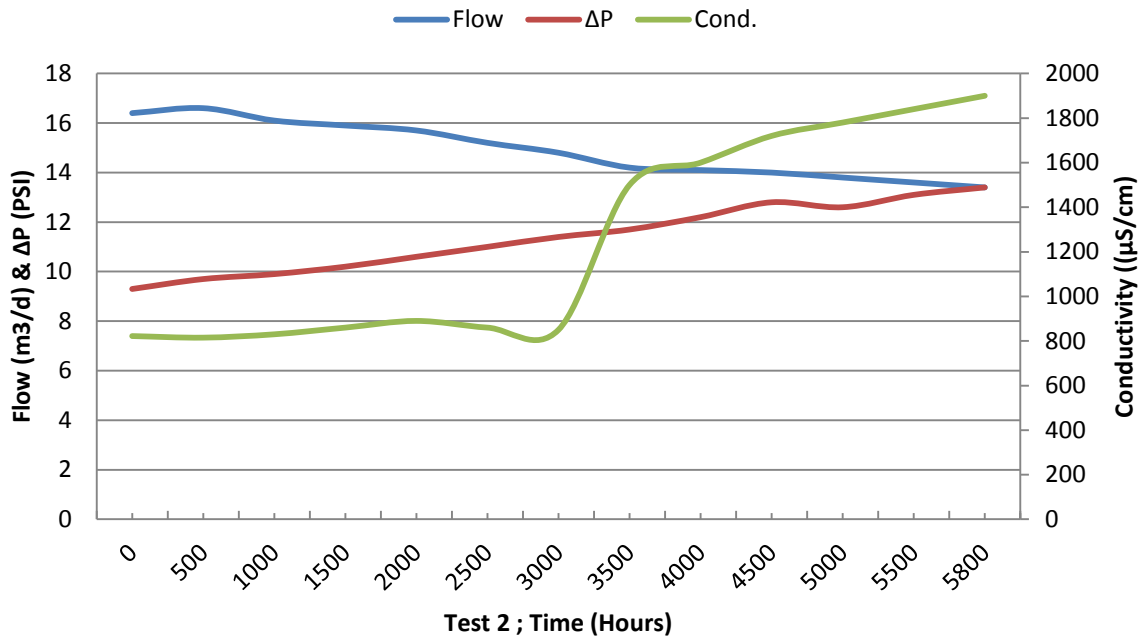
Drawing #6: XXX-C performance



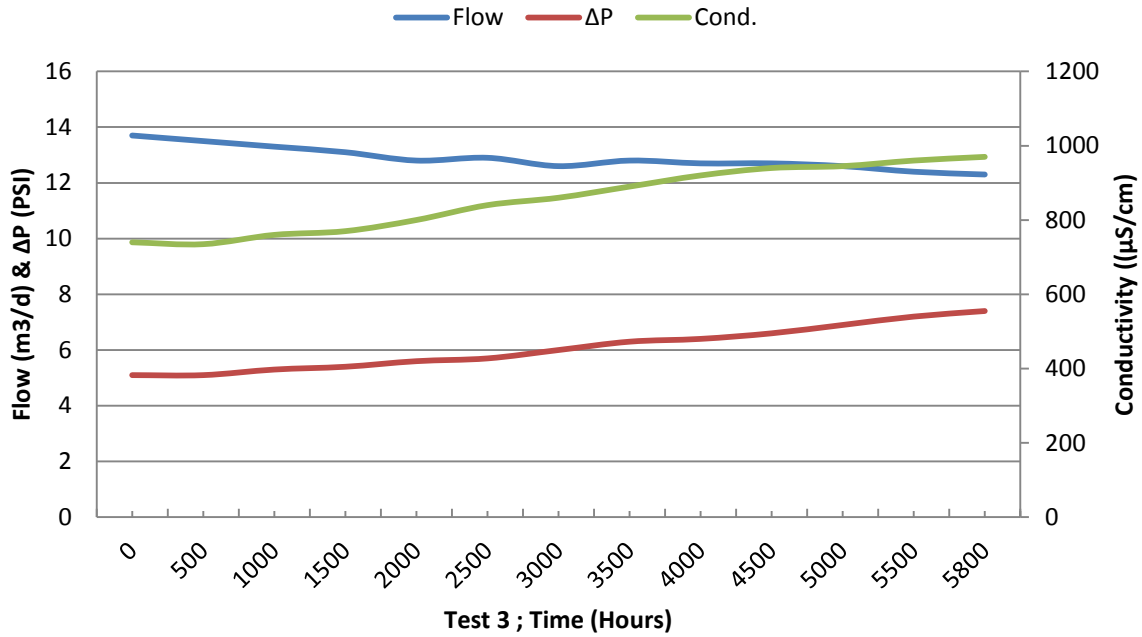
Drawing #7: XXX-H performance



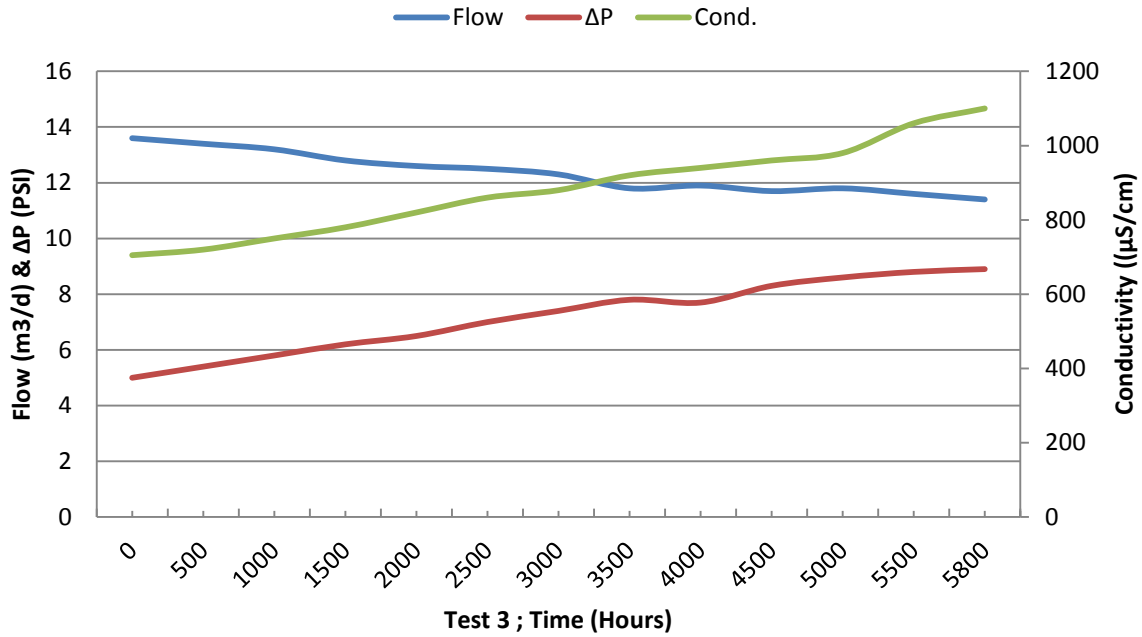
Drawing #8: XXX-C performance



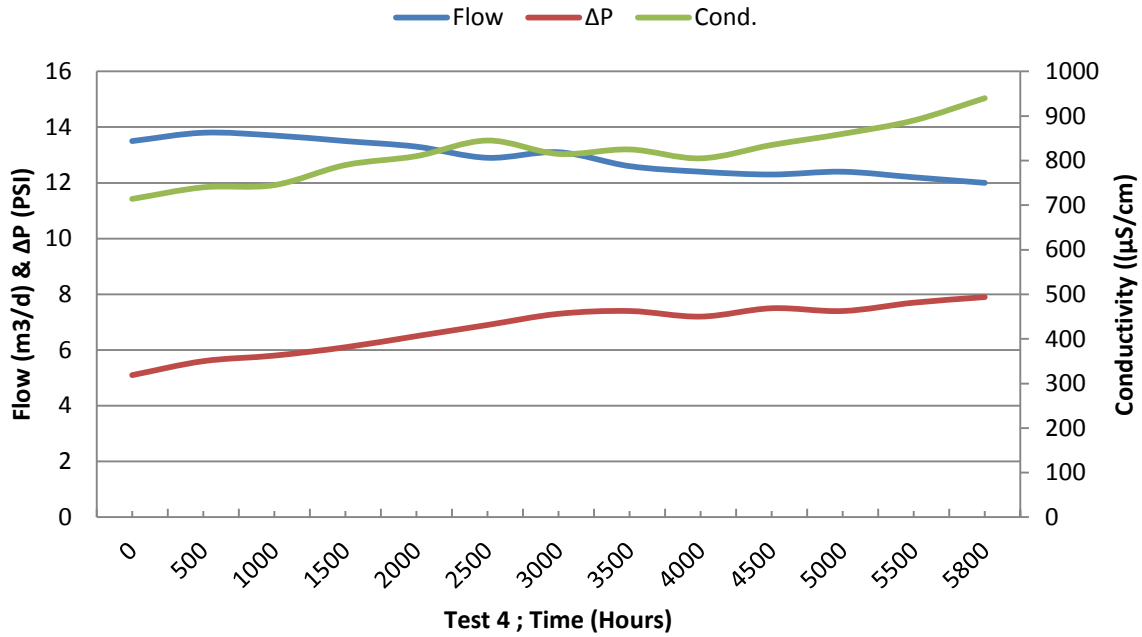
Drawing #9: YYY-4 performance



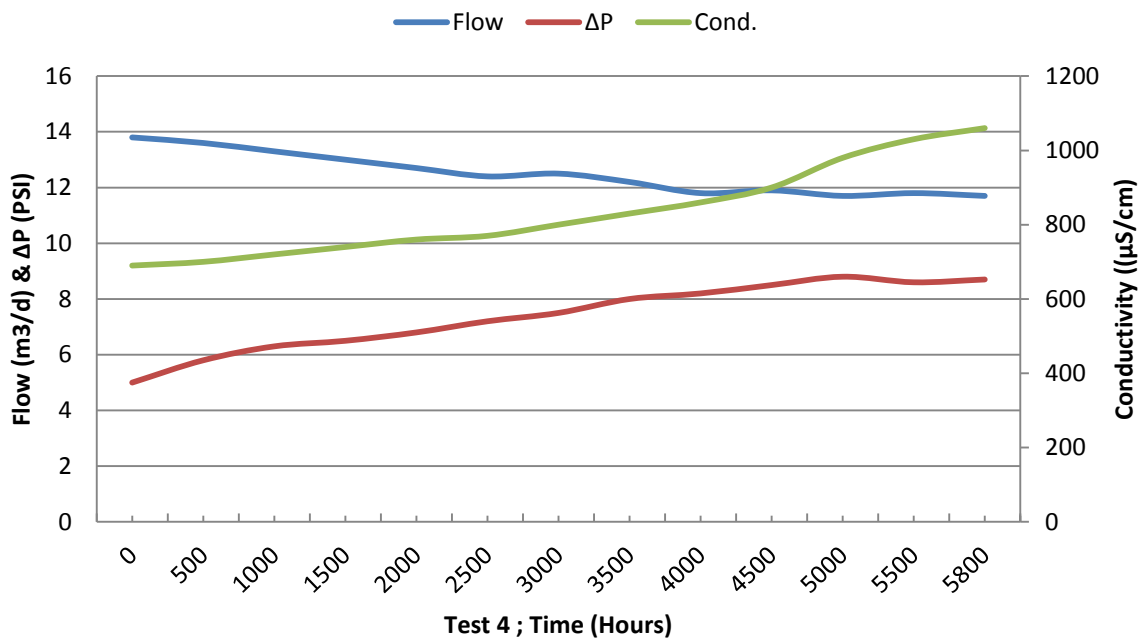
Drawing #10 : YYY-5 performance



Drawing #11 : YYY-4 performance



Drawing #12 : YYY-5 performance



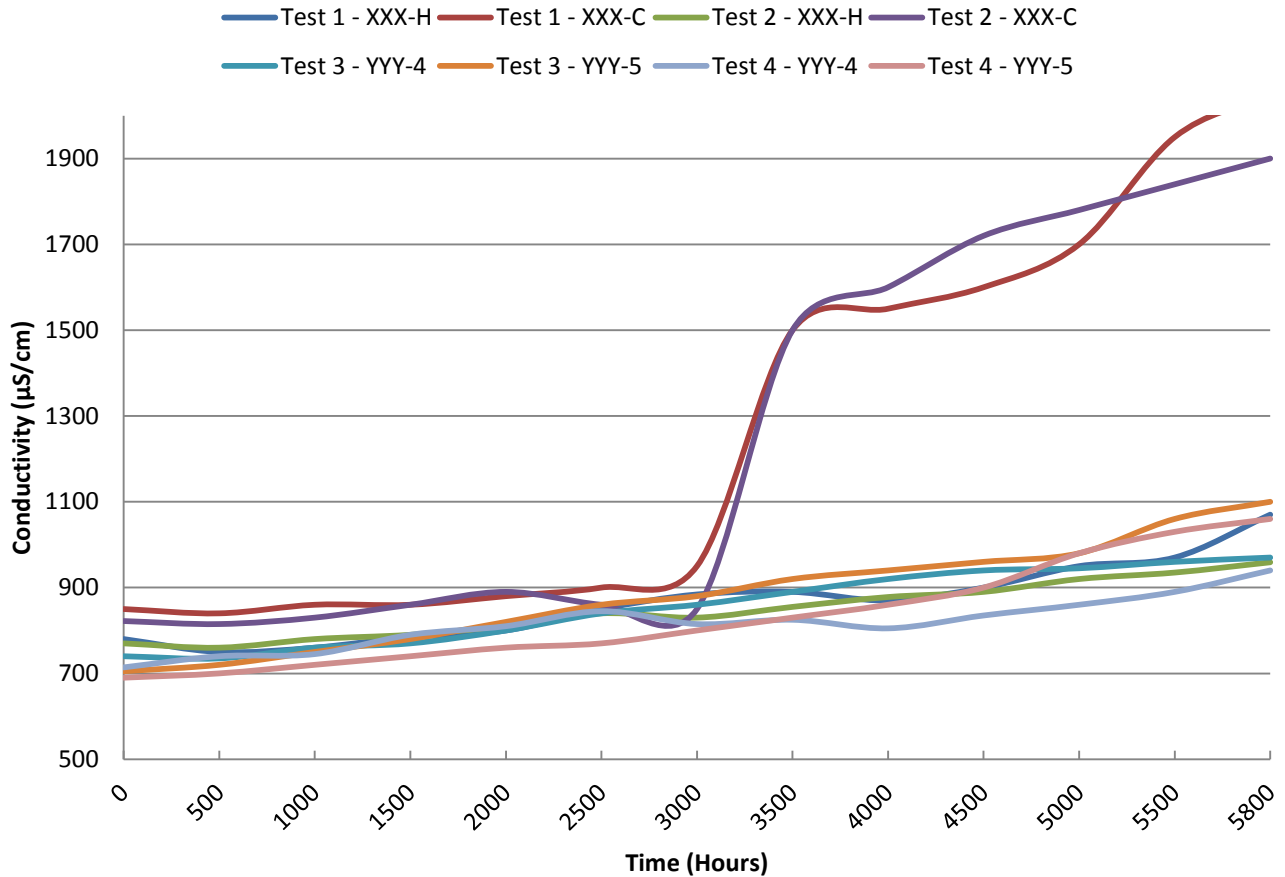
7.4.1- Conductivity:

Permeate conductivity did not obviously vary from one membrane system to another, most of them have permeate product conductivity in the range of 850 ($\mu\text{S}/\text{cm}$) with the exception of the XXX-C having an average in the range of 1240 ($\mu\text{S}/\text{cm}$). A slight amelioration of conductivity has been observed for all membrane when acid treatment has not been used, but this amelioration is negligible since it is in the range of 4-5 % only.

In drawing # 13 appears the performance of all membranes from conductivity point of view, we could note the following:

- YYY-5 having the best Conductivity at the start (around 700 $\mu\text{S}/\text{cm}$) at both case, and proving a good conductivity average around 850 $\mu\text{S}/\text{cm}$, but it shows a defective 55 % percentage increase in conductivity.
- YYY-4 was very stable during all the test, having a very good conductivity at the start (around 725 $\mu\text{S}/\text{cm}$) also it was subject to slight and constant increase during the time in both case (with and without acid), finally the percentage of conductivity increase was also stable at 31 %
- XXX-C has specific case: it was stable the first 3000 hours, when suddenly the conductivity leaps from around 900 $\mu\text{S}/\text{cm}$ to 1500 $\mu\text{S}/\text{cm}$.
- XXX-H shows great performance from the start to the end, having the best conductivity percentage increase of 24 % (without acid treatment) and keeping a steady reading during all the study.

Drawing #13 : Membrane Conductivity performance



7.4.2- Production flow:

All membranes showed some decline in their permeate flow with time. The decline, however, varied from one membrane system to another and depends on the pre-treatment and plant operation. This type of behavior is typical of membranes receiving proper treatment of their feed and is due mostly the membrane intrinsic compaction proportion.

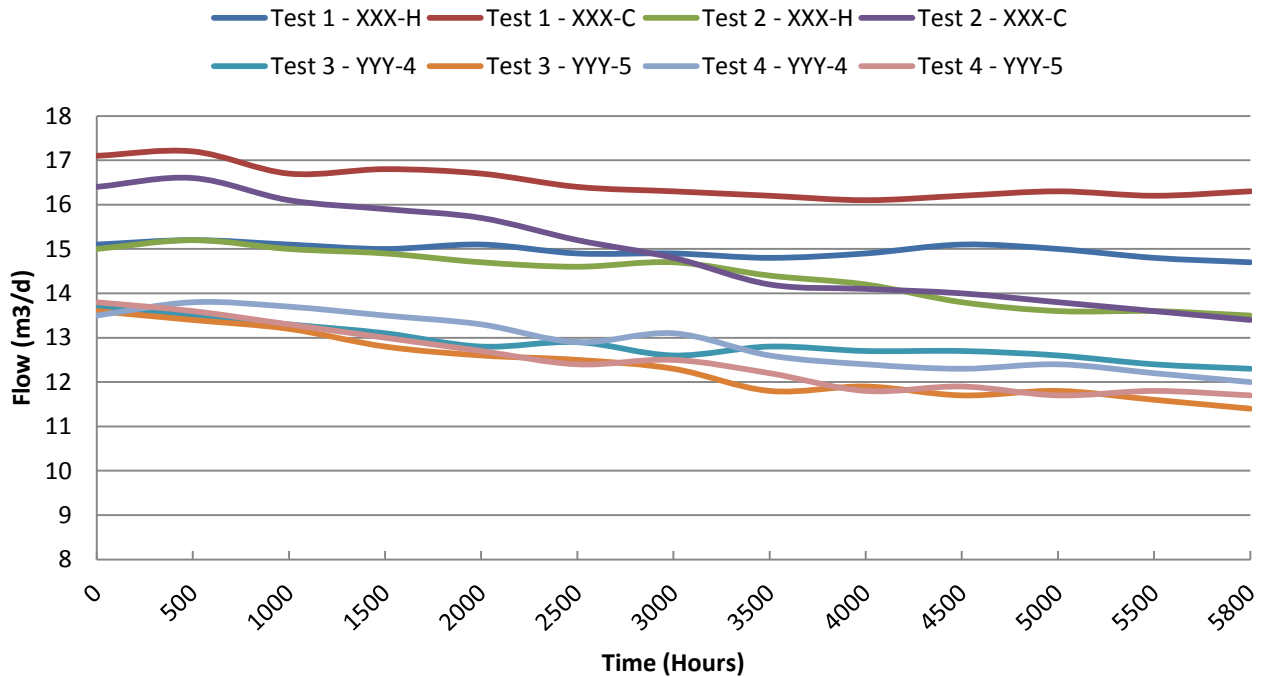
From a general view, the XXX membranes have more production flow (around 15 m³/d) compared to YYY with 13 m³/d. But YYY membrane flow production has not been affected with pH which is not the case of XXX membrane.

Drawing # 14 shows the production flow performance for all the membranes, we could note the following:

- YYY-5 has the lowest production rate at 12.5 m³/d in both case (with and without acid), and the flow decrease was acceptable at the range of 15.5 %
- YYY-4 shows an acceptable production rate of 13 m³/d, also YYY-4 have the best flow performance as it decrease by only 10 %

- XXX-C ensures the highest flow production level at 16.5 m³/d (with acid) and 15 m³/d (without acid). But without acid treatment, it reflect an important decrease in production flow (by 18 %)
- XXX-H membrane has good production rate (around 14.6 m³/d) and proves stable decline in flow production with an remarkable flow decrease of 10 %.

Drawing #14 : Membrane Flow performance



7.4.3- Differential pressure (pressure drop):

The ΔP for all the membranes rose gradually at a moderate rate; for XXX-H (with acid treatment) from an initial $\Delta P_{init} = 8.1$ psi to a value at end of operation $\Delta P_{end} = 10.5$ psi with an average value $\Delta P_{av} = 9.1$ psi for the entire operation, or without acid treatment, the end and average value of ΔP were one unit more.

For membrane XXX-C (with acid treatment) from an initial $\Delta P_{init} = 9.3$ psi to a value at end of operation $\Delta P_{end} = 12.2$ psi with an average value $\Delta P_{av} = 10.7$ psi for the entire operation, or without acid treatment, starting from the same $\Delta P_{init} = 9.3$ psi, the ΔP_{end} has been increased to 13.4 psi with an average value $\Delta P_{av} = 11.4$ psi

More or less similar behavior in rise in ΔP was observed for YYY-4 and YYY-5 membranes: with acid treatment, the ΔP_{init} , ΔP_{end} and ΔP_{av} were respectively 5.1 ; 7.4 ; 6 for YYY-4 and 5 ; 8.9 ; 7.2 for YYY-5. Without acid treatment the situation was worst, from the

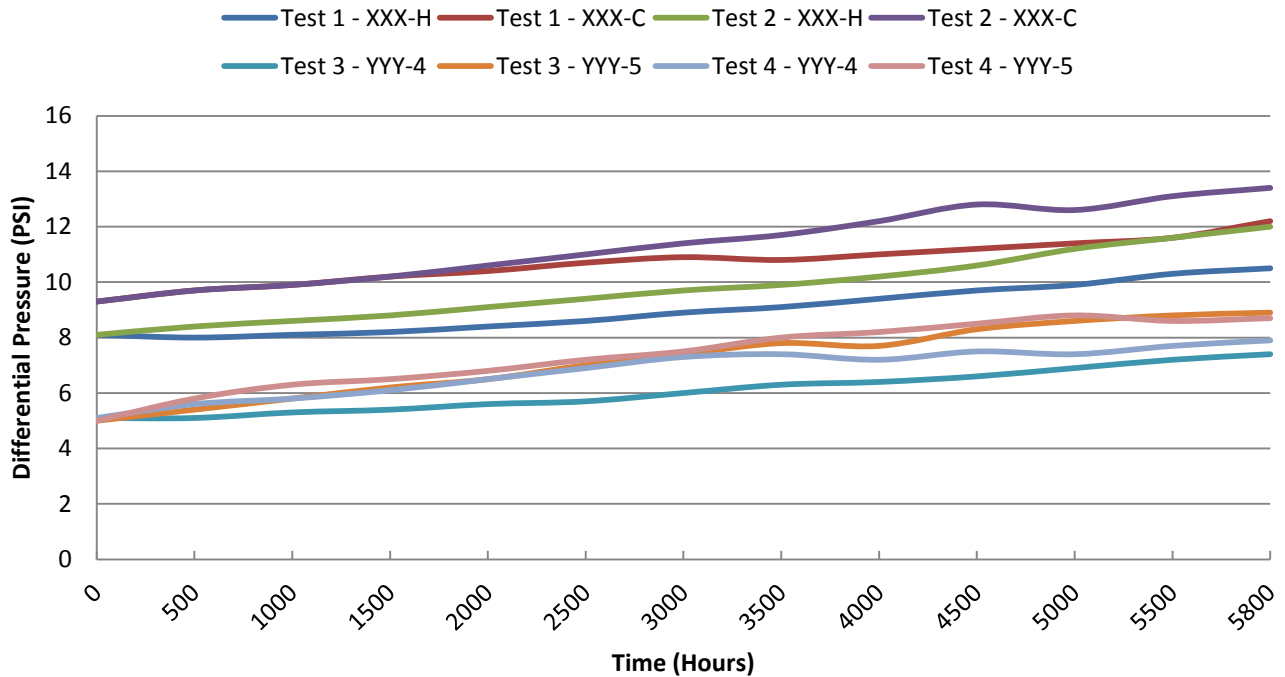
same ΔP_{init} YYY-4 shows $\Delta P_{end} = 7.9$ and $\Delta P_{av} = 6.8$; while the value for YYY-5 were 8.7 and 7.4 respectively.

Drawing # 15 reflects the differential pressure (pressure drop) performance for the four membranes at the same time, we could note the following:

- YYY-5 has very good ΔP drop, but from percentage drop point of view it is the worst with 78 % (with acid) and 74 % (without Acid).
- YYY-4 shows the best values for ΔP (6 and 6.8 psi with and without acid), or percentage of ΔP drop between the start and the end of the study is relatively high with 45 % (with acid) and 55 % (without acid).
- XXX-C case is the opposite of YYY-5, having the highest ΔP level at 10.7 and 11.4 (with and without acid), but has the lowest percentage drop at 31 % (with acid) and 44 % without acid.
- XXX-H are somehow in the middle of all that, with an acceptable ΔP level at 9.1 and 10 (with and without acid), XXX-H shows a very good percentage drop of ΔP at 29.6 % (with acid) and 48 % without acid.

An important note has to be taken in consideration, rinsing the membranes with permeate for 35-50 minutes was found effective in lowering ΔP by about 2.3 – 3 – 3.8 – 4 psi units for XXX-C, YYY-4, YYY-5 and XXX-H respectively, indicating that some of the precipitants were loosely held on the membrane surface.

Drawing #15 : Membrane ΔP performance



7.4.4- Conclusion

The use of coagulant is essential as it help to drop the SDI to an acceptable level for the SWRO operation process. The acid treatment to reduce the pH has it advantage, but from membrane performance point of view (in our case) it was not effective and did not show an important advantage. This conclusion is in consistence with other studies: at the study of Larnaca SWRO Plant, [Koutsakos et al., 2009] stated that the plant has lead the way in operating for a number of years at normal sea water feed pH (pH 8.2) by suppressing the acid injection. The removal of acid dosing did not have an adverse effect on the pretreatment efficiency and the higher operating pH had the positive impact of increased boron rejection. Another study by [Hassan et al., 1995] concluded that dosing of acid in seawater ahead of the filtration step has no major effect on filtrate SDI when compared to the SDI of non-acidified filtrates. There seems to be a body of evidence building that acidification of the feed water could be significantly reduced or replaced without impacting the effectiveness of iron coagulants and the antiscalant performance.

For the membrane selection, all the data and parameters have to be taken in consideration (including the prices). All the membrane types proved that they are good enough to be used and reflected theirs eligibility (Table 30).

Items to consider	XXX-C	XXX-H	YYY-4	YYY-5
Permeat Conductivity	-	++	+++	++
Production Flow	+++	+++	++	+
Differential Pressure	++	++	+++	+
Rising improvement	+	++++	++	+++
Price	+++	+++	++	++

Table 30: recapitulation of overall performance.

A decision must be taken, therefore, XXX-C has been eliminated specially for the suddenly jump in produced water conductivity; YYY-5 was also eliminated because her performance with time was less than the remaining types. Both YYY-4 and XXX-H were the best choice; from technical point of view, YYY-4 has a slight advantage, but XXX-H has the better advantage from price and economical point of view while preserving the high level performance, therefore XXX-H was selected.

8- Our case: design, material specification and principle of operation

The majority of RO membrane manufacturers (Dow FilmTec, TORAY, Hydranautics, Trisep, Koch Membrane Systems, Saehan, GE Osmonics) introduce and develop computer software that will propose the best design for SWRO Plant and portend the working efficiency of the membranes once installed in the plants. The input data are almost the same for all the suppliers, essentially consisting of the produced water quality and the feed water quality.

The membranes are installed in racks (units), the racks could be grouped in different stages depending on the desired objective. As our case, the easiest and modest one is the single racks, and as the desired produced water quantity increased as the number of parallel racks do.

For some specific treatment or for better produced water quality, racks could be placed in series raising the cost of the treatment plant, in this case, the brine or permeate from of the first stage represents the feed water for a posterior stage.

8.1- Design and configuration of RO unit.

For a SWRO plants, the membrane disposition and arrangement inside group of vessels called rack, array or unit. It affects the plants performance, operation cost and general cost of the plant. To succeed, the designers should determine the number of racks and the number of membranes per vessels.

8.1.1- Plant configuration

In the past, the SWRO plants were designed into two stages of vessels, six membranes per vessel. The rationale imposing the two stages configuration is that it produces an elevated feed-concentrate flux, which minimizes concentration polarization. In SWRO facilities, reducing concentration polarization will impose reducing of ions concentration near membrane superficies and thus, reducing the conductivity of the produced permeates. Or due to the increment of the differential pressure across the racks, the inlet water flow increase in parallel with inlet pressure [Wilf and Bartels, 2005].

Amelioration of membrane technologies (recent manufactures of seawater membranes produced top quality of membranes characterized by very high salt rejection up to 99.8%), efforts on the design, variety of advantaged pre-treatment, innovation of recovery turbine to reduce power consumption and other varieties development in different domains inducted the reduction of system cost, all the previous lead to the transmission of seawater plant configuration to a single stage accompanied with the augmentation of number of membranes per vessel.

Recently, most of SWRO plants configuration are single stage with six/seven membranes per vessel. The majority of the big plants are configured and run using eight membranes per vessel. Facilities using eight membranes profit from economical advantage compared to plants using six membranes per vessel; in fact, additional 34% pressure vessels are required when adopting the configuration of six membranes per vessel.

A little comparison for the above both configurations could be summarized as follow:

- The water quality in the two stages configuration is much better than the water quality produced in the one stage configuration; therefore it is mostly adopted when strict norms are applied on produced water quality like chloride or boron limits. Other example: for same target water use, a single stage maybe enough in some area while in other area (due to the elevated inlet conductivity or temperature) the two stages design must be applied.
- The differential pressure drop across membranes in a single stage design will be 1 – 1.5 bar compared to 3 – 4.5 bar for the two stages configuration.
- The higher pressure drop imposes an increase of 2- 3 % power requirement of the two stages configuration.
- In the two stages configuration, the additional pressure drop leads to high pressure at the inlet side and low pressure at the permeate side.
- For the same recovery ratio, the flux difference rating between the first and the last membrane in a two-stage design is higher than in a single-stage design.

Note: in a two-stage design, the best practical solution to ameliorate flux distribution is the installation of an interstage booster, but [Stevens L. et al., 2003] concluded that additional equipments cost is generated without getting a considerable advantages of minimizing the power consumption.

8.1.2- Number of unit

The principle for choosing the number of units relays on existing situations (example: daily vs. night demand). It is important to provide high flexibility in operation which mean it is more advisable to have two (even three) units of production instead of one unit. In our case, in order to produce 20.000 m³/d in one stage, it is wise to install 2 units of one stage having 10.000 m³/d production capacity instead of one unit having production capacity of 20.000 m³/d. In this way, while one rack is running, the second rack will be washed, cleaned or under maintenance.

8.1.3- Number of needed membranes

The number of membranes is calculated based on the SWRO plant capacity and depending on membrane manufacture average flux (found in operating facilities), for SWRO: 12-17 L/m²/hour

Note: manufacture standard test flux for membrane is higher than that adopted during operating. For example, the XXX-H membrane is tested at a flux of 48.2 L/m²/hour.

The majority of actual SWRO membrane has an active area of 34 m² or 37m². In our case, the XXX-H has an active area = 37 m².

So translating flux to element projection: for seawater RO -37m² 0.44-0.63 m³/hour (10.56 – 15.12 m³/d).

To get an assessment concerning the needed number of membrane for our plant, it is enough to divide the target permeate production by the average membrane element production: $10.000 \text{ m}^3/\text{d} / 13 \text{ m}^3/\text{d}/\text{membrane} = 769.2 = 770$ membranes.

8.1.4- Number of Vessels

The membranes are encased into vessel; one vessel could handle 1 to 8 membranes depending on the desired use, water quality and productivity. In general, SWRO plants operate using 6 to 7 membranes per vessel respecting the recovery ratio between 40-45%. Some plants operate with vessels having 8 membranes; this particular case should be in accordance with the membrane manufacture.

In our case, we adopted the use of 7 membranes per vessel, therefore the number of vessels will be calculated by simple mathematics, which means 110 pressure vessels per rack.

8.1.5- estimation of permeate water quality.

To accomplish this estimate, the following data must be available:

- Recovery rate : 40% assumed to be used in our case
- Feed Water Salinity (around 41000 ppm in our case)
- The salt rejection rate of the membrane (99.8% as per membrane specification)
- The feed water flow ($25.000 \text{ m}^3/\text{d}$ in our case)

From the recovery rate, the Concentration Factor (CF) could be calculated through the formula: $CF = 1/(1-0.4) = 1/0.6 = 1.666667$

At 99.8 % salt rejection, the correction of the CF will be: $CF = 1.66667 * 99.8\% = 1.66333$. So the reject (brine) salt concentration will be: $41.000 * 1.6633 = 68.195$ ppm. Therefore the permeate water quality will be around 226 ppm.

In Summary, for one unit, the membrane group will be composed of 770 spiral wound polyamide membranes organized inside 110 pressure vessels rated to run at an applied pressure of 59 bars, and to handle the raw inlet water quality (assuming 41, 000 ppm and 30°C). The membrane arrangement is efficiently configured to ensure the production of required flow rate ($10.000 \text{ m}^3/\text{d}$) at optimal flux speed through the membrane for long lasting life expectancy

8.2- The Pressure Vessels

In our plant, the installed Pressure vessels are made of Fiberglass Reinforced Plastic (FRP). The vessels pipe dimensions are convenient for insertion of seven membranes (8 inches diameter, 40 inches length). The pipe vessel is fitted with two end caps (closures) provided with appropriate holding systems. The end cap parts in touch with the feed salt water are made of PVC (inert plastic). The end cap located at the end of the vessel has ports for produced water. The end cap and the holding system are fabricated from 316 high quality stainless steel, they play the role of drip-tight seal, and they hold and retain the mechanism of the whole vessels.

Entry (for feed/concentrate) and exit ports are available on the side or at the front of each pressure vessels; the feed/concentrate port parts are made from high quality super systematic stainless steel, the permeate ports are made from NSF-approved ABS [MEDRC, 2006].

Our code stamped vessels can be used at 1015 psi (70 bar) working pressure, at 55°C (132° F), and as per the manufacture certificate, each pressure vessel is tested in manufacture laboratory at 1.4 times working pressure.

Our pressure vessels are installed on a high quality rubber coated base. The base is equipped with four points of support, for this purpose, we used 4 stainless steel rubber coated climbs. Structural components are fabricated from FRP Structural shapes complying with ASTM (American Society for Testing and Materials) for water adsorption.

All bolts, washers, nuts and other supports items are 316 SS.

Finally, the support structures are anchored to concrete foundations.

8.3- Feed, Concentrate and Permeate Piping

Pipes driving the raw water driven from the sea to the feed pumps, through the pre-treatment system to reach the HPP are from GRP 16 BAR SN10000 UGS CFW. Feed manifolds from HPP to Pressure Vessels, a whole part of the membrane structure, are made from 316 SS stainless steel piping. Permeate manifold are made from Class 4 PVC food graded. Concentrate outfall are made from GRP 16 BAR SN10000 UGS CFW. All the piping networks should be frequently flashed, cleaned and disinfected to completely remove welding and dust particles.

As part of ARAMCO standard, the full system should be hydro-tested with clean potable water at minimum 1.5 times working pressure.

Victaulic-type connectors are used to join the inlet water and brine headers to the ports of the pressure vessels; Victaulic-type connectors are made from 316 SS Stainless steel.

The produced water collector and the pressure vessels are connected together via high quality PVC pipes Class IV PN10 Food Graded and approved by NSF.

The Chemical dosing system is connected to the piping networks of the plant through PVC schedule 80 and schedule 40. The microprocessor controlled solenoid Dosing Pumps are from ProMinent® (Type gamma/ L), they have non-metallic bodies and they allow the manual monitoring of speed and stroke.

In order to respect the standard membrane systems, the following flow rate guidelines should be respected:

- Feed flow/vessel: 17m³/hour maximum
 10m³/hour minimum
- Concentrate flow/vessel: 3m³/hour minimum

In general, based on the material of fabrication, pipe velocities installed in SWRO systems respect the level of norms. Therefore, the following velocities should be the goal for pipe size design [The Engineering ToolBox, 2016].

- Stainless steel 2.5 to 3.5 m/sec
- Schedule 80 PVC 1.5 to 2 m/sec
- Schedule 40 PVC 1 to 1.5 m/sec
- GRP 2.5 to 4 m/sec

8.4- Instrument and control items on piping networks

Most of recent SWRO plants are fully automatic controlled, the intervention of human action is for general periodic maintenance and for detected fault intervention. However some desalination plants are not fully automatic, the level of automation control varies from fully manual to fully automated depending on the designer and stakeholder decision.

8.4.1- Control philosophy

For SWRO Plant capacity more than 20m³/d, the majorities utilize a control device based on a Programmable Logic Controller (PLC). The control philosophy is designed with safe grades to avoid the prohibited modification of fixed points. The technicians interact with the PLC via a laptop or desktop PC.

As most of actual SWRO, our plant is monitored on the principle of fixed produced water flow, and recovery rate. For plants using feed pumps that operate at constant speed, the programmed flow of the produced water flow defines the position of the adjustable feed valve; in other plants where the feed pumps are equipped with a variable speed drive, the monitor could be done by controlling the variable speed drive. In the other hand, the brine flow is detected and compared to permeate flow in the PLC, finally the electronic output signal monitors the opening of the concentrate control valve [MEDRC, 2006].

8.4.2- Instrument safety control

From desalination point of view, the control of the SWRO plants is done through the previous two loops. The additional placed monitoring devices are to manage and control the safety of the plants equipment. The following instruments and control components (table 31) have been provided to PLC for monitoring and controlling the Plant operation:

Additional control instrumentations are available on the system for more data control but have not been connected to the PLC:

Pressure gauge before and after each Sand filter

Pressure gauge before and after each cartridge filter

Control data	Location of measure	Alarm (A) Emergency Shutdown (S)
Flow	Feed	A if high and S if low
	Permeat	A if high or low
	Concentrate	A if high or low
Pressure	Feed water	S if low and A if high
	Permeat	A if high or low
	Concentrate	A if high or low
	HPP (after CF) After HPP	S if low S if low
Conductivity	Feed water	A if high
	Permeat	A if high
	Concentrate	A if high
Temperature	Feed Water	A if high
	HPP	S if high
PH	Feed water	A if high or low
	Permeat	A if high or low
	Concentrate	A if high or low
Turbidity	Feed water	S if high
ORP	Feed water	S if high

Table 31: Control parameter connected to the PLC [MEDRC, 2006].

8.4.3- Use of Data

The collected operation data are monitored and recorded in the PLC memory device, they are the base source for the normalization of the membranes performance. The periodic survey of the data is essential for plant O&M, it represents the single useful key to the plants technicians in order to estimate the membranes performance, to define the requirement of membrane autopsy, to decide the necessity of cleaning or flashing, and to estimate the efficiency of corrective taken action. Event alarms are stored, primarily as a tool for evaluating ongoing operational problems.

8.5- Membrane autopsy

Membrane elements operate simultaneously and normally, when incident occurs, the whole plants keep running, the affected membrane will be by-passed while the others remain in operation mode avoiding banal stop until other incident imposes the shutdown of the facilities, then the damage or defected membrane will be subject of autopsy. Generally, when fixed the affected or failed membrane(s) are sent for autopsy.

[Darton E.G. and Fazell M., 2001] defined the concept of membrane autopsy as the only real method to discover what is happening inside the membrane; the concept is as old as membranes themselves and based on cutting, checking and if needed analyzing. Since last decade, the autopsying specialists become more rigorous in their estimation taking advantage from the advanced technologies such as Fourier Transmission by Infrared (FTIR) and X-ray Photoelectron Spectroscopy (XPS), and affordability of techniques such as EDAX and SEM [Chesters Stephen P. et al., 2011]. From the other hand, it becomes more familiar for desalination management to provide their membrane for autopsy especially with the huge decrease of membrane prices [Darton Ted et al., 2004].

Membrane autopsy could be accomplished using some, all or more of the following steps:

- Identifying steps: the manufacture, the model, the serial number, production year and serial number are noted.
- Working data: the position in the rack, the start working date and the working condition including the dosed chemical.
- Physical condition: including the eye external check-up and took of photos. Sometime a vacuum test is applied to detect the presence of any membrane damage.
- Samples: water samples are taken from the feed, from concentrate and from permeate.
- Internal check: the external casing is totally removed; the membrane sheet is unrolled allowing internal examination.

Once the membrane sheet are unrolled, samples are taken from existing precipitation on the membrane superficies; membrane pieces are also taken and will be subject of additional analysis in a specific flat sheet test rig where flow rate and salt rejection are tested, measured and compared to plants set-up parameters. The membrane corporal deterioration are detected by the methylene blue dye test, halogens oxidation test could be accomplish by Fujiwara test or by attenuated total reflectance infrared spectroscopy (ATR/FTIR) [Milosevic, 2012].

The previous tests and analysis provide precious data concerning the main cause of membrane harmful causing low performance: precipitation, scaling, fouling, biofouling. In the mid-infrared, absorption of radiation is related to fundamental vibrations of the chemical bonds [Khoshhesab, 2012]. Internal reflection spectrometry provides information related to the presence of specific functional groups which can determine the presence of halogens.

The coupling of Scanning Electron Microscopes (SEM) technology with the Energy Dispersive X-ray Analysis (EDXA) allows detailing the chemical characterization of precipitation at any chosen zone up to few microns depth. The SEM-EDXA system relies on analysis of X-rays radiation emitted via electron beam excitation of a sample, and it is used for elemental local analysis to detail chemical composition. Its characterization capabilities are due in large part to the fundamental principle that each element has a unique atomic structure allowing a unique set of peaks on its electromagnetic emission spectrum, the X- Ray diffraction

is used to determine crystalline solids by measuring the specific spaces between layers of atoms or molecules in a crystal [Chesters et al., 2011].

In the physic-chemical sciences, the crystal form is a fingerprint for each element, and it is used to identify and differentiate the elements of the deposits on the membrane superficies. Once the precipitation is identified, membrane sample will be subject of cleaning using different types of cleaner at different temperature and pH until finding the best cleaning procedure of membrane and later on adopt it on the large plant scale.

9- Cleaning procedure

The cleaning procedure has been quoted and recapitulated from Guidelines for RO cleaning [Manual for membrane elements, 2004].

A malfunction in the pre-treatment, pressure control, or increase in recovery can result in reduced product water output or an increase in salt passage. If a problem is observed, these causes should be considered first. The elements may not require cleaning.

It should be noted that frequent cleaning is not required for a properly designed and properly operated RO system. In our case, with the XXX-H membrane's distinct combination of pH range and temperature resistance, cleaning may be completed very effectively.

Chemical cleaning is used to remove contaminations and foulants from membrane surfaces by dissolving and/or separating through physical and chemical interaction with cleaning chemicals.

9.1- When to clean

In normal operation of SWRO plant, membrane could be fouled as previously described in paragraph 6. Precipitate start up on the membrane surfaces during operation until they cause loss in normalized permeate flow, loss of normalized salt rejection, or both.

In such cases, membrane should be cleaned when one or more of the below mentioned parameters are applicable:

- The normalized pressure drop (feed-brine) of any bank = 150% of the initial value; Differential Pressure (ΔP) should be measured and recorded across each stage of the array of pressure vessels. If the feed channels within the element become plugged, the ΔP will increase.
- The normalized permeate flow decrease by more than 10%
- The normalized permeate quality decrease by more than 20%

Note: If long time passes before taking action, cleaning may not restore the membrane element performance successfully. In addition, the time between cleanings becomes shorter as the membrane elements will foul or scale more rapidly.

9.2- Type of foulants and cleaning solution

Once cleaning action should take place, it is important to determine the type of foulants on the membrane surface before cleaning. The best approach for this is a chemical analysis of residues collected with a membrane filter for SDI₁₅ value determination.

If chemical analysis could not be done, it is often possible to classified foulants based on color and consistency of residue on the membrane filter: a brownish color ⇒ iron fouling, white or beige ⇒ Silica, loam, calcium scale, biological fouling (slimy & sticky), crystalline constitution ⇒ calcium scale or inorganic colloids.

Once the type of fouling has been determined, then we have to select to type of cleaning solution to be used and impose the cleaning procedure and condition. Table 32 listed the type of cleaning solution advised by the manufacture.

Contamination	Chemical Reagent	Cleaning Condition	Reference
Calcium scale	P3-Aquaclean ACS 1%	pH value 2-3	RSU-534
Metal hydroxides	Citric Acid 1 – 2 %	pH value 2-4	RSU-533
Inorganic colloids		adjust with ammonia	
Organic matter Bacteria matter	P3-Aquaclean ACS 1%	pH value 2-3	RSU-534
	P3-Aquaclean LAC 1%	pH = 11 adjusted by HCl	RSU-535
	P3-Aquaclean ENZ 1/2% + P3-Aquaclean LAC	pH = 11 adjusted with P3-Aquaclean LAC	RSU-536
	Dodecyl Sodium Sulfate or Polyoxyethylene Sodium Lauryl Sulfate (0.1 – 0.5%)	pH = 7-11 adjusted with sodium hydroxide, sodium tripolyphosphate or trisodium phosphate	RSU-537
Acid insoluble scaling CaF, BaSO ₄ , SrSO ₄ , CaSO ₄	P3-Aquaclean SAL 1/2%	pH = 11	RSU-538
	P3-Aquaclean BUF 2.5% + P3-Aquaclean SAL	pH = 11 adjusted with P3-Aquaclean SAL	RSU-539
	Sodium Hexametaphosphate 1%	pH = 2 adjusted by HCl	RSU-540
Silica SiO ₂	P3-Aquaclean SAL 1/2%	pH = 11	RSU-538
	P3-Aquaclean BUF 2.5% + P3-Aquaclean SAL	pH = 11 adjusted with P3-Aquaclean SAL	RSU-539

Table 32: Chemical cleaning solution and conditions [Manual for membrane elements, 2004].

9.3- Dimensioning the cleaning tank, cleaning pumps and line control.

Different rules could be used in sizing a cleaning tank, the major used one is to approximately estimate the empty pressure vessels volume and then add the volume of the feed and return hoses or pipes and headers.

In our case we have to clean 110 pressure vessels (8-inch diameter) with seven elements per vessel, the following calculations would apply:

$$\text{Volume in Vessels} = V_1 = \pi r^2 L = 3.14 (0.1016 \text{ m})^2 (7.767 \text{ m}) = 0.25 \text{ m}^3 / 1 \text{ vessel}$$

$$\text{Volume of all Vessels} = 0.25 \times 110 = 27.5 \text{ m}^3$$

$$\text{Volume in Pipes and headers assumed to be } 2.8 \text{ m}^3.$$

$$\text{Volume of cleaning tank} = V_t = 27.5 + 2.8 = 30.3 \text{ m}^3.$$

The volume of cleaning solution for 8 inches membrane is between 40-80 l/membrane; generally the low level or 40 is used when the degree of fouling is low, while the 80 is for the high degree of contamination.

The cleaning pump should be sized for the flows and pressures given in the membrane manual, making allowances for pressure loss in the piping and across the cartridge filter.

Appropriate valves, flow meters, and pressure gauges should be installed to adequately control the flow.

9.4- Importance of temperature

The cleaning procedure is more effective when performed at a warm temperature as high as possible; or during recirculation of cleaning solutions, the maximum allowed temperature of 45°C must not be exceeded; in case temperature of cleaning solution exceeds 45°C due to heat build-up (liquid friction) from circulation pump, a cooling facility must be installed. The maximum temperature is dependent on pH and membrane type. During the cleaning process, temperature should not drop or increase by more than 5°C.

It is not recommended to use a cleaning temperature below 20°C because of the very slow chemical kinetics at low temperatures. In addition, chemicals such as sodium lauryl sulfate might precipitate at low temperatures.

9.5- Importance of pH

The pH of cleaning solutions used with XXX-H elements can be in the range of 2 to 11 (see Table 32), and therefore non-corroding materials should be used in the cleaning system.

Always measure the pH during cleaning because it is recommended that the solution be maintained according to the pH: if the pH increases more than 0.5 pH units during acid cleaning,

more acid needs to be added. If the pH decreases more than 0.5 pH units during alkaline cleaning, more caustic needs to be added.

9.6- Cleaning Procedure

During cleaning process the pumps transfer the cleaning chemical at low flow rate between 3-4 m³/h, this should be done at low pressure, generally between 1-2 bars to displace the process water. The use of low pressure is to compensate for the pressure drop from feed to concentrate. The pressure should be low enough that essentially no or little permeate is produced. A low pressure minimizes the redeposit of dirt on the membrane. The concentrate should be dumped out, as necessary, to prevent dilution of the cleaning solution.

Most of membrane manufactures advice to pass by flashing procedure with pre-treated feed water. In fact, flushing cleans membrane surface by high flow velocity (12 m³/h/membrane) using a large quantity of feed water at low pressure (1–2 bars). It is effective for cleaning of light organic fouling. For the best results, flashing should be executed several hours after shutdown of the RO system, in order to utilize the soaking effect for separation of foulants layers from the membrane's surface.

Recycle: After the process water is displaced, cleaning solution will be present in the concentrate stream. The concentrate and permeate will be recycled to the cleaning solution tank during 30 to 60 minutes, which allow the temperature to stabilize. The pH of the solution should be measured and adjusted if needed. This step could be repeated 2-3 times if needed.

Soak: Turning the pump off allows the elements to soak. Soaking period varies between 2-24 hours depending of type and degree of foulants, sometimes a soak period of about 1 hour is sufficient. In case of difficult fouling, temperature must be maintained during the extended soak period.

For more efficiency: it is wise to adapt alternation of recirculation and soaking.

Note: Turbid or strong colored cleaning solutions should be replaced. The cleaning is repeated with a fresh cleaning solution.

High-flow pumping: Feed the cleaning solution at high flow rates (6-9 m³/h) for 30-60 minutes. The high flow rate flushes out the foulants removed from the membrane surface by the cleaning. If the elements are heavily fouled, a flow rate which is 50 percent higher may aid cleaning. At higher flow rates, excessive pressure drop may be a problem.

Flush out: after cleaning, it is recommended to flush out the cleaning solution from the elements with good quality (chlorine-free) water at 20°C minimum temperature for 1-2 hours.

Permeate water or deionized water is recommended. Pre-filtered raw water or feed water should be avoided as its components may react with the cleaning solution: precipitation of foulants may occur in the membrane elements.

Care should be taken to operate initially at reduced flow and pressure to flush the bulk of the cleaning solution from the elements before resuming normal operating pressures and flows. Despite this precaution, cleaning chemicals will be present on the permeate side following cleaning. Therefore, the permeate must be diverted to drain for at least 30 minutes or until the water is clear when starting up after cleaning.

CHAPTER 4: ENVIRONMENTAL IMPACT

Environmental impact

1- Introduction

The cost of concentrate discharge is another important item that must be taken into account. In coastal desalination plants the cost of brine disposal to the sea ranges from 4 to 23% of the total cost of SWRO Plant; being the disposal cost higher for inland desalination plants than for coastal plants where brine is discharged into the sea. In both cases, the cost of concentrate disposal relies on the concentrate characteristics, level of pre-treatment before discharge, disposal method and concentrate volume.

In general, **Marine Environment impact** reside in: Constituents in waste discharges, thermal effects, feed water intake process, effects of biocides in discharge water, and toxic metals, oxygen levels, turbidity, salinity, mixing zones, commercial fishing impacts, recreation, and many others [WHO, 2007].

Environmental protection issues are evident when considering the impacts of any large construction project sited in a coastal or other environmentally sensitive area. Protection of the coastal ecosystem and protection of groundwater from contamination by surface disposal of concentrates are examples of issues that must be addressed during the design, construction and operation of a desalination facility [Mauguin and Corsin, 2005].

As any industrial facilities, the seawater desalination plants are being introduced to areas where they did not previously exist; their potential effects on marine biological resources and water quality have fallen under increased scrutiny. The intake and outfall are the two primary elements of a desalination plant likely to cause adverse environmental impacts. Environmental impacts associated with concentrate discharge have historically been considered the greatest single ecological impediment when sitting a seawater desalination facility. Methods to mitigate this risk must be taken into consideration in their design and operation [Pankratz, 2004].

The basis of all desalination processes using semi-permeable membrane technology is conversion of part of the inlet feed water flow into fresh purified water production (permeate). This has the inevitable result that a stream of water relatively concentrated in dissolved salts and retained compounds (concentrate or brine) will be discharged from the plant [Morton et al., 1996]. The environment concerns associated with the discharge from any SWRO facility revolve around the brine that is produced as a byproduct of the desalination process and its potential bad effects on receiving water organisms and ecosystem.

In fact, wastes from desalination plants include concentrated brines, backwash liquids containing scale and corrosion salts and antifouling chemicals, and pre-treatment chemicals in filter waste sludge.

2- Brine characteristic

As seen before, all desalination process produce two types of water; a *product water* stream that is essentially “pure”, and a *concentrate*, or reject stream. This liquid stream contains most of the minerals and contaminants of the source water and pre-treatment additives in concentrated form, and whose salt content includes the salt removed from the product water. In a seawater desalination facility, the salt concentration of the concentrate stream is usually less than two times (1.5 – 1.8) that of the seawater. In desalination plants, generation of brine is about 55% of collected seawater [Meneses et al., 2010]. Recent estimates suggest that up to 25 million m³ of desalinated water is produced daily around the world [Lattemann and Hopner, 2008].

Depending on the pre-treatment process, various chemical such as coagulants, antiscalants, polymers or disinfectants are used in desalination plants to control the formation of mineral scale and biological growth that would otherwise interfere with the process. These chemicals, or their reaction products, are commonly discharged with the reject brine to water bodies and constitute a potentially serious threat to marine ecosystems [Morton et al., 1996].

The characteristics of the waste stream, named concentrate, retentate or brine, depend on the quality of the feed water, the quality of the produced water, the pre-treatment method (added chemicals) and cleaning procedures used; therefore, concentrate streams vary dramatically in quantity and chemical composition. The level of chemicals added to control scaling, fouling, and corrosion is relatively low and the concentrate stream is defined by original constituents in the feed water. SWRO concentrate is fairly predictable in quantity and concentration [Pankratz, 2004] (Conductivity, total dissolved solids and chloride concentration present significantly higher values in RO brines); most facilities operate at a product water recovery rate of 35 to 50% and a concentration factor of 1.54 to 2.

3- Effect on marine life

Most seawater desalination facilities are discharging concentrate back in the sea where it is almost immediately diluted by the large volume of available water. It is important that the discharge be accomplished in responsible, well-engineered manner to minimize its environmental impact, and the following factors will impact the cost of the disposal system [Pankratz, 2004]:

- Distance from the desalination facility to the discharge point.
- Quantity and quality of concentrate.
- Quality and sensitivity of the receiving water: Compatibility between the composition of the desalination plant concentrate and receiving waters (ion-imbalance driven toxicity).
- Salinity increase beyond the tolerance thresholds of the species in the area of the discharge
- Concentration of metals and radioactive ions to harmful levels

- Concentration and discharge of nutrients that trigger change in marine flora and fauna in the area of the discharge
- Disturbance of bottom marine flora and fauna during outfall installation
- Availability of dilution water.
- Method of discharge.
- Permitting requirements.
- Monitoring requirements.

The primary environmental concern with a concentrate direct discharge is that it poses a potentially serious threat to marine ecosystems. The main issues which will need to be addressed during the feasibility evaluation of disposal of seawater desalination plant concentrate to the ocean include:

- A. evaluation of discharge dispersion and recirculation of the discharge plume to the plant intake
- B. evaluation of the potential for whole effluent toxicity of the discharge
- C. assessment whether the discharge water quality meets the numeric and qualitative effluent water quality standards applicable to the point of discharge
- D. establishment of the marine organism salinity tolerance threshold for the site-specific conditions of the discharge location and outfall configuration in order to design the outfall for dilution which meets this threshold within a short distance from the point of discharge.

3.1- Effect of high Salinity

When returned to the ocean without dilution, the concentrate may have a negative impact on the aquatic environment in the area of the discharge unless managed adequately [Gude, 2016]. The hyper saline discharge tends to be of a higher density than the receiving water and can, therefore, sink to the bottom and negatively impact benthic and demersal organisms in the vicinity of the discharge [WATER RESEARCH FOUNDATION, 2011]. This impact is very site-specific and it depends to a great extent on the salinity tolerance of the marine organisms inhabiting the water column and benthic environment influenced by the discharge as well as the rate of its dissipation in the ambient seawater.

3.2- Effect of used Chemicals

Concentrate disposal may also have impacts other than direct changes in salinity. In some circumstances, concentrate plume density may lead to increased stratification reducing vertical mixing; this stratification may in turn reduce dissolved oxygen level in the water column or at the bottom of the ocean in the area of the discharge, which may have ecological implications. Chemicals in concentrate water may exert toxicity in the receiving waters, particularly with regards to the chloride content [Nitto Group Company, 2013]. Certain metals (copper, nickel, iron, chromium, zinc, etc.) may lead to eutrophication, pH value variations and accumulation of heavy

metals [Meerganz von Medeazza, 2005]. Actually some research on the development of effective anti-scalant with no biological effects may assist in the production of less toxic brines in the future [Roberts et al., 2010].

3.3- Zone of Initial Dilution

The total or whole-effluent toxicity must be shown to fall below acute toxicity limits in receiving waters with the exception of small zones of initial dilution (ZID) at the point(s) of discharge [Pankratz, 2004]. Acute criteria may be exceeded in a ZID if the estimated toxicity levels are not lethal to local marine organisms. The ZID for a seawater outfall are usually considered on a case-by case basis, although the ZID in bay or estuary may be a volume equal to a 15m radius in all directions from the discharge point.

The main purpose of the evaluation of the concentrate dispersion rate from the point of discharge is to establish the size of the ZID required to dissipate the discharge salinity plume to down to within 10% of ambient seawater TDS levels; and to determine the TDS concentrations at the surface, mid-level of the water column, and at the ocean bottom in the ZID. The TDS concentration fields at these three levels are then compared to the salinity tolerance of the marine organisms inhabiting the surface (mostly plankton), the water column (predominantly invertebrates), and the ocean bottom sediments in order to determine the impact of the concentrate salinity discharge on these organisms.

The ZID discharge salinity and boundaries are established via hydrodynamic modeling. This modeling permits determining the most suitable location, design configuration and size of the outfall, and diffusers if a new outfall is needed, or to assess the feasibility of using existing wastewater or power plant outfall facilities.

3.4- Need of action to improve the reject

The widespread belief and recognition of the negative ecological impact of the reject concentrate stream have been proved by Laboratory-based experiments, toxicological investigations and manipulative field experiments clearly demonstrate the potential for brines and their constituents to illicit adverse impacts on aquatic organisms when present at sufficient concentrations especially to fragile ecosystems such as corals [Roberts et al., 2010]. Therefore, proposed desalination facilities must demonstrate that the discharge will be controlled so that applicable acute and chronic toxicity standards are not exceeded.

4- Applied technologies for solution

Depending upon the location and other circumstances including access to the ocean and sensitive aquifers, concentrations of toxic substances etc., wastes could be discharged directly to the sea, mixed with other waste streams before discharge, discharged to sewers or treated at a sewage treatment plant, placed in lined lagoons and dried and disposed in landfills [WHO, 2007]. Concentrates disposal is one of the most challenging issues with respect to desalination processes.

Recovery of important minerals from concentrates is possible and may be economically viable in some cases, because it also reduces waste disposal costs. Starting with traditional treatments such as evaporation and crystallization other technologies that have emerged in last years to reduce the volume of the concentrate before disposal and with the objective of achieving zero liquid discharge and recovery of valuable compounds from these effluents are also reviewed. Most of these emerging technologies have been developed at laboratory or pilot plant scale (see Table 33) [Pérez-Gonzalez et al., 2012].

Used Technique	Level of use	Note
Direct reject in Seawater	Most used	Restricted to low flow rate
Direct reject with diffuser	Widely used	
Dilution with Power Plant	Industrial application	Need the presence of 2 facilities nearby
Dilution with sewage Plant	Industrial application	Need the presence of 2 facilities nearby
Discharged in sewage Plant	Few application	High cost for water treatment
Placed in Lagoons/Landfills	Few application	Need big area
Solar evaporation	Industrial application	Large area needed + low productivity
WAIV	Pilot Plant – Laboratory level	Industrial feasibility not proved, Moderate investment cost; Difficult operational control; Scaling and fouling; Moderate energy consumption
Forward Osmosis	Laboratory level	Use of drawn solution ; Moderate energy consumption
Liquid-Liquid extraction	Laboratory level	Several treatment stages; Extractants consumption

Table 33: most used concentrate discharge technologies [Pérez-Gonzalez et al., 2012].

4.1- Direct discharge to sea water

Discharge of seawater desalination plant concentrate through a new outfall is widely used for projects of all sizes. Over 90% of the large seawater desalination plants in operation today dispose their concentrate through a new outfall specifically designed and build for that purpose.

Direct discharge or dispersion occurs when a by-product stream is directly diverted to seawater without any treatment or combination. The main purpose of ocean outfalls is to dispose of the plant concentrate in an environmentally safe manner, which in practical terms means to minimize the size of the zone of discharge in which the salinity is elevated outside of the typical range of tolerance of the marine organisms inhabiting the discharge area.

The two key options available to accelerate concentrate mixing from an ocean outfall discharge is to either rely on the naturally occurring mixing capacity of the tidal (surf) zone or to discharge the concentrate beyond the tidal zone and to install diffusers at the end of the discharge outfall in order to improve mixing.

4.1.1- simple direct discharge to seawater

Generally, open near-shore tidal zones usually carry a significant amount of turbulent energy and usually provide much better mixing than the end of pipe type of diffuser outfall system, such zones have limited capacity to transport and dissipate the saline discharge load into the open ocean. Therefore, the tidal zone is usually a suitable location for salinity discharge only when it has adequate capacity to receive, mix and transport this discharge into the open ocean.

Desalination plant concentrate is usually accomplished by means of a submerged offshore pipe that discharges directly into the sea. Where ambient conditions favor rapid dilution, there is a very large bulk mixing ratio, or where flows are relatively low (less than 5000 m³/d), a single port outfall may be used.

In most cases, the brine is diluted with the excess intake water and/or with the back wash water of sand filter in order to reduce its salinity prior to discharge; this can minimize negative effects but in this case the particles, total suspended solids (TSS) and biochemical oxidation demand (BOD) resulting from the back wash of sand filter will occur in the concentrate with high turbidity level. Or if this is accomplished by increasing the intake volume, then the reduced discharge effects may be offset by the increased impacts associated with the elevated intake flow rate [WATER RESEARCH FOUNDATION, 2011].

4.1.2- Multi discharge / diffusers

If the mass of the saline discharge exceeds the threshold of the discharge zone's salinity load transport capacity, the excess salinity would begin to accumulate in the discharge zone and could ultimately result in a long-term salinity increment in this zone beyond the level of tolerance of the aquatic life in the area of the discharge.

The diffuser is a bifurcated double-T-arrangement (figure 31) and incorporates a discharge angle of 60°. This design was adopted with the expectation that the plume would rise to a height of 8.5 m before beginning to sink due to its elevated density. It was designed to achieve a plume thickness at the edge of the mixing zone of 2.5 m and, in the absence of ambient cross-flow, 40m laterally from the diffuser to the edge of the mixing zone.

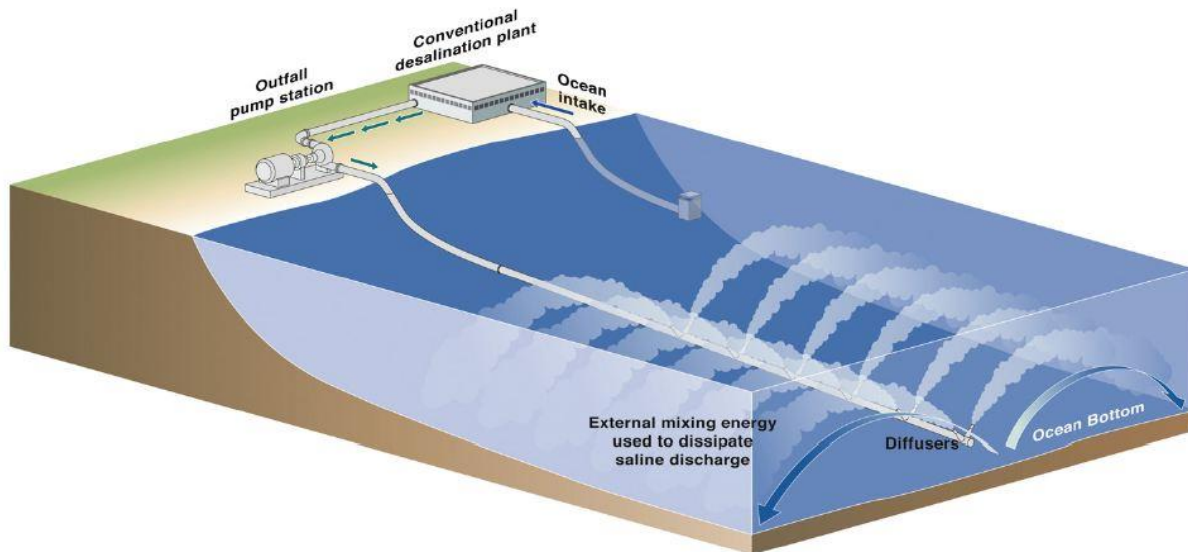


Figure 31: Conventional concentrate discharge with diffusers [Voutchkov, 2011].

Multi-port diffusers – where a header pipe contains two or more ports that inject concentrate at a high velocity into the ambient seawater – are used for facilities with larger flows, or where maximum dispersion is imperative [Pankratz, 2004]. The number, size, and alignment of diffusers are based on hydraulic analysis.

Dispersion models are used to choose the discharge point with less environmental impact but these structures appear to have limited success with the high flow rate ($50,000 \text{ m}^3/\text{d}$) and the environmental damage is also incurred [Munoz and Fernandez-Alba, 2008].

Key advantages related to using a direct outfall are that this type of concentrate disposal option allows to accommodate practically any size of seawater desalination plant and that it provides for more freedom in selecting plant location, as compared to the other two disposal approaches where existing wastewater plant or power plant outfalls are used and therefore, the desalination plant location and capacity are most often driven by the location and size of the existing outfall facilities. Also, the direct outfall is easy to construct and require low maintenance.

Principal disadvantages of this discharge alternative are that it usually is very costly and that its implementation requires extensive and lengthy environmental and engineering studies. Depending on the site-specific conditions, the costs for a new ocean outfall are significant, and they typically range from 10 to 20% of the total desalination plant construction expenditures.

4.2- Dilution with power plant outlet

One mechanism that has been applied to reduce adverse environmental effects of brine relies on its dilution with power plant cooling waters. Under a collocation configuration, the intake of the seawater desalination plant is connected to the discharge canal of the power plant to collect a portion of the cooling water of this plant for desalination (see Figure 32). After the seawater is pretreated, the concentrate is returned to the power plant discharge downstream of

the point of cooling water intake. This configuration allows effectively using cooling water from an electric power plant both as source water for the seawater desalination plant and as a blending water to dilute desalination plant concentrate prior to its discharge to the sea.

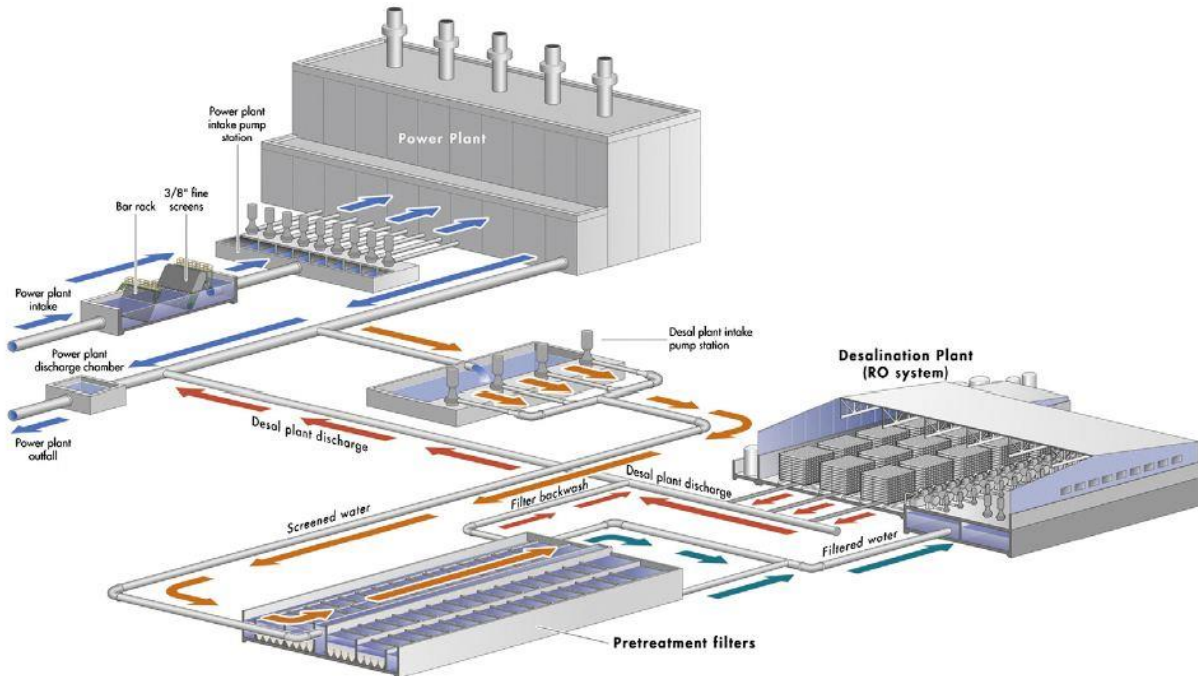


Figure 32: Collocation of SWRO plant & coastal Power Generation Station [Voutchkov, 2011].

Once-through electric power generating plants often have cooling water flows far exceeding 1.5 million m³/d. High blending ratios is advantageous since it dilutes the concentrate and minimizing environmental impacts, and is usually looked upon much more favorably by permitting agencies. The cooling water discharged from the condensers typically is 5 to 15 °C warmer than the source ocean water which could be beneficial for the desalination process because warmer seawater has lower viscosity and therefore lower osmotic pressure.

4.2.1- Plenty of advantages:

Collocation of SWRO desalination plants with existing cooling coastal power plants yields many key benefits [Voutchkov, 2011]:

Usually, coastal power plants with once-through cooling systems use large volumes of seawater. Because the power plant intake seawater has to pass through the small diameter tubes (typically 10- mm or less), therefore, the power plant discharge cooling water is already screened through bar racks and fine screens similar to these used at surface water intake desalination plants. Therefore, a desalination plant which intake is connected to the discharge outfall of a power plant usually does not require the construction of a separate intake structure, intake pipeline and screening facilities. So power plant collocation could yield significant construction cost savings.

The construction of a separate desalination plant outfall structure is avoided thereby reducing the overall cost of desalinated water. Also, the length and configuration of the desalination plant concentrate discharge outfall are closely related to the discharge salinity. Usually, the lower the discharge salinity, the shorter the outfall and the less sophisticated the discharge diffuser configuration needed to achieve environmentally safe concentrate discharge. Blending the desalination plant concentrate with the lower salinity power plant cooling water (which has ambient seawater salinity) often reduce the overall salinity of the desalination plant discharge as a result of the mixing and dilution of the concentrate discharge with the power plant discharge; this salinity reduce is within the range of natural variability of the seawater at the end of the discharge pipe, thereby completely alleviating the need for complex and costly discharge diffuser structures (figure 33).

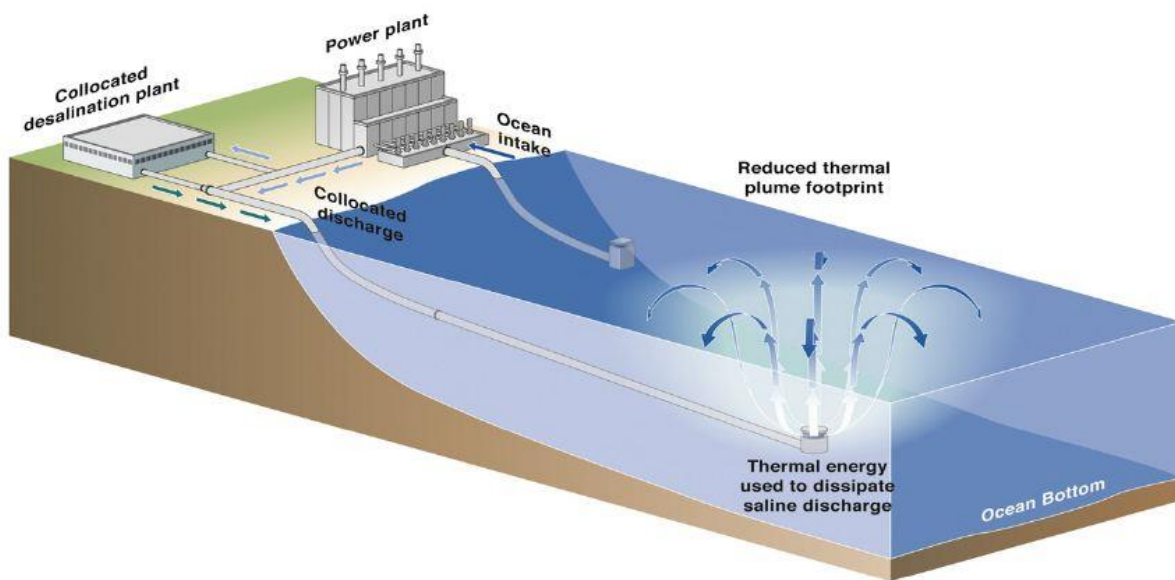


Figure 33: Collocate concentrate discharge with simplified diffuser [Voutchkov, 2011].

Because a portion of the discharge water is converted into potable water, the power plant thermal discharge load is decreased, which in turn lessens the negative effect of the power plant thermal plume on the aquatic environment.

The blending of the desalination plant and the power plant discharges results in accelerated dissipation of both the salinity and the thermal discharges; in fact, the power plant thermal discharge is lighter than the ambient ocean water because of its elevated temperature and therefore, it tends to float on the ocean surface. The heavier saline discharge from the desalination plant draws the lighter cooling water downwards and thereby engages the entire depth of the ocean water column into the heat and salinity dissipation process. As a result the time for dissipation of both discharges shortens significantly and the area of their impact is reduced.

Sharing intake and outfall infrastructure with the power plant has environmental benefits because it avoids the need for new intake and new outfall construction in the sea and the seashore area near the desalination plant. Such construction could cause a measurable

disturbance of the benthic marine organisms on the sea floor. Another clear environmental benefit of the collocation of power generation stations and desalination plants is the overall reduction of entrainment, impingement and entrapment of marine organisms as compared to the construction of two separate open intake structures.

One of the key additional benefits of collocation is the overall reduction of the desalination plant power demand and associated costs of water production as a result of the use of warmer source water. In this combination, the source water of the RO plant is typically 5 to 10 °C warmer than the temperature of the ambient ocean water. This is a significant benefit, especially for desalination plants with cold source seawater, because the feed pressure required for RO membrane separation decreases with 6 to 8% for every 10 °C of source water temperature increase. Since the power costs are approximately 30 to 40% of the total costs for production of desalinated water, the use of warmer source water could have a measurable beneficial effect on the overall water production expenditures

As a result of the collocation the desalination plant unit power costs could be further decreased by avoiding the need for using the power grid and the associated fees for power transmission to the desalination plant. Typically, the electricity tariff (unit power cost) structure includes two components: fees for power production and for power grid transmission. Often, the power transmission grid portion of the tariff is 30 to 50% of the total unit power cost. By connecting the desalination plant directly to the power plant electricity generation equipment, the grid transmission portion of the power fees could be substantially reduced or completely avoided, thereby further reducing the overall seawater desalination cost.

4.2.2- few disadvantage:

A particular consideration has to be given to the effect of the power plant operations on the cooling water quality, since this discharge is used as source water for the desalination plant. For example, if the power plant discharge contains levels of copper, nickel or iron significantly higher than these of the ambient seawater, this power plant discharge may not be suitable for collocation because these metals may cause irreversible fouling of the membrane elements.

The presence of power plant waste screenings in the desalination plant intake water had a detrimental effect of the pre-treatment filter operations because the screening debris frequently clogged the filter distribution piping, airlifts and sand media.

Use of warmer seawater may accelerate membrane bio-fouling, especially if the source water is rich in organics. Also it may result in lower boron rejection and require feed water pH adjustment to meet stringent boron water quality targets.

Source seawater has to be cooled if its temperature increases above 40 °C in order to protect RO membrane integrity.

4.3- Dilution with Waste Water Treatment Plant

Waste water treatment plants frequently discharge to an ocean outfall. Waste water plant effluents usually have total dissolved solids (TDS) much lower than desalination plant concentrate; therefore brines can be also diluted with municipal wastewaters to reduce salinity prior to discharge.

The key feature of this combined discharge method is the benefit of accelerated mixing that stems from blending the heavier than ocean/sea water concentrate with the lighter wastewater discharge. Depending on the volume of the concentrate and on how well the two waste streams are mixed prior to the point of discharge, the blending may allow to reduce the size of the wastewater discharge plume and dilute some of its constituents; the blending of the negatively buoyant concentrate with the positively buoyant waste water provides an effluent that more closely approximates the buoyancy of the receiving waters [Pankratz, 2004]. Co-discharge with the lighter-than seawater wastewater effluent would also accelerate the dissipation of the saline plume by floating this plume upwards and expanding the volume of the ocean water with which it mixes.

Direct discharge through an existing wastewater treatment plant outfall has found a limited application to date. The largest plant in operation at present which practices co-discharge of desalination plant concentrate and wastewater effluent is the 200.000 m³/day Barcelona SWRO facility in Spain.

4.3.1- Advantage of this technology:

The use of existing wastewater treatment plant outfalls for concentrate discharge has the key advantages of avoiding costs and environmental impacts associated with the construction of new outfall for the seawater desalination plant.

Mixing of the negatively buoyant wastewater discharge with the heavier than ocean water concentrate, promotes the accelerated dissipation of both the wastewater plume which tends to float to the ocean surface, and the concentrate which tends to sink towards the ocean bottom. In addition, often concentrate contains metals, organics and pathogens which are of an order of magnitude lower levels than these in the wastewater discharge, which helps reducing the overall waste discharge load of the mix.

Although the use of existing wastewater treatment plant outfalls or concentrate discharge to the sanitary sewer system may seem attractive for its simplicity and low construction costs

4.3.2- Disadvantage of this technology:

The whole idea rely on the availability of wastewater outfall facility, then on the possibility to get agreement between the two facilities' owners on the use of unique outfall with all related concern of cost of construction, operation and maintenance, and the ability of the outfall to support the extra outfall discharge capacity.

Another important issue is the potential for the new mixed effluent toxicity of the blended discharge that may result from ion imbalance of the blend of the two waste streams. Therefore, the ion-imbalance effect has to be investigated in order to ascertain that marine organisms in the vicinity of the discharge are not negatively affected by the combined wastewater-concentrate discharge [Voutchkov, 2011]. In fact, this combination failed in Santa Barbara – California where sea urchin fertilization has been affected.

In some case, outfall modifications need to be taken place at the existing seawater desalination plant in order to altered buoyancy of the concentrate– wastewater mix

The persistent issue is the diurnal fluctuation of the secondary effluent flow with the diurnal fluctuation of the concentrate discharge flow. Often, the seawater desalination plants are operated at a constant production rate and as a result they produce stable concentrate discharge

with little or no diurnal flow variation. On the other hand, wastewater treatment plant availability for dilution of the desalination plant concentrate typically follows a distinctive diurnal variation pattern. Since adequate protection of marine life requires a certain minimum concentrate dilution ratio in the ZID to be maintained at all times, during periods of low wastewater effluent flows (i.e., at night) the amount of concentrate disposed by the desalination plant (and therefore, the plant production capacity) may be limited by the lack of secondary effluent for blending. In order to address this concern, the desalination plant operational regime and capacity may need to be altered in order to match the wastewater effluent [Voutchkov, 2011].

A final concern of combining wastewater and desalination plant discharges is that the high discharge salinity may cause wastewater contaminants and/or other particles to aggregate in particles of different sizes than they would otherwise. This could result in an enhanced sedimentation or some of the metals and solids contained in the wastewater treatment plant effluent, and could potentially impact benthic organisms and phytoplankton in the vicinity of the discharge.

4.4- Discharge via Sewage Networks

Discharge to the nearby wastewater collection system is one of the most widely used methods for disposal of concentrate from small brackish and seawater desalination plants worldwide [Mickley, 2006].

This indirect wastewater plant outfall discharge method however, is only suitable for disposal of very small volumes of concentrate into large-capacity wastewater treatment facilities mainly because of the potential negative effects of the concentrate's high TDS content on the operations of the receiving wastewater treatment plant. In fact, wastewater treatment plants' biological treatment process is inhibited by high salinity when the plant influent TDS concentration exceeds 3000 mg/L. Therefore, before directing desalination plant concentrate to the sanitary sewer the increase in the wastewater treatment plant influent salinity must be assessed and its effect on the plant's biological treatment system should be investigated, especially if the effluent from the wastewater treatment plant is used for water reuse (basically for irrigation).

Feasibility of this disposal method is limited by the hydraulic capacity of the wastewater collection system and by the treatment capacity of the wastewater treatment plant receiving the discharge.

4.5 – Discharge via beach well

Traditionally, options for disposal of the concentrates from inland desalination plants have been deep well injection [Arnal et al., 2005] and surface water discharge [Chelme-Ayala et al., 2009]. Concentrate may be discharged via a vertical or horizontal beach well acting as a reverse infiltration gallery arrangement [Gabelich et al., 2010] where it would be diluted below the seabed to minimize impact on marine life.

4.6- Alternative treatment technique

Due to the adverse effects of brine disposal together with its associated costs, current research is focused on reducing the impact of RO concentrates by reducing the volume and/or by diminishing the pollutant load of these concentrates. Besides, the beneficial use of brine byproducts is also studied and includes the technical feasibility of isolating salts of the required morphology and purity [Stanford et al., 2010]. Recovering commercial byproducts from RO concentrates would be the optimum treatment option, as it solves the environmental problem of concentrate disposal, as well as the economic profitability of reverse osmosis is improved at the same time.

4.6.1- Solar evaporation

Evaporation techniques have been widely applied to concentrate brines in evaporation ponds [Malaeb and Ayoub, 2011], since their application allow to obtain a solid waste easier to be managed than the original waste and a decontaminated liquid flow that can be directly discharged or even reused.

Solar evaporation is one of the techniques considered as a common solution for brine disposal [Greenlee et al., 2009], especially for inland desalination plants in arid and semi-arid areas. The reverse osmosis concentrate is placed in a shallow lined pond which allows the water to evaporate naturally by using the solar energy; after water evaporates the salt is either left in the ponds or removed for disposal. Pond size includes two components: surface area and depth. Pond depths ranging from 25 to 45 cm are considered optimal for maximizing the rate of evaporation [Ahmed et al., 2000].

The main advantage of Evaporation ponds are: relatively easy to construct, require little operation attention compared to mechanical equipment and no mechanical equipment is required.

The main disadvantage reside in the extensive land use, especially if they are located in places with low evaporation rates whereas they pose a high potential for contamination of groundwater coupled to the risk of leakage underneath the pond. Additionally, the productivity of the process is quite low (around 4 L/m²d) [Katzir et al., 2010].

This drawback can be overcome by using wet surfaces (capillaries or clothes) exposed to wind action to increase the evaporation surface. Scientists tested different adsorbent materials in order to improve the water evaporation rate of brines from desalination plants. According to the experimental results, the most suitable adsorbent for natural evaporation was a rectangular cloth made of cellulose (65%) and cotton (35%) [Arnal et al., 2005]. It was also concluded that air velocity improved natural evaporation, although the overall efficiency was limited by the blowing of solids onto the surface of water.

Following this investigation line, a proprietary technique WAIV (Wind Aided Intensified eVaporation) was developed as alternative to natural evaporation. WAIV is a less land intensive method to reduce brine volumes by the use of the drying power of the wind without generating small droplets that can cause salt drift. This configuration employs recirculation of brines as falling films on vertical hydrophilic surfaces that are largely mounted parallel to the wind direction [Macedonio et al., 2011]. Better results were obtained when using materials with no internal surfaces (netting) that are less susceptible to plugging than those with internal surfaces (nonwoven geotextiles). The WAIV technology was further studied in order to recover salts that

can be potentially useful as raw materials [Katzir et al., 2010]. The main advantage of this technology reside in the following:

- A. Previous studies on normal desalination brines in a pilot unit with 31-43 m² wetted evaporation surfaces showed that evaporation rates (L/D-m²) can be improved by 50-90% relative to open ponds.
- B. It can be an interesting option whenever precipitated salts are recovered.
- C. This technology presents advantages with respect to evaporation ponds in land use.

Although of all the cited advantages, the availability of WAIV technology has been only demonstrated at laboratory scale

4.6.2- Vacuum Membrane Distillation (VMD)

Vacuum Membrane Distillation (VMD) has been studied as alternative for the processing of highly concentrated aqueous solutions; it is an evaporative technology that uses a membrane to support the liquid-vapor interface [Urriaga et al., 2001].

The main advantages of membrane distillation over conventional distillation processes are that the operating temperature is in the range of 60-80°C and that the membranes provide a high contact area per unit of equipment volume, allowing very compact installations and reduced footprint. Scientists simulated an increase from 40% to 89% in the water recovery of a 40.000 m³/day RO plant fed with seawater together with a reduction of the brine volume by a factor of 5.5 after coupling RO with VMD [Mericq et al., 2010]. The model used for this simulation was based on experimental results obtained at a bench-scale batch unit.

Some disadvantages occur when the experiments developed with real RO brines: even that organic fouling or biofouling was not observed, at least at the time scale of a few hours, however, for high salt concentrations, calcium scaling occurred and impacted the permeate flux. Scaling effects of CaCO₃ and CaSO₄ in membrane distillation operated at high seawater concentrations have been observed to be the main conclusions that scaling reduces the transmembrane permeate flux [Curcio et al., 2010]. Also, the detrimental effect of the presence of humic acid substances became significant at higher concentration factors.

Nevertheless, calcium scaling was found to be reversible after appropriate washing and chemical cleaning. Calcium scaling could also be controlled by accelerated precipitation softening prior to the direct contact membrane distillation of the RO concentrat.

4.6.3- Membrane Distillation coupled with Crystallization

In a recent study, Membrane distillation coupled with crystallization (MDC) was investigated in a bench-scale plant operated with concentrate discharged from a seawater reverse RO unit [Ji et al., 2010]. Seawater was collected from the Tyrrhenian Sea in Amantea (Calabria) and further processed in an RO lab-scale unit. Lime/soda softening was applied to the RO brine to reduce the hardness of calcium and magnesium and to limit scaling problems. Experiments were focused on NaCl crystallization, obtaining a production of 17 kg/m³ of NaCl crystals, representing 34% of the total content of dissolved solids in the brine.

The major advantage of the MDC process is its capability to concentrate the salt up to the supersaturated state, which allows its crystallization and achieving water recovery efficiency

higher than 90%. In MDC, the high contact area provided by hollow fiber membranes allows to achieve reliable evaporation fluxes at moderate temperatures (40-50°C) with energy consumption of about 15-20 kWh/m³, while conventional evaporative equipments for NaCl crystallization need to operate at temperatures higher than 70°C, with specific energy consumption of about 30 kWh/m³.

However the main problem of membrane distillation is that the technology is not yet commercially available at industrial scale [Singh, 2009].

4.6.4- Electrodialysis

When electrodialysis (ED) has been applied to brine effluents, their salt concentration is increased from 0.2 - 2% to 12-20% with an energy requirement of 1.0-7.0 kWh/m³ V/S to around 25 kWh/m³ needed by thermal evaporation [Korngold et al., 2009]. In ED operation, there are two major technical problems to be overcome: firstly to find solutions for operating at concentrations up to 20% of salts without significantly diminishing the energy efficiency and secondly to prevent CaSO₄ precipitation on the membrane. This last disadvantage could be prevented by continuous removal of gypsum from the brine in a separate precipitator.

4.6.5- Forward Osmosis

Forward osmosis (FO) is presented as an innovative technique to reduce brine volume, FO utilizes a highly concentrated solution generally referred to as the draw solution to generate an osmotic pressure differential across the membrane, thus resulting in the transport of water from the less concentrate feed stream to the highly concentrated draw solution.

This technique has main advantage of lower energy requirement than RO. However, the inconvenient reside in the need of a draw effective solute to create an effective driving force that allows water flux, and besides the economic feasibility of the technology has not been demonstrated [Singh, 2009].

4.6.6- Zero Liquid Discharge

One of the most innovative investigation line focused on reducing the concentrate volume to the highest point is called Zero Liquid Discharge (ZLD), which is aimed to achieve the maximum water recovery, through several stages of treatment in order to avoid liquid effluent disposal [Pérez-Gonzalez et al., 2012].

The basic combination is a multi stage RO (Primary RO & Secondary RO). The use of multi stage RO was also studied by several authors who confirmed that there is a need of intermediate treatment in multi stage processes in order to increase the recovery and avoid precipitation. The most studied and tested intermediate treatments are the following:

- ❖ Ion exchange resins for silica removal
- ❖ Ion exchange resins for hardness removal (Calcium and Magnesium)
- ❖ Chemical demineralization for salts and silica removal
- ❖ Chemical Enhanced Seeded Precipitation for anti-scalant & fouling compound removal
- ❖ Precipitation treatment (alkaline-induced) with NaOH or with alum {Al₂(SO₄).14H₂O}
- ❖ WAIV with Membrane Crystallization for salt removal

- ❖ Electrodialysis Reversal
- ❖ Lime Softening to limit the foulants of Silica and Barium Sulfate
- ❖ Lime Softening + evaporation + crystallization
- ❖ Other techniques: Fluidized bed crystallization & adsorption on activated alumina

Fouling and precipitation of scaling compounds are two of the main limiting factors for the RO recovery, Antifouling and anti-scalant compounds are usually added to feed waters in order to avoid the diminishing of membrane performance. However, the addition of these compounds can have negative effects in the post-treatment of RO concentrates [Pérez-Gonzalez et al., 2012].

In conclusion, the evaluation of treatment costs comparing the system without intermediate treatment with the system with ZLD process shows that treatment cost would be reduced by 50-70%, and energy consumption would be reduced by 60-75%.

These systems achieve high recoveries, although the zero discharge goal is not accomplished. Treatment schemes based on ZLD objective are pointed to be a promising option for the treatment of RO concentrates. Initial estimation about treatment costs indicates that these systems would be feasible, but it would be necessary leap from pilot plant to industrial level to safely evaluate the applicability of these systems.

4.6.7- Emerging Technologies for salts recovery

Recovering commercial products is the final challenge to improve the management of RO concentrates whatever their water source is. If valuable substances are recovered from RO concentrates a double objective will be achieved: the reduction of the environmental impact of RO concentrates disposal added to the improvement of the economy of the global treatment process [Pérez-Gonzalez et al., 2012]. Through combination of evaporation and crystallization technologies, valuable salts can be recovered.; although the economic profit is not so high, it is indisputable that the recovery of potential commercial salts is a great option to improve the cost-effectiveness of desalination processes.

Around the world, valuable salts have been recovered from the SWRO concentrate:

- Salts like NaCl, KCl, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, using the isothermal & isobaric evaporation of the rejected brine [Hajbi et al., 2010].
- In USA, 45 million Tons of salt are annually produced and 70% are used by chemical industries [Ahmad and Williams, 2011].
- In Netherlands (Holland) all solids generated from fluidized bed crystallization processes are used by industries like steel production [Bond and Veerapaneni, 2008].
- Production of mixed acid and mixed bases using Electrodialysis with bipolar membrane [Mavrov et al., 1999].
- The recovery of rubidium using liquid-liquid extraction [Jegatheesan et al., 2009] and [Jeppesen et al., 2009].
- In Tunisia, using liquid-liquid extraction, they could recover cesium, indium, gallium, carnallite crystals and germanium and magnesium [Le Dirach et al., 2005].

5- Our environment & marine life at the reject point.

Typically, concentrate from seawater desalination plants using open ocean intakes has the same color, odor, oxygen content and transparency as the source seawater from which it was produced, and increase or decrease in salinity will not change its physical characteristics or aesthetic impact on the environment [Cotruvo et al., 2010].

Also, there is no relation between the level of salinity and biological or chemical oxygen demand of the desalination plant concentrate; over 80% of the minerals that encompass concentrate salinity are sodium and chloride and they are not a prime food source or a macro or micro nutrients for aquatic organisms.

Salinity contained in concentrate discharges from seawater desalination plants is not of anthropogenic origin as compared to the pollutants contained in discharges from industrial or municipal wastewater treatment plants or water reclamation plants. The minerals in the desalination plant concentrate discharge have originated from the same source to which they usually are returned. Also in most coastal urban centers seawater desalination plant outfalls and wastewater treatment plant discharges are well within a 15 to 30-kilometer radius, therefore the long-term regional environmental impact of seawater concentrate on the sea is equivalent to the effect of naturally occurring evaporation [Einav et al., 2002].

Similarly, seawater desalination plants temporarily remove a small portion of sea water, produce fresh drinking water, which in turns is returned to the sea via the sea discharges of the wastewater treatment plants located in the vicinity of the desalination plant, thereby re-uniting the separated fresh water and salts, both of which originated from the sea, within a period much shorter than the seasonal interval which returns the water removed from the sea by evaporation. This regional close-cycle balance between seawater intakes and discharges is often poorly understood and the environmental impact of concentrate discharges is commonly considered in isolation from the balancing dilution impact of the desalinated water returned in the vicinity of its origin.

The seawater reverse osmosis (SWRO) membranes reject all key seawater ions at approximately the same level. As a result, the ratios between the concentrations of the individual key ions that contribute to the seawater salinity and the TDS of the concentrate are approximately the same as these ratios in the ambient seawater. As a result, marine organisms are not exposed to conditions of ion-ratio imbalance, if this concentrate is directly disposed to the ocean.

Based on 24 hours operation, the feed seawater to the RO of nominal capacity 25000 m³/d will be discharged at a rate of 1041 m³/h to the RO, with salinity 41.000 ppm. The permeate production for the RO will be 410 m³/h at a salinity concentration of 300 ppm. The brine production will be 631 m³/h from the RO with a salinity of 68.300 ppm.

The calculation has been based on the following equation:

$$\text{TDS}_{\text{concentrate}} = \{ \text{TDS}_{\text{feed}} (1/(1-Y)) \} - \{ Y \times \text{TDS}_{\text{permeate}} / (100(1-Y)) \}$$

Where $Y = \text{Permeate flow rate} / \text{Feed flow rate}$

By neglecting the permeate salinity (which is usually about 1%) of feed salinity for seawater reverse osmosis (SWRO)), the concentrate TDS can be more simply defined as:

$$\text{TDS}_{\text{concentrate}} = \text{TDS}_{\text{feed}} (1/(1-Y))$$

The brine concentration factor is then defined as $\text{TDS}_{\text{concentrate}} / \text{TDS}_{\text{feed}}$ [Voutchkov, 2011].

Based on the above studies, we decided to go for the direct multiple outfalls taking into consideration the high seawater flux and current at the outfall area. In our case study and for many reasons, we did not take sea water sample before and after the operation of the SWRO Plant; but in order to be sure and follow up that the concentrate discharge is not affecting the marine life and ecosystems, our HUTA Environment department sent technical team to periodically and visually checkup the state and situation of the outfall marine zone. During 2 months the divers team reported good results having almost the absence of any minor change in the aquatic ecosystems.

6- Membrane cleaning solution

As seen in Chapter 3 Para. 6, Reverse Osmosis membranes may be subject of cleaning process. Once it occurs, membranes cleaning impose the use of different kind of chemical with relatively high concentration in very short time and using high volume of cleaning solution.

Therefore, in order to respect the aquatic environment and prevent the marine ecosystems, HUTA introduce two huge GRP holding tanks in order to collect all the cleaning solution. This huge tanks are connected together and one of them is connected to two small discharge pumps (1/2 horse power capacity each one), one pump to be in duty and the other one as stand by. When membrane cleaning process is applied, the membrane cleaning solution is collected in the two holding tanks; once the cleaning is completed, we started the discharge of the two holding tanks via one small pump, the pump discharges the membrane cleaning solution with the reject concentrate (brine) in small quantity in order to ensure the maximum dilution of chemical present in the cleaning solution.

This procedure has been granted by ARAMCO, Petro Rabigh and Saudi Environment Department.

During our operation, we have made many flashing for the membranes using high volume of produced potable water; SBS is added to the water in order to eliminate the free chlorine from the water and avoiding damaging the membranes. The membranes have been cleaned one time using the Citric Acid 2 %, the pH of the solution was has been reduced up to 3 using high quality ammonia. The cleaning solution has been recycled between the holding tanks and the membranes passing through the cartridge filter; once the cleaning procedure has been completed, the cleaning solution has been stored in the holding tanks; the pH of this solution has

been raised up to 5. Later then this solution is pumped by the small discharge pump, mixed with the brine and rejected via the outfall to the body of the sea. The pH of the mixed solution (between the brine and the cleaning solution) ranges between 7 and 8.2, the temperature was a little bit higher from the sea water temperature by 1°C in average, and the salinity was almost the same of the salinity of the brine.

Due to the high security working condition of Petro Rabigh and since the coast guard are strict, we could not accomplish our environmental studies and tracing for the ecological effect of the brine on the maritime life (initially programmed for this thesis); however, the visual observation before the outfall installation and after the operation of the plants show no big difference between the two stages, we have perceived almost the same maritime life and maritime ecosystem.

Reference

Internet sources

- NIST, 2014, Standard Reference Database, <http://physics.nist.gov/cuu/Constants/>, the NIST reference on constants, units, and uncertainty.
- Technical Aspects of Desalination Plant, 2010; www.sswm.info REPUBLIC OF MAURITIUS - Desalination Plants
- Technical Service Bulletin, October 2013, www.membranes.com Nitto Hydranautics Nitto Group Company, TSB113.03
- The Engineering ToolBox, 2016, www.EngineeringToolBox.com
- Tom Pankratz, 2004, Seawater Intake & Outfall Cost Aspects, CH2M Hill, <http://texaswater.tamu.edu/readings/desal/seawaterdesal.pdf>.
- Water Treatment Guide, 2014, www.watertreatmentguide.com Technical Database for the Water Treatment Industry.

Bibliography

- Abdulgader Ata Yaseen, Mustafa Ghulam M., Nada Nabil, Al-Hassani Kheder and Khafagy Mohamed, April 2001, Performance Evaluation of a Modified Polymaleic Acid as Antiscalant in a Reheat Plant, SWCC, Proceeding of the Fourth Annual Workshop on Water Conversation in the Kingdom, Dahrn.
- Ahmed M., Shayya W.H., Hoey D., Mahendran A., Morris R. and Al-Handaly J., 2000, Use of evaporation ponds for brine disposal in desalination plants. Desalination 130 (2), P.155-168.
- Ahmad M. and Williams P., 2011, Assessment of desalination technologies for high saline brine applications - discussion paper. Desalination and Water Treatment 30, P.22-36.
- Applegate L.E., Erkenbrecher Jr. C.W. and Winters H., 1989, New chloroamine process to control aftergrowth and biofouling in permasep^R B-10 RO surface seawater plants, Desalination, 74 P.52-65.
- Al-Mutaz I.S., 2000; Water Desalination in the Arabian Gulf Region, in Water management, purification and conservation in arid climats. Vol.2 Water Purification (Lancaster Technomic Publishing Company), P.245-265.

- Amjad Zahid, 1996, Scale Inhibition in Desalination Applications: An Overview; Noveon, Inc. (formerly BFGoodrich Performance Materials); The NACE International Annual Conference and Exposition.
- Anderson D.M., McCarthy S. (Eds.), 2012, Red Tides and Harmful Algal Blooms: Impacts on Desalination Systems, Middle East Desalination Research Center, Muscat, Oman.
- Andrews W.T., Bergman R.A., 1986, The Malta seawater RO facility, *Desalination* 60 P.135–144.
- Armstrong M.W., Gallego S. and Chesters S.P., 2009, Cleaning Clay from fouled membranes, Genesys International Limited, Unit 4 Ion Path.
- Arnal J.M., Sancho M., Iborra I., Gozalvez J.M., Santafe´ A. and Lora J., 2005, Concentration of brines from RO desalination plants by natural evaporation. *Desalination* 182, P.435-439.
- AWWA (American Water Works Association), February 1999, “Current Issues in Membrane Applications and Research”, AWWA Membrane Technology Conference Preconference Workshop.
- Bartak R., Grischek T., Ghodeif K., Ray C., 2012, Beach sand filtration as pre-treatment for RO desalination, *Int. J. Water Sci.* 1 (2) P.1–10.
- Berkday A., 2011, Environmental approach and influence of red tide to desalination process in the Middle East region, *Int. J. Chem. Environ. Eng.* 2 (3) P.183–188.
- Bond R. and Veerapaneni S., 2008, Zeroing in on ZLD technologies for inland desalination. *Journal American Water Works Association (AWWA)* 100, P.76-89.
- Bonnelye V., Sanz M.A., Durand J.-P., Plasse L., Gueguen F., Mazounie P., 2004, Reverse osmosis on open intake seawater: pre-treatment strategy, *Desalination* 167 P.191–200.
- Brehant A., Bonnelye V., Perez M., 2003, Assessment of ultrafiltration as a pretreatment of reverse osmosis membranes for surface seawater desalination, *Water Sci. Technol. Water Supply* 3 (5–6) P.437–445.
- Bruins Jantinus H., Petrusevski Branislav, Slokar Yness M.; Kruithof Joop C. and Kennedy Maria D., Jun 2014, Manganese removal from groundwater: characterization of filter media coating; *Desalination and Water Treatment*.
- Cartier G., Corsin P., 2007, 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, IDAWC/MP07-185, 2007.
- Chelme-Ayala P., Smith D.W. and El-Din M.G., 2009, Membrane concentrate management options: a comprehensive critical review. *Canadian Journal of Civil Engineering* 36 (6), P.1107-1119.
- Chen-Tung Arthur Chen, 2007, Carbonate chemistry of the ocean, In: “Oceanography” (<http://www.eolss.net/eBooks>), ed. by J.C.J. Nihoul and C.T.A. Chen, in *Encyclopedia of Life Support Systems (EOLSS)*, Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford, UK, ISBN: 978-1-905839-62-9 e-Book, Vol. 1, P.344-358.
- Chesters Stephen P., Pena Nuria, Gallego Silvia, Fazel Maqsood, Armstrong Matthew W.; del Vigo Fernando, 2011, RESULTS FROM 99 SEAWATER RO MEMBRANE AUTOPSIES;

- World Congress/Perth Convention and Exhibition Centre (PCEC), Perth, Western Australia September 4-9.
- Choules P., Schotter J.-C., Leparc J., Gai K., Lafon D., 2007, Operation experience from seawater reverse osmosis plants, Proceedings, American Membrane Technology Conference and Exposition, Las Vegas, Nevada.
- Cotruvo J., 2005; Water Desalination Processes and Associated Health Issues. Water Conditioning and Purification, January, 13-17. www.wcponline, Issue 47, #1.
- Cotruvo Joseph, Voutchkov Nikolay, Fawell John, Payment Pierre, Cunliffe David, Lattemann Sabine, 2010; Desalination Technology, Health and Environmental impacts, TD479.D473. CRC Press, International Standard Book Number: 9781439859841.
- Curcio E., Ji X., Di Profio G., Sulaiman A.O., Fontananova E. and Drioli E., 2010, Membrane distillation operated at high seawater concentration factors: role of the membrane on CaCO₃ scaling in presence of humic acid. Journal of Membrane Science 346 (2), P.263-269.
- Darton Ted, Annunziata Ursula, del Vigo Pisano Fernando, Gallego Silvia, 2004, Membrane autopsy helps to provide solutions to operational problems Desalination 167 P.239–245.
- Darton E.G. and Fazell M., October 2001, A Statistical Review of 150 Membrane Autopsies, PermaCare, presented at the 62nd Annual International Water Conference, Pittsburgh.
- David B., Pinot J.-P., Morrillon M., 2009, Beach wells 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, November 7-12, IDAW/DB09-106, 2009.
- Davil Mehdi, Mahvi Amir, Norouzi Mehdi, Mazloomi Sajad, Amarluie Ali, Tardast Ali and Karamitabar Yazdan, 2009, Survey of Corrosion and Scaling Potential Produced Water from Ilam Water Treatment Plant, World Applied Sciences Journal 7 (Special Issue of Applied Math), ISSN 1818-4952, IDOSI Publications.
- Einav R., Harussi K. and Perry D., 2002, The footprint of the desalination processes on the environment, Desalination 152, P.141.
- Ellis Donald, Bouchard Christian, Lantagne Gaetan, 2000, Removal of iron and manganese from groundwater by oxidation and microfiltration; ELSEVIER-DESALINATION; [Volume 130, Issue 3](#), 20 November 2000, P.255–264.
- Erin D. Mackey, Nicki Pozos, Wendie James, Tom Seacord, Henry Hunt and David L. Mayer, 2011, Assessing Seawater Intake Systems for Desalination Plants - Water Research Foundation.
- EMS (2006) Reuters .co.uk, July 24, 2006.
- Flemming H.C.and Schaule G.; Desalination, 70 (1988) 95-119.
- Filmtec, 2011, Reverse Osmosis Membranes Technical Manual Form No. 609-00071-0808.
- Gabelich C.J., Xu P. and Cohen Y., 2010, Chapter 10 concentrate treatment for inland desalting. Sustainability Science and Engineering 2, P.295-326.
- Galloway Merrilee A.and Minnery John G., 2001, Ultrafiltration as Pre-treatment to Seawater Reverse Osmosis; Ionics Technical Paper.

- Ghaffour Noreddine, Missimer Thomas M and Amy Gary L., January 2013, Technical review and evaluation of the economics of water desalination: Current and future challenges for better water supply sustainability, *Desalination*, Volume 309, P.197–207
- Glueckstern P., Priel M. and Wilf M., 2002, Field evaluation of capillary UF technology as a pretreatment for large seawater RO systems, *Proc. EDS Conference, Toulouse*).
- Glueckstern P. and Priel M., 2003, Optimization of boron removal in old and new SWRO systems, *Desalination*, 156 P.219-228.
- Gollnitz W.B., Clancy J.L., Whittenberry B.L., Vogt J.A., 2003, RBF as a microbial treatment process, *J. Am. Water Works Assoc.* 95 (12) P.56–66.
- Gollnitz W.B., Clancy J.L., Whittenberry B.L., Vogt J.A., 2004, Riverbank filtration: induced infiltration and groundwater quality, *J. Am. Water Works Assoc.* 96 (12) P.98–110.
- Gollnitz W.B., Clancy J.L., McEwen J.B., Garner S., 2005, Riverbank filtration for IESWTR compliance, *J. Am. Water Works Assoc.* 97 (12) P.64–76.
- Greenlee L.F., Lawler D.F., Freeman B.D., Marrot B., Moulin P., 2009, Reverse osmosis desalination: water sources, technology, and today's challenges, *Water Research* 43 (9) P.2317–2348.
- Gude Veera Gnaneswar, 2016, Desalination and sustainability – An appraisal and current perspective, *Water Research* 89 (2016) P.87-106.
- Hajbi F., Hammi H. and M’Nif A., 2010, Reuse of RO desalination plant reject brine. *Journal of Phase Equilibria and Diffusion* 31 (4), P.341-347.
- Hamidi Abdul Aziz, Salina Alias, Faridah Assari, Mohd Nordin Adlan, 2007, The use of Alum, Ferric chloride and Ferrous sulphate as coagulants in removing suspended solids, colour and COD from semiaerobic landfill leachate at controlled pH, *The Journal of the international Solids Wastes and Public Cleansing Association ISWA*, P.65.
- Hassan Ata M. and Malik A.U., 1989, Corrosion Resistance Materials for SWRO plants, a SWCC Report, also *Desalination*, 74 P.157-170.
- Hassan A.M., Abanmy A.M., Al-Thobiety M., Mani T., 1991, Performance evaluation of SWCC SWRO Plants – PartII, *IDA World Conference on Desalination and Water Reuse*, August 1991, P.412-439
- Hassan A. M., Abanmy A. M. and Jamaluddin A. T. M., Nov 1995, Membrane Evaluation for Hybrid System, paper submitted for presentation at *IDA World Congress on Desalination and Water Science*, Abu Dhabi, U. A. E.
- Hassan A. M., Abanmy A. M., Farooque A. M. and Jamaluddin A. T. M., Nov 1995, Optimization of SWRO Pre-treatment - SWRO Membranes Evaluation and their use in Evaluating SWRO Pre-treatment; Presented at *IDA World Conference “Desalination and Water Sciences”*, Abu-Dhabi.
- Hassan Ata.M., Abanmy A., Farooque A.M, Jamaluddin A. T. M., Al-Amoudi A. and Mani T., Nov. 1995, Optimization of SWRO Pre-treatment - Part 1 SDI Measurement Technical Report No. SWCC (RDC) - 37 - Partly Presented at *IDA World Conference, “Desalination and Water Sciences”*, P.18-24, Abu-Dhabi.

- Hassan A., Jamaluddin A.T.M., Rowaili A., Abart E., Lovo R., 1997, 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, p. 1350-1365.
- Hellmann D.-H., Rosenbeger H.F.R., Tusel E., 2002, Seawater intake systems for desalination plants, Proceedings of the International Desalination Association World Congress on Desalination and Water Reuse, Manama, Bahrain.
- Hubbs S.A. (Ed.), 2005, Riverbank Filtration Hydrology — Impacts on System Capacity and Water Quality, Springer, Dordrecht.
- Jamaluddin A.T.M., Hassan A.M., Reweli A.A., Saeed M.O., 2005, Operation of Al-Birk Plant introducing beachwell intake system, Technical Report, Saline Water Desalination Research Institute, Al-Birk SWRO Plant, Saudi Arabia.
- Jamaluddin A.T.M.¹, Hassan A.M., Al-Reweli A., Saeed M.O., Bakhit L.M., Al-Amri M.M., 2005, Operation of Al-Birk plant introducing beachwell intake system, Saline Water Conversion Corporation Technical Report No. TR 3807/APP02005.
- Jamaluddin A.T.M., Hassan A.M., Al-Reweli A., Saeed M.O., 2007, Operation of Al-Birk. - Pant Introducing Beachwell Intake System, International Desalination Association World Congress on Desalination and Water Reuse, Singapore.
- Jegatheesan V., Liow J.L., Shu L., Kim S.H. and Visvanathan C., 2009, The need for global coordination in sustainable development. *Journal of Cleaner Production* 17 (7), P.637-643.
- Jeppesen T., Shu L., Keir G. and Jegatheesan V., 2009, Metal recovery from reverse osmosis concentrate. *Journal of Cleaner Production* 17 (7), P.703-707.
- Ji X., Curcio E., Al Obaidani S., Di Profio G., Fontananova E. and Drioli, E., 2010, Membrane distillation-crystallization of seawater reverse osmosis brines. *Separation and Purification Technology* 71 (1), P.76-82.
- Juffali / ItN Nanovation AG, October 2009, Water Treatment Technologies in the Kingdom of Saudi Arabia; Nanotechnology CFM SYSTEMS^{K.S.A.}.
- Kammourie N., Dajani T.F.F., Cioffi S., Rybar S., 2008, SAWACO — North Obhor SWRO plant operational experience, *Desalination* 221 P.101–106.
- Katzir L., Volkmann Y., Daltrophe N., Korngold E., Mesalem R., Oren Y. and Gilron J., 2010, WAIV e wind aided intensified evaporation for brine volume reduction and generating mineral byproducts. *Desalination and Water Treatment* 13, P.63-73.
- Khoshhesab Zahra Monsef, 2012, Reflectance IR Spectroscopy, Infrared Spectroscopy - Materials Science Engineering and Technology, P.233-244, Payame Noor University.
- Kivimaki A.-L., Lahti K., Hatva T., Tuominen S.M., Miettinen I.T., 1998, Removal of organic matter during bank filtration, in: J.H. Peters, et al., (Eds.), *Artificial Recharge of Groundwater*, A.A. Balkema, P.107–112.
- Ko A., King R., 2005, Guantanamo Bay, Cuba, seawater desalination plant operation and experience, Proceeding, American waterWorks Association Membrane Technology Conference, Phoenix, Arizona.

- Korngold E., Aronov L. and Daltrophe N., 2009, Electrodialysis of brine solutions discharged from an RO plant. *Desalination* 2428, P.215-227.
- Koutsakos E., Delaisse G., Van der Wal W., May 2009, Successful antiscalant field trial - Optimization at higher pH and Sea water Temperature – Larnaca Desalination Plant EDS Conference – Desalination for the Environment, Baden, Germany.
- Kreshman S.A., 1985, Seawater intakes for desalination plants in Libya, *Desalination* 55 P.493–502.
- Kusky Timothy M., 2005, Encyclopedia of Earth Sceince, Department of Earth and Atmospheric Sciences, St. Louis University, P.379
- Laparc J., Schotter J.-C., Rapenne S., Croue J.P., Lebaron P., Lafon D., Gaid K., 2007, Use of advanced analytical tools for monitoring performance of seawater pretreatment processes, Proceedings, International Desalination Association World Congress on Desalination and Water Reuse, Maspalomas, Gran Canaria, Spain, October 21–26, IDAWC/MP07-124, 2007.
- Laszlo F., Ray C., Bourg A. (Eds.), 2002, Riverbank Filtration: Understanding Biochemistry and Pathogen Removal, Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Lattemann S. and Hopner T., 2008, Environmental impact and impact assessment of seawater desalination. *Desalination* 220, P.1-15.
- Le Dirach J., Nisan S. and Poletiko C., 2005, Extraction of strategic materials from the concentrated brine rejected by integrated nuclear desalination systems. *Desalination* 182, P.449-460.
- Light W.G., Perlman J.L., Riedinger A.B. and Needham D.F., 1988, *Desalination*, 70 P. 47-64.
- Light¹ W.C., Chu H.C., Haddock K.A., 1988, AICHE Symposium Series V 84, N261, P.130 - 138.
- Macedonio F., Katzir L., Geisma N., Simone S., Drioli E. and Gilron J., 2011, Wind-Aided Intensified eVaporation (WAIIV) and membrane crystallizer (MCr) integrated brackish water desalination process: advantages and drawbacks. *Desalination* 273 (1), P.127-135.
- Mackey E.D., Pozos N., James W., Seacord T., Hunt H., Mayer D.L., 2001, Assessing Seawater Intake Systems for Desalination Plants, Water Reuse Foundation.
- Malaeb L. and Ayoub G.M., 2011, Reverse osmosis technology for water treatment: state of the art review. *Desalination* 267 (1), P.1-8.
- Manual for membrane elements, February 2004, Operation, Maintenance and Handling, XXX Reverse Osmosis Membranes.
- Mauguin G. and Corsin P., 2005, Concentrate and other waste disposals from SWRO plants: characterization and reduction of their environmental impact. *Desalination* 182, P.355-364.
- Mavrov V., Chmiel H., Heitele B. and Rogener F., 1999, Desalination of surface water to industrial water with lower impact on the environment part 4: treatment of effluents from water desalination stages for reuse and balance of the new technological concept for water desalination. *Desalination* 124, P.205-216.

- McCutcheon J.R., McGinnis R.L., and Elimelech M, "Desalination by Ammonia-Carbon Dioxide Forward Osmosis: Influence of Draw and Feed Solution Concentrations on Process Performance", *Journal of Membrane Science*, Volume 278, July 2006, pages 114-123.
- MEDRC, 2003, Assessment of the Composition of Desalination Plant Disposal Brines. Middle East Desalination Research Center (MEDRC), Project NO. 98-AS-026.
- MEDRC, 2006, Reverse Osmosis – Water Treatment Systems; Middle East Desalination Research Center – Muscat – Oman.
- Meerganz von Medeazza G.L., 2005, “Direct” and socially-induced environmental impacts of desalination. *Desalination* 185, P.57-70.
- Meneses M., Pasqualino J.C., Ce’spedes-Sa’nchez R. and Castells F., 2010, Alternatives for reducing the environmental impact of the main residue from a desalination plant. *Journal of Industrial Ecology* 14 (3), P.512-527.
- Mericq J., Laborie S. and Cabassud C., 2010, Vacuum membrane distillation of seawater reverse osmosis brines. *Water Research* 44 (18), P.5260-5273.
- Meyer S., 2000, “Seawater Reverse Osmosis Plant – Energy Recovery and Capital Cost Reduction”, presented at The Changing World of Water & Power, Curacao, Netherlands Antilles, October 2000.
- Mickley M.C., 2006, Membrane Concentrate Disposal: Practices and Regulation, Desalination and Water Purification Research and Development Program Report N. 123, Second Edition U.S. Department of Interior, Bureau of Reclamation, 128 pp.
- Milosevic Milan, June 2012, Internal Reflection and ATR Spectroscopy, MeV Technologies LLC, WILEY- A John Wiley & Sons Inc. Publication, Section 7.
- Missimer T.M., 1994, Water Supply Development for Membrane Water Treatment Facilities, CRC Press, Boca Raton, Florida, 1994.
- Missimer T.M., Winters H., 1998, Seawater supply wells for reverse osmosis desalination facilities on Grand Cayman Island, Proceedings, Third International Symposium on Tropical Hydrology and the Fifth Caribbean Islands Water Resources Conference, Am. Water Resources Assoc, P.219–223.
- Missimer T.M., 2009, Water Supply Development, Aquifer Storage, and Concentrate Disposal for Membrane Water Treatment Facilities, 2nd edition Schlumberger Limited, Sugar Land, Texas.
- Missimer Thomas M., Ghaffour Noreddine, Dehwah Abdullah H.A., Rachman Rinaldi, Maliva Robert G., Amy Gary, 2013, Subsurface intakes for seawater reverse osmosis facilities: Capacity. Limitation, water quality improvement, and economics – ELSEVIER, *Desalination* 322 P 37-51
- Morton A.J., Callister I.K. and Wade N.M., 1996, Environment impact of seawater distillation and reverse osmosis processes; ELSEVIER-DESALINATION; 108 P.1-10.
- Munoz I. and Fernandez-Alba A.R., 2008, Reducing the environmental impacts of reverse osmosis desalination by using brackish groundwater resources. *Water Research* 42 (3), P.801-811.

- Murphy A.P., 1991, Accelerated deacetylation of cellulose acetate by metal salts with aqueous chlorine, *Research Journal, WPCF*, 63, P.177-180.
- Murrer J., Rosberg R., 1998, “Desalting of Seawater Using UF and RO — Results of a Pilot Study”, *Desalination* 118, P.1-4.
- Nada Nabil, December 1984, Evaluation of various additives at Jubail phase I during reliability trials, *Desalination* 51(2) P.137-148.
- Nitto Group Company, October 2013, Chemical Pre-treatment for RO and NF, Technical Application.
- Pankratz Tom, 2004, An Overview of Seawater Intake Facilities for Seawater Desalination - CH2M Hill, Inc. Texas.
- Pankratz T., 2006^A, Seawater desalination technology overview, Presentation for Georgia Joint Comprehensive Study Committee, St. Simons Island, Georgia, August 22–23.
- Pankratz T., 2006^B, A Review of Seawater Intake, Pretreatment and Discharge Technologies. In *Proc. of the International Desalination Association Seminar on Water Desalination Technologies*, November 19–20, Tehran, Iran.
- Pearce G., Allan J. and Chida K., 2003, Ultrafiltration pretreatment at Kindasa water services, Jeddah, Saudi Arabia, Proc. IDA Congress, Bahamas.
- Pérez-Gonzalez A., Urtiaga A.M., Ibanez R. and Ortiz I., 2012, State of the art and review on the treatment technologies of water reverse osmosis concentrates. *ELSEVIER / Science Direct / Water Research* 46 (2012), P.267 - 283.
- Perkin Elmer, 2005, FT-IR Spectroscopy Attenuated Total Reflectance (ATR); Perkin Elmer Life and Analytical Sciences, from the original on 16 February 2007.
- Poseidon Resources Corporation. 2004. Carlsbad Seawater Desalination Project Alternatives to the Proposed Intake. March 2.
- Prato T., Schoepke E., Etchison L., O’Brien T., Hernon B., Perry K. and Peterson M., August 2000, “Production of High Purity Water from Seawater”, presented at ADA 2000 Biennial Conference & Exposition, South Lake Tahoe, NV.
- Ray C., Melin G., Linsky R.B. (Eds.), 2002, *Riverbank Filtration: Improving Source Water Quality*, Klumer Academic Publishers.
- Ridgeway H.F., 1988, Microbial Adhesion and Biofouling of Reverse Osmosis Membranes. In B.S. Parekh (ed.): *Reverse Osmosis Technology: Application for High-Purity Water Production*. (New York: Marcel Decker) P.429-481.
- Roberts D.A., Johnston E.L. and Knott N.A., 2010, Impacts of desalination plant discharges on the marine environment: a critical review of published studies. *Water Research* 44 (18), P.5117-5128.
- Rovell J.-M., 2001, Current and Future Trends in SWRO (pretreatment). In *Proc. of the 2001 International Desalination Association Annual Conference*.
- Saeed M.O.; Jamaluddin A.T.; Tisan I.A., 1999, Biofouling in a Seawater Reverse Osmosis Plant on the Red Sea Coast; Saudi Arabia by, *Proceedings of the IDA World Congress on Desalination, San Diego, CA, Volume II*, P.207-221.

- Schwarz J., 2003, Beach well intakes improve feed-water quality - Water & Wastewater International, November.
- Schwarz J., 2000, Beach well intakes for Small Seawater Reverse Osmosis Plants – Middle East Desalination Research Center (MEDRC) Project: 97- BS-015 – August.
- Singh R., 2009, Brine recovery at industrial RO plants: conceptual process design studies. *Desalination and Water Treatment* 8, P.54-67.
- Stanford B.D., Leising J.F., Bond R.G. and Snyder S.A., 2010, current practices, environmental implications, and case studies in Las Vegas, NV- Chapter 11 inland desalination, *Sustainability Science and Engineering* 2, P.327.
- Stevens L., Kowal J., Herd K., Wilf M. and Bates W., 2003, Tampa Bay seawater desalination facility: start to finish, Proc. IDA Congress, Bahamas.
- Stolarski Mathias, 2013, Filter and Filtration Process / Coagulant, Flocculation and agglomeration, DuET Particle Technology – Separations DuPont - Experimental Station Wilmington, DE, American Filtrations and Separations Society.
- Stryer Lubert, Berg Jeremy M., Tymoczko John L., 2007, "2". *Biochemistry* (6. ed., 3. print. ed.). New York: Freeman.
- Swaddle T.W., 1990, *Inorganic chemistry, an industrial and environmental perspective*. Academic Press Limited.
- Taylor S.W., Headland L.C., 2005, Analysis and design of infiltration seawater intakes, Proceedings, World Water and Environmental Resources Congress, Anchorage, Alaska, May 15–19, 2005.
- Teuler A., Glucina K., Laine J.M., 1999, Assessment of UF pretreatment prior to RO membranes for seawater desalination, *Desalination* 125, P.89–96.
- UNEP, 2002, *Environmental Impact Assessment Training Resource Manual*. 2nd Edition, Two Volumes (Manual 573 p.; transparency overheads 226 p.). Print version available at Earthprint 158; (<http://www.earthprint.com>). Electronic version available at UNEP; (<http://www.unep.ch/etu/publications>).
- Urtiaga A.M., Gorri E.D., Ruiz G. and Ortiz I., 2001, Parallelism and differences of pervaporation and vacuum membrane distillation in the removal of VOCs from aqueous streams. *Separation and Purification Technology* 22-23, P.327-337.
- Van Hoof S.C.J.M., Hashim A., Kordes A.J., 1999, “The Effect of Ultrafiltration as Pretreatment to Reverse Osmosis in Wastewater Reuse and Seawater Desalination Applications”, *Desalination* 124, P.231-242.
- Van Hoof S., 2000, “Semi Dead-End Ultrafiltration in Potable Water Production”, *Filtration + Separation*, January/February 2000.
- Von Gottberg A.J.M., Persechino J.M., August 2000 “Using Membrane Filtration as Pretreatment for Reverse Osmosis to Improve System Performance”, presented at ADA 2000 Biennial Conference & Exposition, South Lake Tahoe, NV.
- Voutchkov N., 2005, Thorough study is key to large beach-well intakes, *Desalin. Water Reuse* Q. 14 (1) P.16–20.

- Voutchkov N²., 2005, SWRO desalination process: on the beach–seawater intakes, *Filter. Sep.* 42 (8) P.24–27.
- Voutchkov, N., and R. Bergman, 2007, Facility Design and Construction. In *AWWA Manual M46, Reverse Osmosis and Nanofiltration*. 2nd ed. Denver, Colo.: AWWA.
- Voutchkov Nikolay, June 2011, Overview of sea water concentrate disposal alternatives; *Desalination* Volume 273, issue 1, P.205-219.
- Vrouwenvelder H.S., Van Paassen J.A.M., Folmer H.C., Hofman J.A.M.H., Nederlof M.M., Van Der Kooij D., 1998, Biofouling of membranes for drinking water production, *Desalination* 118 (1–3) P.157–166.
- Wang Lawrence K., Chen Jiaping Paul, Hung Yung-Tse, Shammas Nazih K., 2010, Membrane and Desalination Technologies, Volume 13 of Handbook of Environmental Engineering, Springer Science & Business Media, P.585.
- Wang Sunny, Leung Eric, Cheng Robert, Tseng Tai, Vuong Diem, Carlson David, Henson Jeff, Veerapaneni Srinivas, 2007, Under Ocean Floor Seawater Intake and Discharge System - IDA World Congress-Maspalomas, Gran Canaria – Spain October P.21-26, REF: IDAWC/MP07-104.
- WATER RESEARCH FOUNDATION, 2011, Assessing Seawater Intake Systems for Desalination Plants – Ch.2 State-of-the-science in ocean intake design and permitting for seawater desalination.
- WateReuse Association¹, 2011, Seawater Concentrate Management, WateReuse Association White Paper.
- WateReuse Association², 2011, Desalination Plant Intakes: Impingement and Entrainment Impacts and Solutions, WateReuse Association White Paper.
- WDRr Water (2006) Water Desalination Report, Vol. 42, No. 35, September 25, 2006.
- WDR (2008) Water Desalination Report, Vol. 44, No. 33, 15 September, 2008
- WDR/DesalData, 2011. Personal communication Tom Pankratz
- Weiss W.J., Brouwer E.J., Aboytes R., LeChevallier M.W., O'Melia C.R., Le B.T., Schwab K.J., 2005, Riverbank filtration for control of microorganisms: results from field monitoring, *Water Res.* 39 (10) 1990–2001.
- WHO, 2004, The precautionary principle: protecting public health, the environment and the future of our children. World Health Organization, Regional Office for Europe, Denmark.
Available at <http://www.euro.who.int/document/e83079.pdf>
- WHO, 2007 Geneva. Desalination for safe water supply; Guidance for the health and environment aspects applicable to desalination; Public Health and the Environment.
- Wilf Mark, Bartels Craig, 2005; Optimization of seawater RO systems design, *Desalination* 173 P.1-12
- Winters H., 1994, Biofouling Status of the Saline Water Conversion Corporation (SWCC) Reverse Osmosis (RO) Plants in the Kingdom of Saudi Arabia; A Consultancy Report.
- Wolf Peter H. and Siverns Steve, 2005, The New Generation for Reliable Pretreatment.

Wright R. R. and Missimer T.M., 1997, Alternative Intake Systems for Seawater Membrane Water Treatment Plants. In *Proc. of the 1997 International Desalination Association Annual Conference*, Madrid, Spain.

Zeebe Richard, Gattuso Jean-Pierre, October 2011, Marine Carbonate Chemistry; The Encyclopedia of Earth.

ANNEX – 1

DAILY WATER ANALYSIS FROM 18-25 SEPTEMBER 2012

Date	Shift	Time	Sea Water			Feed Water			
			Conductivity	pH	Temp	Conductivity	pH	Temp	SDI
18-Sep-2012	Day	12:00	56,100	8.00	33.2	43,356	7.80	34.5	7.89
		16:00	56,100	8.21	34.0	43,198	8.00	35.4	7.65
18-Sep-2012	Night	22:00	55,900	7.80	31.5	43,213	7.60	33.2	7.26
		4:00	55,800	7.80	29.3	43,056	7.90	30.2	7.45
19-Sep-2012	Day	8:00	56,000	8.00	31.3	43,214	7.80	32.5	7.97
		14:00	56,100	7.80	33.0	43,165	7.70	33.2	7.54
19-Sep-2012	Night	20:00	56,000	8.00	32.3	43,125	7.80	31.9	7.43
		2:00	55,700	7.90	31.4	42,897	7.80	31.8	7.21
20-Sep-2012	Day	8:00	55,900	7.80	31.1	42,985	7.70	32.6	7.16
		10:00	55,700	7.70	31.0	42,873	7.60	32.2	7.25
20-Sep-2012	Night	20:00	55,900	8.00	29.9	43,120	7.90	31.0	7.64
		2:00	55,900	8.10	28.3	43,178	8.00	29.8	7.58
21-Sep-2012	Day	10:00	56,100	8.20	32.1	43,168	8.10	33.1	7.39
		16:00	56,300	8.30	34.1	43,278	8.20	35.2	7.46
21-Sep-2012	Night	22:00	55,900	8.02	30.2	43,020	7.90	31.0	7.47
		4:00	55,800	8.12	27.7	43,005	7.90	29.1	7.38
22-Sep-2012	Day	9:00	56,300	8.20	34.2	43,270	8.00	35.2	7.89
		15:00	56,200	8.10	33.5	43,273	8.00	33.9	8.05
22-Sep-2012	Night	21:00	56,000	7.90	32.4	43,221	7.80	33.8	8.12
		3:00	55,800	8.10	29.8	43,006	8.00	31.2	7.87
23-Sep-2012	Day	8:00	55,800	7.70	28.7	42,978	7.60	29.7	7.65
		14:00	56,000	8.10	30.8	43,268	8.10	32.0	7.55
23-Sep-2012	Night	0:00	56,000	8.03	30.0	43,169	7.90	31.2	7.42
		4:00	55,900	7.84	27.1	43,165	7.70	28.1	7.59
24-Sep-2012	Day	9:00	56,100	8.00	31.7	43,210	7.90	32.9	7.61
		15:00	56,100	8.10	32.8	43,170	8.10	34.0	7.38
24-Sep-2012	Night	23:00	55,800	7.90	28.5	43,060	7.90	29.4	7.29
		4:00	56,000	8.11	27.6	43,185	8.20	28.7	7.48
25-Sep-2012	Day	11:00	56,100	8.00	31.3	43,237	7.80	32.5	7.79
		17:00	56,000	8.10	30.6	43,009	7.80	32.1	7.58
25-Sep-2012	Night	22:00	55,800	7.94	28.2	42,906	7.70	29.8	7.32
		2:00	55,600	7.90	27.8	42,840	7.80	28.5	7.26
AVERAGE			55,959	7.99	30.8	43,119	7.88	31.9	7.55

Date	Shift	Time	Product Water			Reject Water		
			Conductivity	pH	Temp	Conductivity	pH	Temp
18-Sep-2012	Day	12:00	1,117	8.20	32.3	85,700	7.80	33.2
		16:00	1,177	8.40	33.7	87,000	8.00	35.0
18-Sep-2012	Night	22:00	1,021	8.20	31.1	87,700	7.70	32.4
		4:00	995	8.00	30.2	87,300	7.80	29.4
19-Sep-2012	Day	8:00	1,008	8.30	30.8	86,400	7.80	31.8
		14:00	1,100	8.20	32.0	86,000	7.90	32.0
19-Sep-2012	Night	20:00	1,070	8.40	31.4	86,700	7.80	32.2
		2:00	1,037	8.20	30.5	86,400	7.74	31.9
20-Sep-2012	Day	8:00	1,070	7.90	30.7	86,200	7.70	32.0
		10:00	1,070	8.20	31.0	86,300	7.80	32.1
20-Sep-2012	Night	20:00	1,145	8.40	28.0	85,400	7.80	30.7
		2:00	1,190	8.40	28.5	85,000	7.80	30.0
21-Sep-2012	Day	10:00	1,187	7.90	27.8	84,600	7.79	29.4
		16:00	1,052	8.20	31.8	86,000	7.80	33.0
21-Sep-2012	Night	22:00	1,154	8.24	28.1	85,000	7.75	29.7
		4:00	1,116	8.10	27.8	84,800	7.70	29.0
22-Sep-2012	Day	9:00	1,000	8.20	32.8	86,100	7.70	33.8
		15:00	1,160	8.30	31.8	85,800	7.90	33.4
22-Sep-2012	Night	21:00	1,130	8.33	28.3	84,500	7.80	30.0
		3:00	1,120	8.23	27.7	84,300	7.70	29.1
23-Sep-2012	Day	8:00	1,098	8.15	27.8	85,200	7.90	29.1
		14:00	1,084	8.10	29.7	85,500	7.70	31.0
23-Sep-2012	Night	0:00	1,113	8.15	27.4	84,300	7.80	28.9
		4:00	1,060	8.10	27.6	84,300	7.70	28.8
24-Sep-2012	Day	9:00	1,168	8.05	30.6	85,600	7.70	31.9
		15:00	1,180	8.20	31.9	85,600	7.90	33.2
24-Sep-2012	Night	23:00	1,231	8.36	29.2	84,900	7.80	30.1
		4:00	1,184	8.37	28.7	84,800	7.77	30.1
25-Sep-2012	Day	11:00	1,197	8.30	30.1	85,600	7.80	31.4
		17:00	1,205	8.25	30.2	85,500	7.70	31.6
25-Sep-2012	Night	22:00	1,203	8.20	28.4	85,200	7.80	29.8
		2:00	1,187	8.15	27.1	84,900	7.90	28.3
AVERAGE			1,119.66	8.21	29.84	85,581.25	7.79	31.07

ANNEX – 2

DAILY WATER ANALYSIS FROM 5 TO 18 OCTOBER 2012

Date	Shift	Time	Sea Water			Feed Water			
			Conductivity	pH	Temp	Conductivity	pH	Temp	SDI
5-Oct-2012	Day	10:00	53,600	8.35	28.6	40,600	7.96	29.7	6.57
		14:00	53,500	8.55	31.8	40,500	8.16	32.8	6.63
5-Oct-2012	Night	0:00	52,900	8.32	30.2	40,100	7.90	31.1	6.31
		4:00	52,800	8.22	30.4	40,000	7.88	30.1	6.28
6-Oct-2012	Day	10:00	52,100	8.40	30.5	39,400	8.05	30.3	5.87
		14:00	51,900	8.45	31.5	39,300	8.12	33.0	6.15
6-Oct-2012	Night	22:00	51,600	8.50	31.6	39,100	8.20	33.0	5.92
		2:00	51,500	8.36	29.0	39,000	8.00	30.4	5.84
7-Oct-2012	Day	10:00	51,500	8.36	30.4	39,000	7.97	30.3	5.73
		16:00	53,300	8.52	32.3	40,400	8.30	33.8	6.70
7-Oct-2012	Night	0:00	52,200	8.40	29.3	39,500	8.00	30.9	6.10
		4:00	52,100	8.36	30.0	39,500	7.95	30.0	6.06
8-Oct-2012	Day	8:00	51,500	8.32	28.3	39,000	7.96	29.9	5.86
		16:00	53,100	8.57	31.7	40,200	8.28	33.6	6.13
8-Oct-2012	Night	20:00	53,700	8.56	31.5	40,700	8.19	32.9	6.34
		4:00	54,600	8.29	27.2	41,300	7.90	27.0	6.58
9-Oct-2012	Day	14:00	55,500	8.24	31.3	42,000	7.80	32.5	6.76
		18:00	55,800	8.41	30.2	42,300	8.01	31.8	6.71
9-Oct-2012	Night	22:00	55,100	8.31	30.9	41,700	7.90	31.3	6.81
		2:00	55,000	8.32	29.6	41,700	7.94	31.0	6.68
10-Oct-2012	Day	8:00	55,600	8.09	29.0	42,100	7.70	30.2	6.72
		12:00	55,600	8.14	28.7	42,100	7.80	31.2	6.68
10-Oct-2012	Night	18:00	55,900	8.40	30.8	42,300	8.10	32.8	6.86
		22:00	55,400	8.37	30.8	42,000	8.10	30.5	6.74
11-Oct-2012	Day	10:00	55,600	8.16	29.1	42,100	7.74	30.6	6.49
		14:00	55,700	8.41	30.0	42,200	8.10	32.1	6.57
11-Oct-2012	Night	20:00	55,200	8.60	29.7	41,800	8.70	31.9	6.67
		0:00	54,900	8.23	29.5	41,600	7.90	31.1	6.37
12-Oct-2012	Day	10:00	55,400	8.24	28.8	41,900	7.90	30.4	6.46
		16:00	55,400	8.26	31.1	41,900	7.90	32.0	6.57
12-Oct-2012	Night	20:00	55,700	8.41	30.5	42,200	8.00	31.4	6.62
		4:00	55,100	8.29	29.5	41,700	7.90	30.5	6.68
13-Oct-2012	Day	8:00	55,300	8.31	28.7	41,900	7.90	30.1	6.76
		16:00	55,700	8.40	31.9	42,200	8.10	32.5	6.57
13-Oct-2012	Night	18:00	55,800	8.34	30.9	42,300	8.00	31.5	6.53
		4:00	55,600	8.32	29.6	42,100	7.90	29.0	6.64
14-Oct-	Day	10:00	56,400	8.46	29.1	42,700	8.15	30.5	6.81

2012		12:00	56,200	8.31	29.3	42,600	7.95	31.2	6.89
14-Oct-2012	Night	22:00	56,400	8.18	29.6	42,700	7.83	31.0	7.13
		2:00	56,100	8.26	28.1	42,500	7.80	29.8	7.02
15-Oct-2012	Day	6:00	55,700	8.28	27.3	42,200	7.90	28.9	7.11
		14:00	56,000	8.29	31.9	42,400	8.09	32.7	7.01
15-Oct-2012	Night	20:00	54,800	8.42	29.8	41,500	8.16	30.7	6.89
		6:00	54,700	8.46	27.9	41,400	8.00	29.0	6.76
16-Oct-2012	Day	14:00	55,500	8.26	31.0	42,000	7.80	32.5	6.67
		18:00	56,300	8.02	29.3	42,600	7.50	30.0	6.94
16-Oct-2012	Night	0:00	55,300	8.09	29.4	41,900	7.70	30.4	6.57
		4:00	56,100	8.01	28.5	42,500	7.60	29.9	6.73
17-Oct-2012	Day	10:00	55,700	8.16	30.4	42,200	7.80	31.5	6.63
		16:00	56,000	8.34	31.9	42,400	8.09	32.7	6.49
17-Oct-2012	Night	20:00	56,100	8.35	31.2	42,500	8.07	31.3	6.57
		4:00	55,600	8.19	28.3	42,100	7.80	29.6	6.48
18-Oct-2012	Day	8:00	55,400	8.12	28.1	41,900	7.70	29.7	6.38
		12:00	55,400	8.15	29.4	41,900	7.76	31.0	6.56
18-Oct-2012	Night	0:00	56,000	8.28	29.3	42,400	7.90	31.0	6.44
		6:00	54,900	8.12	27.2	41,600	7.80	26.8	6.38
Average			54,746	8.31	29.85	41,459	7.96	30.95	6.54

Date	Shift	Time	Product Water			Reject Water		
			Conductivity	pH	Temp	Conductivity	pH	Temp
5-Oct-2012	Day	10:00	819	8.50	29.1	80,100	7.71	30.4
		14:00	959	8.70	32.4	81,200	7.91	33.4
5-Oct-2012	Night	0:00	848	8.40	29.1	80,100	7.75	31.4
		4:00	796	8.29	29.4	79,600	7.65	30.7
6-Oct-2012	Day	10:00	769	8.39	29.6	79,500	7.73	30.8
		14:00	912	8.62	32.6	80,000	7.89	33.8
6-Oct-2012	Night	22:00	790	8.50	30.5	79,200	7.92	32.9
		2:00	744	8.56	29.7	78,700	7.76	30.2
7-Oct-2012	Day	10:00	755	8.57	29.8	79,000	7.76	31.1
		16:00	896	8.70	30.9	79,200	7.90	32.0
7-Oct-2012	Night	0:00	791	8.55	30.5	79,500	7.74	31.6
		4:00	770	8.30	28.1	79,100	7.72	30.7
8-Oct-2012	Day	8:00	750	8.52	28.9	78,600	7.73	30.5
		16:00	950	8.80	32.3	79,300	7.95	33.8
8-Oct-2012	Night	20:00	885	8.79	32.5	78,600	7.88	33.4
		4:00	752	8.10	26.9	78,000	7.60	28.8
9-Oct-2012	Day	14:00	1,100	8.40	31.9	80,400	7.50	32.9
		18:00	948	8.60	31.5	76,700	7.70	31.7
9-Oct-2012	Night	22:00	910	8.50	30.6	77,900	7.70	32.0

		2:00	877	8.50	30.3	77,500	7.70	31.5
10-Oct-2012	Day	8:00	850	8.00	29.4	80,000	7.50	30.6
		12:00	902	8.40	30.9	78,300	7.60	31.4
10-Oct-2012	Night	18:00	988	8.60	32.1	78,700	7.80	33.5
		22:00	905	8.60	30.0	78,500	7.80	31.8
11-Oct-2012	Day	10:00	859	8.10	29.8	78,200	7.50	31.1
		14:00	1,038	8.60	31.7	79,100	7.80	33.1
11-Oct-2012	Night	20:00	917	8.60	31.3	77,800	7.80	32.4
		0:00	896	8.50	30.4	77,700	7.70	31.7
12-Oct-2012	Day	10:00	860	8.40	30.0	77,600	7.70	31.0
		16:00	1,012	8.60	32.7	77,800	7.80	32.0
12-Oct-2012	Night	20:00	915	8.60	30.8	76,700	7.80	32.1
		4:00	861	8.44	29.9	77,300	7.70	30.7
13-Oct-2012	Day	8:00	815	8.40	29.8	77,600	7.60	30.8
		16:00	1,033	8.70	31.8	78,400	7.90	33.4
13-Oct-2012	Night	18:00	1,003	8.50	30.6	78,400	7.80	32.8
		4:00	843	8.52	28.1	77,400	7.70	29.6
14-Oct-2012	Day	10:00	956	8.40	30.9	78,300	7.80	32.1
		12:00	927	8.50	30.4	78,900	7.71	31.9
14-Oct-2012	Night	22:00	917	8.30	30.0	79,100	7.60	31.7
		2:00	886	8.40	29.3	78,600	7.63	30.0
15-Oct-2012	Day	6:00	872	8.50	28.0	77,600	7.70	29.1
		14:00	968	8.60	32.4	78,800	7.85	32.4
15-Oct-2012	Night	20:00	928	8.70	29.9	79,100	7.80	30.7
		6:00	858	8.50	28.0	77,000	7.70	30.0
16-Oct-2012	Day	14:00	1,100	8.40	31.9	80,400	7.50	32.9
		18:00	862	7.20	29.1	78,700	7.30	30.2
16-Oct-2012	Night	0:00	906	8.20	29.4	79,200	7.20	31.1
		4:00	880	7.85	29.3	79,200	7.40	30.6
17-Oct-2012	Day	10:00	940	8.40	31.2	78,500	7.64	32.4
		16:00	968	8.60	32.4	78,800	7.85	32.4
17-Oct-2012	Night	20:00	894	8.70	30.7	78,400	7.80	31.9
		4:00	869	8.40	29.6	78,400	7.60	30.0
18-Oct-2012	Day	8:00	823	8.20	29.6	78,200	7.50	30.7
		12:00	913	8.32	31.0	78,200	7.56	31.8
18-Oct-2012	Night	0:00	907	8.50	30.4	78,400	7.70	31.6
		6:00	725	8.00	26.3	77,900	7.70	27.5
Average			890	8.44	30.28	78632.14	7.70	31.48

ANNEX – 3

DAILY WATER ANALYSIS FROM 27 OCTOBER TO 27 NOVEMBER 2012

Date	Shift	Time	Sea Water			Feed Water			
			Conductivity	pH	Temp	Conductivity	pH	SDI	Temp
27-Oct-2012	Day	8:00	55,700	8.40	27.2	40,200	7.70	5.40	26.8
		14:00	54,200	8.20	28.9	39,900	8.10	5.51	29.9
27-Oct-2012	Night	20:00	53,100	8.30	28.1	38,900	8.21	5.49	29.6
		0:00	53,200	8.20	27.9	39,100	8.05	5.31	29.0
28-Oct-2012	Day	12:00	53,400	8.20	28.3	39,300	8.10	5.28	29.2
		16:00	53,300	8.30	27.8	39,200	8.10	5.46	29.5
28-Oct-2012	Night	0:00	53,700	8.40	29.2	39,500	8.20	5.67	30.2
		4:00	54,900	8.50	30.0	40,400	8.60	5.64	30.9
29-Oct-2012	Day	6:00	54,000	8.10	28.2	39,800	8.00	5.54	28.0
		11:00	53,800	7.90	24.9	39,600	7.60	5.28	25.3
29-Oct-2012	Night	23:00	54,700	8.20	25.8	39,200	8.00	5.43	29.4
		4:00	54,200	8.00	27.5	39,900	8.00	5.59	29.1
30-Oct-2012	Day	8:00	54,000	8.40	27.1	40,000	8.00	5.38	28.5
		12:00	53,400	8.10	28.7	39,300	8.10	5.67	29.8
30-Oct-2012	Night	18:00	54,300	8.30	28.6	40,000	8.15	5.24	29.7
		21:00	54,000	8.20	27.6	39,800	8.10	5.38	28.3
31-Oct-2012	Day	10:00	54,300	7.90	25.2	40,000	7.70	5.00	25.5
		14:00	54,600	8.00	26.4	40,200	8.00	5.29	28.3
31-Oct-2012	Night	0:00	53,500	8.10	27.6	39,400	7.90	5.49	28.2
		4:00	53,700	8.00	25.4	39,500	7.70	5.37	26.0
1-Nov-2012	Day	10:00	54,600	8.10	26.6	40,200	7.80	5.44	28.1
		16:00	53,800	8.60	31.4	39,900	8.20	5.27	31.5
1-Nov-2012	Night	22:00	53,900	8.10	25.8	39,700	8.00	5.41	28.0
		2:00	53,500	8.00	26.6	39,400	7.90	5.55	27.3
2-Nov-2012	Day	8:00	54,000	7.80	24.4	39,800	7.86	5.48	25.0
		16:00	54,600	8.10	27.8	40,200	8.20	5.64	28.4
2-Nov-2012	Night	22:00	55,700	8.30	26.2	41,000	8.10	5.71	27.0
		2:00	55,800	7.80	24.3	41,100	7.89	5.76	25.2
3-Nov-2012	Day	8:00	56,700	8.00	23.8	41,700	7.90	5.69	24.4
		16:00	54,500	8.50	28.7	41,100	8.21	5.64	29.5
3-Nov-2012	Night	22:00	55,800	8.40	26.9	41,100	8.20	5.72	29.0
		4:00	55,000	8.00	25.7	40,500	7.90	5.46	26.2
4-Nov-2012	Day	8:00	53,000	8.30	26.4	40,300	7.90	5.41	26.3
		14:00	56,200	8.40	26.8	41,400	8.70	5.57	28.4
4-Nov-2012	Night	20:00	55,700	8.10	28.1	41,000	8.20	5.67	29.7
		23:00	54,400	8.40	27.7	40,800	8.00	5.46	28.5
5-Nov-	Day	8:00	53,600	8.20	26.1	41,400	7.86	5.77	26.5

2012		16:00	55,300	8.60	30.4	40,800	8.10	5.78	31.4
5-Nov-2012	Night	22:00	56,100	8.50	29.3	41,300	8.60	5.68	31.0
		6:00	55,400	8.10	26.3	40,800	7.80	5.61	27.5
6-Nov-2012	Day	8:00	53,700	8.30	27.1	40,800	7.80	5.59	27.4
		16:00	55,400	8.20	30.0	40,800	8.10	5.54	31.3
6-Nov-2012	Night	22:00	55,100	8.10	28.4	40,600	8.00	5.37	29.6
		2:00	55,500	8.30	27.6	40,800	7.80	5.74	28.8
7-Nov-2012	Day	8:00	53,700	8.30	26.7	40,900	7.88	5.71	28.1
		16:00	54,800	8.60	29.5	40,800	8.20	5.61	32.1
7-Nov-2012	Night	20:00	54,700	8.40	29.8	40,300	8.20	5.53	31.0
		0:00	54,900	7.80	27.9	40,400	7.90	5.48	30.1
8-Nov-2012	Day	8:00	54,300	8.40	26.7	40,500	7.80	5.36	29.0
		14:00	55,600	8.60	30.3	40,300	8.05	5.24	31.0
8-Nov-2012	Night	22:00	55,100	8.00	27.4	40,600	7.90	5.81	30.0
		2:00	55,000	8.20	28.6	40,200	7.90	5.64	29.4
9-Nov-2012	Day	10:00	55,400	8.30	30.1	40,200	7.93	5.57	30.1
		14:00	54,900	8.30	30.5	40,400	8.10	5.33	31.2
9-Nov-2012	Night	20:00	55,000	8.10	29.1	40,500	8.00	5.40	30.9
		4:00	54,300	8.00	28.6	40,000	7.90	5.12	29.7
10-Nov-2012	Day	8:00	55,700	8.50	28.3	40,200	8.00	5.18	30.1
		12:00	55,900	8.30	30.7	40,100	8.10	5.27	31.0
10-Nov-2012	Night	22:00	55,100	8.30	29.7	40,600	8.19	5.31	30.9
		4:00	55,500	8.10	27.7	40,900	7.90	5.62	29.6
11-Nov-2012	Day	8:00	54,000	8.00	27.2	41,700	8.90	5.74	30.7
		14:00	56,200	8.40	29.6	41,400	8.20	5.68	31.6
11-Nov-2012	Night	0:00	55,800	8.30	27.1	41,100	8.10	5.37	29.0
		4:00	55,600	8.00	28.2	40,900	7.90	5.39	29.7
12-Nov-2012	Day	8:00	54,900	8.10	28.4	41,600	8.10	5.42	30.4
		10:00	54,700	8.20	29.8	41,900	8.00	5.57	30.1
12-Nov-2012	Night	21:00	54,400	8.00	29.9	41,800	8.90	5.49	30.8
		0:00	56,200	8.10	28.5	41,400	8.00	5.53	29.4
13-Nov-2012	Day	10:00	55,900	8.30	28.6	41,200	8.00	5.44	30.3
		16:00	55,400	8.40	30.2	41,400	8.30	5.51	31.9
13-Nov-2012	Night	2:00	55,500	8.00	28.4	40,900	7.90	5.46	29.5
		4:00	55,800	7.80	28.8	40,900	7.90	5.42	29.6
14-Nov-2012	Day	8:00	54,200	8.30	28.0	41,400	7.99	5.41	30.0
		12:00	56,000	8.40	30.2	41,500	8.26	5.48	31.2
14-Nov-2012	Night	18:00	56,400	8.30	30.3	41,500	8.20	5.68	31.4
		23:00	56,400	8.30	28.4	41,400	8.20	5.39	29.2
15-Nov-2012	Day	8:00	54,900	8.20	27.9	40,900	8.12	5.71	29.6
		16:00	56,400	8.30	30.5	41,100	8.20	5.83	31.6
15-Nov-2012	Night	20:00	56,700	8.40	29.7	41,300	8.20	5.61	30.4
		4:00	56,000	8.50	26.9	41,500	8.70	5.54	28.3
16-Nov-	Day	10:00	55,200	8.00	28.0	40,900	8.10	5.37	29.2

2012		16:00	55,700	8.40	29.8	41,200	8.70	5.58	31.0
16-Nov-2012	Night	0:00	55,000	8.10	28.3	40,600	8.20	5.69	29.8
		4:00	55,600	7.90	26.9	40,700	8.20	5.72	29.0
17-Nov-2012	Day	8:00	55,000	8.30	27.4	41,200	8.11	5.78	28.5
		14:00	54,800	8.40	28.7	41,300	8.10	5.54	30.8
17-Nov-2012	Night	20:00	55,800	8.40	29.1	40,800	8.30	5.59	30.8
		2:00	55,100	8.50	27.4	40,700	8.20	5.84	29.0
18-Nov-2012	Day	8:00	53,800	8.10	26.5	40,300	8.40	5.47	28.6
		11:00	54,700	8.30	27.4	40,500	8.14	5.29	29.1
18-Nov-2012	Night	20:00	55,200	8.40	28.4	40,400	8.20	5.37	29.7
		23:00	54,700	8.30	30.3	40,900	8.16	5.39	30.8
19-Nov-2012	Day	9:00	53,800	8.10	27.3	40,400	8.00	5.56	28.1
		14:00	53,900	8.40	27.8	40,500	8.70	5.58	28.2
19-Nov-2012	Night	22:00	54,500	8.00	28.1	40,100	8.10	5.43	29.3
		2:00	54,100	8.30	27.3	40,000	8.10	5.37	27.9
20-Nov-2012	Day	10:00	54,800	8.10	28.4	40,100	8.20	5.47	29.5
		15:00	54,700	8.40	30.1	40,700	8.70	5.29	30.4
20-Nov-2012	Night	22:00	54,900	7.70	27.4	40,100	7.90	5.34	28.6
		2:00	54,100	8.00	27.9	40,000	7.90	5.37	28.2
21-Nov-2012	Day	9:00	53,500	8.20	26.5	40,300	8.60	5.28	27.3
		12:00	55,000	8.50	28.5	40,600	8.19	5.19	30.9
21-Nov-2012	Night	20:00	54,600	8.10	27.6	40,500	7.89	5.34	28.6
		0:00	55,200	8.20	28.1	40,300	8.10	5.38	29.0
22-Nov-2012	Day	8:00	53,800	8.40	25.8	40,200	8.72	5.04	26.1
		16:00	53,600	8.20	26.8	40,300	8.50	5.26	27.5
22-Nov-2012	Night	20:00	54,300	8.00	26.9	40,200	7.90	5.38	27.8
		2:00	54,700	8.10	28.1	40,100	8.10	5.48	29.6
23-Nov-2012	Day	8:00	54,900	8.20	26.7	40,100	8.00	5.46	28.6
		11:00	54,000	8.00	27.5	40,000	8.00	5.68	28.5
23-Nov-2012	Night	0:00	54,300	7.80	27.6	40,000	7.90	5.76	28.2
		4:00	54,900	7.90	26.8	40,100	7.91	5.84	28.4
24-Nov-2012	Day	8:00	55,600	8.40	28.1	40,400	8.00	5.86	30.5
		14:00	54,400	8.30	26.5	40,400	8.00	5.49	30.1
24-Nov-2012	Night	20:00	54,600	8.10	28.2	40,100	8.10	5.30	29.1
		0:00	54,000	7.90	27.5	40,200	7.90	5.66	28.5
25-Nov-2012	Day	8:00	54,100	8.10	26.1	40,100	7.90	5.58	28.0
		15:00	54,900	8.30	28.1	40,300	8.00	5.27	29.6
25-Nov-2012	Night	22:00	53,700	8.20	27.4	39,100	8.10	5.34	29.0
		2:00	53,100	8.10	27.9	39,000	8.00	5.19	29.0
26-Nov-2012	Day	8:00	54,500	8.20	27.5	40,100	8.10	5.24	29.3
		14:00	55,200	8.40	29.7	40,000	8.19	5.38	31.6
26-Nov-2012	Night	20:00	55,200	8.40	26.8	40,100	8.40	5.41	29.0
		4:00	54,200	8.10	26.1	40,200	8.10	5.28	27.5
27-Nov-	Day	8:00	54,500	8.20	27.5	41,700	8.06	5.34	28.5

2012		14:00	55,200	8.30	28.2	41,600	8.00	5.54	28.3
27-Nov-2012	Night	20:00	54,300	8.00	27.6	41,700	8.00	5.38	28.4
		22:00	53,900	8.10	27.3	41,700	8.10	5.22	28.3
Average			54,752	8.20	27.90	40,502	8.10	5.48	29.12

Date	Shift	Time	Product Water			Reject Water		
			Conductivity	pH	Temp	Conductivity	pH	Temp
27-Oct-2012	Day	8:00	714	8.20	26.4	78,100	7.60	27.4
		14:00	852	8.60	30.2	78,600	7.90	31.5
27-Oct-2012	Night	20:00	828	8.79	28.6	73,000	8.00	30.4
		0:00	802	8.60	28.2	72,900	7.90	29.6
28-Oct-2012	Day	12:00	780	8.90	29.1	74,100	7.90	30.7
		16:00	790	8.40	28.7	74,000	7.80	30.4
28-Oct-2012	Night	0:00	779	8.20	28.7	75,200	7.80	30.2
		4:00	930	8.50	30.1	75,500	7.80	30.8
29-Oct-2012	Day	6:00	770	8.60	27.5	74,900	7.80	28.2
		11:00	635	8.20	24.3	77,500	7.60	26.0
29-Oct-2012	Night	23:00	821	8.60	29.0	74,000	7.80	27.4
		4:00	801	8.70	25.8	75,200	7.80	29.2
30-Oct-2012	Day	8:00	812	8.60	27.7	75,500	7.80	29.3
		12:00	809	8.40	27.5	84,000	8.70	29.3
30-Oct-2012	Night	18:00	836	8.70	29.3	78,500	7.90	30.7
		21:00	772	8.60	27.7	78,600	7.90	29.3
31-Oct-2012	Day	10:00	638	8.10	24.5	77,600	7.60	26.7
		14:00	718	8.60	27.5	78,900	7.70	29.5
31-Oct-2012	Night	0:00	761	8.50	29.0	77,600	7.76	28.8
		4:00	680	8.20	23.9	77,500	7.60	27.1
1-Nov-2012	Day	10:00	772	8.40	27.4	78,100	7.60	28.1
		16:00	923	8.60	30.3	79,100	7.90	31.3
1-Nov-2012	Night	22:00	754	8.40	28.2	78,700	7.80	28.7
		2:00	722	8.30	27.3	77,600	7.60	27.3
2-Nov-2012	Day	8:00	632	8.25	24.4	77,500	7.67	25.6
		16:00	774	8.70	28.0	79,100	7.90	28.8
2-Nov-2012	Night	22:00	739	8.60	29.2	78,000	7.80	28.0
		2:00	648	8.40	24.6	77,600	7.71	26.2
3-Nov-2012	Day	8:00	610	8.50	24.1	76,900	7.70	25.6
		16:00	787	8.76	28.8	76,600	7.94	30.1
3-Nov-2012	Night	22:00	755	8.60	27.4	76,900	7.70	30.0
		4:00	707	8.30	26.4	76,600	7.70	27.4
4-Nov-2012	Day	8:00	683	8.50	25.4	75,900	7.76	27.0
		14:00	790	8.60	28.1	77,600	7.80	29.8
4-Nov-2012	Night	20:00	862	8.80	29.2	77,400	8.00	30.7
		23:00	855	8.60	27.5	77,000	8.10	29.5

5-Nov-2012	Day	8:00	707	8.40	25.5	76,600	7.70	27.2
		16:00	919	8.70	31.6	77,300	7.90	32.5
5-Nov-2012	Night	22:00	914	8.70	29.1	77,300	7.80	31.5
		6:00	793	8.10	26.6	77,000	7.70	28.1
6-Nov-2012	Day	8:00	775	8.90	27.9	76,800	7.66	28.0
		16:00	901	8.70	30.0	77,700	7.90	31.5
6-Nov-2012	Night	22:00	842	8.20	29.3	77,300	7.90	30.4
		2:00	815	8.20	27.8	77,000	7.70	29.4
7-Nov-2012	Day	8:00	795	8.40	27.5	76,800	7.70	28.5
		16:00	881	8.70	29.0	75,800	7.90	30.5
7-Nov-2012	Night	20:00	756	8.40	26.8	72,300	7.80	28.9
		0:00	842	8.50	28.8	76,500	7.70	30.7
8-Nov-2012	Day	8:00	790	8.20	27.8	76,100	7.60	29.5
		14:00	868	8.50	30.1	76,200	7.80	31.9
8-Nov-2012	Night	22:00	845	8.50	28.9	76,500	7.80	30.7
		2:00	804	8.60	27.4	76,500	7.70	30.0
9-Nov-2012	Day	10:00	814	8.57	29.4	76,000	7.78	30.6
		14:00	860	8.60	30.5	76,500	7.90	32.0
9-Nov-2012	Night	20:00	887	8.60	30.2	76,700	7.85	31.6
		4:00	839	8.40	29.0	76,300	7.70	30.4
10-Nov-2012	Day	8:00	827	8.60	29.6	76,100	7.80	30.7
		12:00	826	8.40	29.7	76,200	7.80	31.3
10-Nov-2012	Night	22:00	884	8.70	29.7	75,900	7.90	30.8
		4:00	903	8.40	28.6	77,000	7.79	30.2
11-Nov-2012	Day	8:00	970	8.67	30.2	77,700	7.80	31.4
		14:00	991	8.80	31.2	77,400	8.00	32.5
11-Nov-2012	Night	0:00	894	8.70	26.5	77,400	7.90	29.6
		4:00	892	8.50	29.1	77,000	7.70	29.9
12-Nov-2012	Day	8:00	904	8.60	30.2	77,300	7.90	30.3
		10:00	1,440	8.53	29.8	83,500	7.80	30.6
12-Nov-2012	Night	21:00	892	8.62	29.4	77,400	7.80	30.9
		0:00	887	8.60	29.0	77,100	7.80	30.6
13-Nov-2012	Day	10:00	890	8.60	29.3	77,300	7.80	31.0
		16:00	990	8.80	29.6	77,400	8.10	32.6
13-Nov-2012	Night	2:00	900	8.40	28.8	77,000	7.70	30.1
		4:00	903	8.40	28.6	77,000	7.79	30.2
14-Nov-2012	Day	8:00	896	8.50	29.2	77,200	7.78	30.5
		12:00	757	8.40	27.4	72,100	7.80	29.0
14-Nov-2012	Night	18:00	913	8.80	29.5	77,600	8.20	31.9
		23:00	884	8.80	29.8	77,300	8.00	30.2
15-Nov-2012	Day	8:00	858	8.60	28.5	77,000	7.90	30.1
		16:00	822	8.70	27.5	75,300	7.80	29.6
15-Nov-2012	Night	20:00	808	8.73	26.2	75,300	7.88	29.5
		4:00	845	8.60	27.3	77,000	7.80	28.7

16-Nov-2012	Day	10:00	816	8.70	28.8	76,500	7.69	30.1
		16:00	928	8.70	29.9	77,000	7.97	31.4
16-Nov-2012	Night	0:00	860	8.70	28.7	76,800	8.00	30.4
		4:00	833	8.70	28.2	76,700	7.80	29.8
17-Nov-2012	Day	8:00	819	8.70	27.4	76,700	7.88	29.3
		14:00	865	8.60	31.2	76,300	7.80	29.7
17-Nov-2012	Night	20:00	910	8.90	30.0	76,500	8.10	31.5
		2:00	860	8.80	28.2	76,100	8.00	29.6
18-Nov-2012	Day	8:00	804	8.70	26.2	75,900	7.90	26.5
		11:00	813	8.77	28.3	75,900	7.93	29.8
18-Nov-2012	Night	20:00	820	8.80	29.3	75,900	7.90	30.5
		23:00	912	8.74	29.9	76,500	7.90	31.4
19-Nov-2012	Day	9:00	884	8.70	29.9	75,800	7.90	30.9
		14:00	880	8.70	29.1	75,800	7.90	30.8
19-Nov-2012	Night	22:00	842	8.70	27.1	75,600	7.90	30.1
		2:00	829	8.70	25.9	75,600	7.80	28.8
20-Nov-2012	Day	10:00	808	8.40	26.5	75,600	7.80	29.9
		15:00	810	8.51	28.2	75,400	7.81	29.3
20-Nov-2012	Night	22:00	796	8.30	27.8	76,000	7.80	29.4
		2:00	820	8.60	26.2	75,200	7.80	29.3
21-Nov-2012	Day	9:00	834	8.70	26.5	75,600	7.80	29.8
		12:00	884	8.70	29.7	75,900	7.90	30.8
21-Nov-2012	Night	20:00	794	8.66	25.2	75,300	7.86	28.5
		0:00	834	8.70	26.5	75,600	7.80	29.8
22-Nov-2012	Day	8:00	741	8.38	27.2	75,700	7.70	28.4
		16:00	736	8.30	27.1	75,600	7.60	28.1
22-Nov-2012	Night	20:00	752	8.50	27.3	75,800	7.70	28.5
		2:00	862	8.70	28.1	75,700	7.80	30.1
23-Nov-2012	Day	8:00	839	8.70	27.0	75,600	7.80	29.2
		11:00	821	8.60	25.1	75,300	7.80	28.8
23-Nov-2012	Night	0:00	820	8.60	26.2	75,200	7.80	29.3
		4:00	815	8.50	28.1	75,400	7.80	29.4
24-Nov-2012	Day	8:00	907	8.50	29.8	76,500	7.80	31.4
		14:00	910	8.50	28.3	76,500	7.80	31.2
24-Nov-2012	Night	20:00	815	8.60	28.5	76,100	7.80	29.9
		0:00	789	8.50	28.0	75,900	7.80	29.1
25-Nov-2012	Day	8:00	747	8.40	26.6	75,500	7.70	28.5
		15:00	864	8.60	28.8	76,100	7.90	30.4
25-Nov-2012	Night	22:00	810	8.70	28.2	73,100	7.90	29.6
		2:00	796	8.60	28.3	72,700	7.88	29.5
26-Nov-2012	Day	8:00	809	8.40	26.3	75,600	7.80	29.8
		14:00	935	8.70	30.7	76,100	7.90	32.0
26-Nov-2012	Night	20:00	933	8.80	27.5	75,700	7.90	30.0
		4:00	827	8.70	25.6	75,600	7.80	28.7

27-Nov-2012	Day	8:00	782	8.56	27.5	72,500	7.85	29.0
		14:00	779	8.50	27.2	72,500	7.80	28.8
27-Nov-2012	Night	20:00	893	8.70	29.5	74,900	7.90	30.9
		22:00	932	8.70	30.4	75,400	7.90	31.7
Average			829	8.57	28.12	76,388	7.83	29.71

ANNEX – 4

DAILY WATER ANALYSIS FROM 5 TO 17 DECEMBER 2012

Date	Shift	Time	Sea Water			Feed Water			
			Conductivity	pH	Temp	Conductivity	pH	Temp	SDI
5-Dec-2012	Day	8:00	56,900	8.30	24.4	53,200	8.10	28.8	11.34
		14:00	58,700	8.50	24.7	53,200	8.10	28.9	11.24
5-Dec-2012	Night	0:00	57,900	8.50	23.7	53,400	8.60	27.9	11.46
		4:00	57,700	8.70	23.3	53,400	8.90	27.9	11.51
6-Dec-2012	Day	8:00	57,500	8.20	23.9	53,400	8.70	27.8	11.16
		14:00	58,300	8.50	23.8	53,400	8.80	27.5	11.38
6-Dec-2012	Night	20:00	57,500	8.30	24.1	53,200	8.05	27.9	11.44
		2:00	57,600	8.40	24.9	53,300	8.07	28.6	11.35
7-Dec-2012	Day	8:00	58,200	8.20	24.5	53,300	8.05	29.0	11.26
		14:00	58,100	8.40	25.3	53,200	8.10	29.8	11.14
7-Dec-2012	Night	22:00	57,700	8.30	25.1	53,300	8.10	29.7	11.09
		4:00	57,500	8.50	25.8	53,200	8.30	29.9	11.38
8-Dec-2012	Day	9:00	57,900	8.20	25.0	53,700	8.20	29.4	11.67
		14:00	58,900	8.40	24.4	53,300	8.20	29.0	11.24
8-Dec-2012	Night	0:00	57,600	8.40	24.5	53,300	8.20	28.9	11.44
		2:00	57,800	8.30	24.0	53,400	8.08	28.3	11.62
9-Dec-2012	Day	8:00	57,300	8.20	24.6	53,400	8.00	28.3	11.74
		14:00	58,000	8.40	24.4	53,400	8.10	28.1	11.28
9-Dec-2012	Night	21:00	57,400	8.40	23.0	53,000	8.04	27.8	11.19
		0:00	57,500	8.50	25.6	53,200	8.20	29.3	11.24
10-Dec-2012	Day	8:00	56,700	8.30	25.0	41,600	8.10	29.5	8.24
		14:00	57,700	8.40	25.9	41,500	8.10	30.0	7.98
10-Dec-2012	Night	20:00	57,834	8.47	26.4	41,500	8.20	30.6	7.65
		23:00	57,834	8.57	26.2	41,500	8.30	30.5	8.11
11-Dec-2012	Day	10:00	57,700	8.50	24.7	41,600	8.10	29.4	8.35
		14:00	58,300	8.60	26.0	41,400	8.30	31.2	7.65
11-Dec-2012	Night	22:00	56,500	8.50	25.4	41,500	8.20	29.4	8.48
		4:00	57,300	8.70	24.3	41,600	8.20	28.3	8.87
12-Dec-2012	Day	8:00	57,800	8.40	24.8	41,100	8.17	28.5	7.80
		10:00	57,500	8.20	24.2	41,200	8.16	29.0	7.92
12-Dec-2012	Night	22:00	57,700	8.40	25.4	41,200	8.20	30.0	8.36
		2:00	58,100	8.60	25.8	41,200	8.30	30.5	8.24
13-Dec-2012	Day	8:00	57,200	8.50	22.4	44,200	7.60	26.2	10.24
		14:00	58,300	8.60	23.7	44,700	7.70	28.0	10.68
13-Dec-2012	Night	21:00	59,100	8.40	22.6	43,500	7.80	26.6	10.14
		1:00	57,300	8.20	22.1	43,400	7.70	26.5	10.06
14-Dec-	Day	10:00	57,700	8.40	25.4	45,900	8.30	30.2	10.50

2012		15:00	59,400	8.30	25.3	45,900	8.40	29.6	10.84
14-Dec-2012	Night	22:00	57,300	8.40	22.2	44,900	7.50	25.4	10.54
		3:00	56,700	8.50	21.8	44,900	7.60	25.3	10.64
15-Dec-2012	Day	12:00	57,600	8.60	25.3	44,100	8.36	30.2	10.72
		18:00	57,100	8.40	25.1	44,200	8.30	29.7	10.81
15-Dec-2012	Night	0:00	57,300	8.20	24.7	44,000	8.20	28.6	10.37
		4:00	56,800	8.50	23.8	43,900	8.10	27.8	10.59
16-Dec-2012	Day	8:00	57,000	8.50	24.0	44,100	8.10	27.8	10.64
		10:00	56,000	8.40	24.4	43,900	8.20	28.9	10.77
16-Dec-2012	Night	22:00	57,100	8.40	25.0	43,800	8.20	29.4	10.34
		2:00	57,200	8.60	25.3	45,700	8.29	29.5	10.86
17-Dec-2012	Day	9:00	56,900	8.40	23.8	53,200	8.14	28.0	11.35
		14:00	58,100	8.50	25.3	46,200	8.30	29.3	10.94
17-Dec-2012	Night	22:00	57,900	8.70	24.8	53,000	8.20	28.5	11.48
		0:00	58,100	8.50	24.3	53,100	8.20	28.1	11.67
Average			57,636	8.43	24.5	47,687	8.16	28.7	10.37

Date	Shift	Time	Reject Water			Product Water		
			Conductivity	pH	Temp	Conductivity	pH	Temp
5-Dec-2012	Day	8:00	81,700	7.90	29.3	1,180	8.60	28.3
		14:00	81,600	7.90	29.0	1,188	8.70	28.0
5-Dec-2012	Night	0:00	81,500	7.90	28.6	1,160	8.60	27.6
		4:00	81,400	7.90	28.2	1,123	8.60	27.0
6-Dec-2012	Day	8:00	81,400	7.90	28.1	1,138	8.40	26.9
		14:00	81,300	7.80	28.0	1,137	8.50	26.8
6-Dec-2012	Night	20:00	81,400	7.90	28.4	1,124	8.50	26.8
		2:00	81,400	7.90	29.2	1,140	8.56	27.5
7-Dec-2012	Day	8:00	81,500	7.90	29.5	1,168	8.57	28.2
		14:00	81,700	7.96	30.6	1,232	8.70	29.0
7-Dec-2012	Night	22:00	81,400	7.80	30.1	1,228	8.60	28.5
		4:00	81,900	8.11	30.5	1,243	8.80	28.5
8-Dec-2012	Day	9:00	81,600	8.10	30.2	1,228	8.90	27.6
		14:00	81,500	8.40	29.5	1,173	8.70	28.1
8-Dec-2012	Night	0:00	81,400	8.40	29.0	1,164	8.60	27.1
		2:00	81,400	7.90	28.4	1,136	8.70	26.9
9-Dec-2012	Day	8:00	81,400	7.90	28.5	1,136	8.70	24.5
		14:00	81,400	7.80	28.2	1,130	8.70	24.7
9-Dec-2012	Night	21:00	81,700	7.90	28.6	1,140	8.60	25.8
		0:00	81,200	7.90	28.8	1,138	8.50	28.1
10-Dec-2012	Day	8:00	73,000	7.80	29.0	693	7.80	28.4
		14:00	72,900	7.90	30.0	698	7.70	28.5
10-Dec-2012	Night	20:00	73,300	8.00	31.4	760	8.80	29.9
		23:00	73,200	8.10	31.4	768	9.05	29.7

11-Dec-2012	Day	10:00	73,000	7.90	30.0	701	8.90	26.9
		14:00	73,200	8.10	31.5	728	8.80	28.8
11-Dec-2012	Night	22:00	73,100	8.04	30.0	720	8.80	28.2
		4:00	73,100	7.90	28.6	700	8.80	27.0
12-Dec-2012	Day	8:00	72,400	7.90	28.7	687	8.78	27.9
		10:00	72,500	7.90	29.4	690	8.70	28.4
12-Dec-2012	Night	22:00	72,400	8.00	31.0	750	8.90	30.0
		2:00	72,800	8.10	31.2	764	9.20	30.3
13-Dec-2012	Day	8:00	73,600	7.40	27.3	726	8.30	22.5
		14:00	75,000	7.70	29.0	839	8.40	27.0
13-Dec-2012	Night	21:00	73,200	7.40	27.7	742	8.40	26.3
		1:00	73,200	7.40	27.6	748	8.30	26.2
14-Dec-2012	Day	10:00	76,900	8.10	31.0	923	8.90	28.8
		15:00	76,900	8.10	30.4	930	9.00	27.7
14-Dec-2012	Night	22:00	75,200	7.30	26.2	781	8.50	22.7
		3:00	75,200	7.40	26.0	762	8.40	22.3
15-Dec-2012	Day	12:00	75,500	8.16	30.8	858	9.00	29.6
		18:00	75,700	8.10	30.4	831	8.92	28.7
15-Dec-2012	Night	0:00	75,100	8.00	29.2	797	8.80	27.5
		4:00	74,800	7.90	28.5	770	8.70	26.8
16-Dec-2012	Day	8:00	74,700	7.90	28.7	742	8.90	27.7
		10:00	74,800	7.90	29.3	757	8.80	27.3
16-Dec-2012	Night	22:00	74,800	8.20	30.2	765	8.80	28.1
		2:00	76,800	8.10	30.5	910	8.80	28.5
17-Dec-2012	Day	9:00	80,600	7.90	28.4	1,184	8.73	27.2
		14:00	76,600	8.10	30.1	882	8.40	28.4
17-Dec-2012	Night	22:00	80,700	8.01	29.0	1,190	8.70	27.7
		0:00	80,300	8.01	29.0	1,196	8.70	27.6
Average			77,390	7.92	29.3	948	8.66	27.5

ANNEX – 5

DAILY WATER ANALYSIS FROM 23 DECEMBER TO 10 JANUARY 2013

Date	Shift	Time	Sea Water			Feed Water			
			Conductivity	pH	Temp	Conductivity	pH	Temp	SDI
23-Dec-2012	Day	10:00	59,100	8.50	23.1	46,400	7.70	22.4	10.72
		14:00	58,500	8.50	22.2	46,500	7.70	22.9	10.81
23-Dec-2012	Night	22:00	58,300	8.44	22.0	46,200	7.80	24.7	10.68
		4:00	58,400	8.35	18.3	46,300	7.70	20.2	10.75
24-Dec-2012	Day	10:00	58,300	8.40	20.9	45,000	7.67	26.6	10.60
		14:00	57,700	8.50	20.2	44,700	7.70	28.0	10.48
		16:00	58,300	8.60	19.1	43,700	8.00	27.5	10.05
		18:00	57,100	8.50	19.4	43,600	7.80	27.4	9.87
24-Dec-2012	Night	20:00	56,800	8.43	23.4	43,500	7.80	26.8	9.56
		22:00	56,900	8.47	23.2	43,500	7.80	26.6	9.45
		0:00	56,700	8.36	23.1	43,400	7.70	26.5	9.34
		2:00	57,100	8.16	23.5	43,700	7.50	26.8	9.31
25-Dec-2012	Day	10:00	57,500	8.50	23.0	44,700	7.60	27.2	9.74
		16:00	57,200	8.40	23.3	44,700	7.78	28.8	9.68
25-Dec-2012	Night	22:00	56,800	8.39	23.5	44,900	7.70	26.8	9.57
		4:00	56,700	8.19	22.7	44,900	7.60	24.8	9.51
26-Dec-2012	Day	8:00	58,600	8.50	21.8	45,000	7.70	26.0	9.68
		14:00	57,600	8.50	22.3	47,500	7.84	28.7	10.69
		16:00	56,800	8.40	21.8	47,300	7.89	28.9	10.58
26-Dec-2012	Night	20:00	58,800	8.31	24.3	47,400	7.70	27.6	10.72
		4:00	58,600	8.18	22.5	47,300	7.60	25.2	10.64
27-Dec-2012	Day	10:00	58,200	8.50	21.7	47,600	7.58	23.9	10.38
		12:00	58,700	8.40	21.5	47,400	7.57	24.3	10.47
27-Dec-2012	Night	22:00	58,800	8.42	20.6	46,600	7.79	22.8	10.27
		2:00	58,400	8.23	19.4	46,300	7.60	20.9	10.18
28-Dec-2012	Day	10:00	59,000	8.40	21.3	46,600	8.05	25.1	10.64
		16:00	58,800	8.40	20.0	46,500	8.03	25.4	10.42
28-Dec-2012	Night	22:00	58,300	8.45	20.4	46,200	7.80	23.0	10.71
		2:00	58,200	8.39	19.9	46,200	7.70	22.1	10.58
29-Dec-2012	Day	8:00	58,500	8.30	20.2	46,400	7.70	22.5	10.26
		12:00	58,600	8.35	20.6	46,500	7.70	22.9	10.34
29-Dec-2012	Night	0:00	57,800	8.59	21.9	45,900	7.90	24.5	10.31
		4:00	57,700	8.51	21.7	45,800	7.90	24.0	10.28
30-Dec-2012	Day	12:00	58,000	8.43	21.9	46,000	7.80	24.2	10.24
		16:00	58,100	8.55	22.7	46,000	7.91	25.6	10.17
30-Dec-2012	Night	21:00	57,000	8.60	24.5	45,300	7.90	28.0	10.25
		3:00	57,000	8.30	24.3	45,200	7.70	28.0	10.33

31-Dec-2012	Day	9:00	57,900	8.60	23.4	45,500	7.70	27.5	10.42
		14:00	57,100	8.50	23.8	45,300	7.70	28.1	10.29
31-Dec-2012	Night	22:00	56,900	8.44	25.1	45,100	7.80	28.5	10.11
		4:00	56,700	8.31	25.0	44,900	7.71	28.2	10.35
1-Jan-2013	Day	11:00	57,000	8.50	27.0	45,400	8.10	29.1	10.40
		16:00	57,300	8.71	25.4	45,400	8.10	29.0	10.54
1-Jan-2013	Night	22:00	56,800	8.41	25.1	45,000	7.80	28.7	10.30
		4:00	56,900	8.38	24.5	45,100	7.68	27.6	10.05
2-Jan-2013	Day	12:00	56,600	8.50	26.1	45,400	8.10	29.0	10.09
		18:00	57,300	8.74	25.6	45,400	8.10	28.9	10.15
2-Jan-2013	Night	20:00	56,900	8.47	25.7	45,100	7.80	29.2	10.17
		2:00	56,800	8.38	24.3	45,000	7.70	27.6	10.08
3-Jan-2013	Day	10:00	56,700	8.50	25.4	45,200	7.80	27.2	10.26
		16:00	57,200	8.38	24.8	45,300	7.70	28.1	9.97
3-Jan-2013	Night	20:00	56,900	8.43	25.9	45,100	7.80	28.9	9.87
		2:00	56,800	8.42	24.4	45,100	7.80	28.0	9.78
4-Jan-2013	Day	9:00	57,300	8.48	24.1	43,900	7.77	27.3	9.25
		13:00	57,200	8.40	24.8	43,800	7.76	27.7	9.21
4-Jan-2013	Night	1:00	56,700	8.39	24.8	43,400	7.72	27.7	9.26
		4:00	56,500	8.34	24.6	43,200	7.75	27.7	9.34
5-Jan-2013	Day	10:00	57,400	8.60	25.4	42,100	7.70	27.7	9.18
		14:00	57,000	8.41	25.5	42,000	7.80	28.8	9.05
5-Jan-2013	Night	0:00	56,400	8.37	23.8	44,700	7.70	26.0	9.88
		4:00	56,500	8.39	23.6	44,700	7.70	26.1	10.14
6-Jan-2013	Day	10:00	57,900	8.60	24.9	45,100	7.80	26.4	10.35
		14:00	58,400	8.40	20.8	45,100	7.80	26.8	10.49
6-Jan-2013	Night	20:00	56,700	8.58	23.7	44,900	7.89	26.9	10.57
		0:00	56,800	8.37	23.4	45,000	7.70	25.9	10.50
7-Jan-2013	Day	8:00	56,900	8.60	23.1	45,400	7.60	24.9	10.25
		12:00	56,900	8.51	23.4	45,100	7.80	26.5	10.05
7-Jan-2013	Night	22:00	56,700	8.00	22.6	45,000	7.76	25.7	9.87
		4:00	56,800	8.42	22.3	45,000	7.70	25.6	9.64
8-Jan-2013	Day	8:00	57,200	8.50	21.3	45,000	7.70	26.2	9.51
		16:00	57,000	8.32	23.3	45,100	7.70	26.5	9.67
8-Jan-2013	Night	21:00	56,900	8.30	23.1	45,100	7.70	26.4	9.75
		2:00	56,700	8.29	22.4	45,000	7.70	25.8	9.45
9-Jan-2013	Day	8:00	57,400	8.40	21.6	45,200	7.70	26.8	9.65
		14:00	57,500	8.51	21.9	45,600	7.90	24.4	9.72
9-Jan-2013	Night	22:00	57,200	8.54	21.5	45,400	7.94	23.9	9.47
		2:00	57,400	8.52	21.4	45,600	7.90	24.4	9.80
10-Jan-2013	Day	8:00	57,100	8.60	23.7	46,400	7.90	24.2	10.34
		17:00	58,100	8.58	21.8	46,100	7.87	24.1	10.15
10-Jan-2013	Night	22:00	58,000	8.53	21.9	46,000	7.90	24.7	10.34
		2:00	57,100	8.51	20.6	45,300	7.92	22.8	9.87

Average			57,462	8.44	22.9	45,286	7.78	26.2	10.07
----------------	--	--	---------------	-------------	-------------	---------------	-------------	-------------	--------------

Date	Shift	Time	Product Water			Reject Water		
			Conductivity	pH	Temp	Conductivity	pH	Temp
23-Dec-2012	Day	10:00	787	8.40	21.1	75,400	7.50	22.9
		14:00	822	8.50	22.1	75,800	7.50	23.2
23-Dec-2012	Night	22:00	867	8.50	24.0	75,800	7.60	25.0
		4:00	870	8.40	20.2	75,700	7.50	22.0
24-Dec-2012	Day	10:00	748	8.55	25.6	75,300	7.51	27.3
		14:00	839	8.40	27.0	75,000	7.70	29.0
		16:00	835	8.50	26.7	73,200	7.90	28.1
		18:00	767	8.30	26.5	73,300	7.60	27.9
24-Dec-2012	Night	20:00	740	8.50	26.5	73,200	7.60	27.5
		22:00	742	8.40	26.3	73,200	7.40	27.7
		0:00	748	8.30	26.2	73,200	7.40	27.6
		2:00	749	8.20	23.2	73,200	7.30	27.2
25-Dec-2012	Day	10:00	790	7.90	25.0	75,000	7.45	28.0
		16:00	849	8.48	27.6	75,400	7.59	29.7
25-Dec-2012	Night	22:00	788	8.60	24.3	75,300	7.50	27.3
		4:00	755	8.30	22.6	75,200	7.60	25.9
26-Dec-2012	Day	8:00	754	8.30	22.6	75,000	7.50	26.5
		14:00	925	8.55	28.1	77,200	7.63	29.2
		16:00	938	8.58	27.9	77,100	7.67	29.8
26-Dec-2012	Night	20:00	865	8.50	27.1	76,800	7.50	28.3
		4:00	833	8.50	24.5	76,600	7.40	25.7
27-Dec-2012	Day	10:00	717	7.58	22.7	76,600	7.41	24.5
		12:00	718	7.57	23.8	76,700	7.41	24.9
27-Dec-2012	Night	22:00	762	8.57	20.9	76,000	7.59	23.5
		2:00	742	8.55	19.5	75,200	7.56	21.3
28-Dec-2012	Day	10:00	920	8.70	24.0	76,200	7.81	26.5
		16:00	904	8.70	24.4	76,000	7.80	26.2
28-Dec-2012	Night	22:00	868	8.50	23.9	75,800	7.50	24.0
		2:00	868	8.40	21.5	75,800	7.50	23.2
29-Dec-2012	Day	8:00	790	8.40	22.1	75,500	7.50	22.9
		12:00	830	8.50	22.6	75,800	7.50	23.1
29-Dec-2012	Night	0:00	890	8.70	24.0	75,800	7.70	25.3
		4:00	875	8.60	23.1	75,700	7.70	24.6
30-Dec-2012	Day	12:00	852	8.60	22.0	75,300	7.70	24.8
		16:00	915	8.60	24.8	75,900	7.75	26.6
30-Dec-2012	Night	21:00	804	8.50	27.9	75,100	7.40	28.3
		3:00	814	8.40	27.8	75,200	7.40	28.8
31-Dec-2012	Day	9:00	820	8.50	26.8	74,800	7.60	28.1
		14:00	900	8.20	27.8	75,200	7.40	28.9
31-Dec-	Night	22:00	808	8.60	27.6	75,200	7.60	29.2

2012		4:00	796	8.36	27.5	74,900	7.51	29.0
1-Jan-2013	Day	11:00	838	7.70	28.5	75,400	7.80	29.8
		16:00	882	8.60	28.8	75,400	7.80	29.5
1-Jan-2013	Night	22:00	850	8.50	27.5	75,300	7.60	29.3
		4:00	810	8.40	26.8	75,200	7.50	28.0
2-Jan-2013	Day	12:00	840	7.70	28.4	75,400	7.80	29.7
		18:00	882	8.59	28.7	75,400	7.80	29.5
2-Jan-2013	Night	20:00	865	8.50	28.8	75,500	7.60	30.0
		2:00	828	8.40	27.3	75,500	7.50	28.2
3-Jan-2013	Day	10:00	825	8.70	28.0	75,100	7.50	28.2
		16:00	815	8.40	27.8	75,200	7.40	28.8
3-Jan-2013	Night	20:00	844	8.50	28.3	75,400	7.60	29.6
		2:00	825	8.50	26.4	75,300	7.60	28.9
4-Jan-2013	Day	9:00	747	8.37	26.0	73,900	7.56	27.9
		13:00	753	8.40	26.4	73,700	7.54	28.0
4-Jan-2013	Night	1:00	736	8.40	26.9	73,300	7.54	28.3
		4:00	732	8.50	26.9	73,000	7.55	28.2
5-Jan-2013	Day	10:00	704	8.50	27.0	72,100	7.55	28.3
		14:00	745	8.60	28.0	72,300	7.60	29.5
5-Jan-2013	Night	0:00	752	8.40	25.2	74,400	7.50	26.3
		4:00	770	8.30	25.1	74,100	7.50	26.9
6-Jan-2013	Day	10:00	758	8.70	22.3	74,400	7.60	27.8
		14:00	760	8.60	22.7	74,500	7.70	27.9
6-Jan-2013	Night	20:00	816	8.44	25.5	74,400	7.66	27.5
		0:00	805	8.50	24.3	74,500	7.60	26.5
7-Jan-2013	Day	8:00	792	8.60	21.3	75,600	7.60	25.8
		12:00	760	8.70	22.5	74,500	7.70	27.8
7-Jan-2013	Night	22:00	795	8.50	24.6	74,600	7.62	26.4
		4:00	832	8.40	24.1	74,500	7.50	26.2
8-Jan-2013	Day	8:00	750	8.60	22.1	74,400	7.50	27.2
		16:00	756	8.60	22.5	74,500	7.70	27.7
8-Jan-2013	Night	21:00	750	8.70	22.4	74,500	7.70	27.5
		2:00	824	8.40	25.1	74,700	7.50	26.4
9-Jan-2013	Day	8:00	822	8.60	27.4	75,200	7.50	27.5
		14:00	896	8.60	23.8	75,800	7.70	25.1
9-Jan-2013	Night	22:00	813	8.75	23.6	74,800	7.76	24.4
		2:00	896	8.60	23.8	75,800	7.70	25.1
10-Jan-2013	Day	8:00	832	8.70	22.1	75,400	7.70	24.8
		17:00	846	8.63	22.9	75,300	7.66	24.3
10-Jan-2013	Night	22:00	880	8.70	24.0	75,800	7.70	25.7
		2:00	814	8.79	22.2	74,800	7.70	23.1
Average			813	8.46	25.0	75,031	7.58	26.9

ANNEX – 6

DAILY WATER ANALYSIS FROM 1 TO 24 FEBRUARY 2013

Date	Shift	Time	Sea Water			Feed Water			
			Conductivity	pH	Temp	Conductivity	pH	Temp	SDI
1-Feb-2013	Day	9:00	57,200	8.30	21.2	45,500	7.80	21.9	9.23
		14:00	57,100	8.20	21.6	45,600	7.90	21.4	9.15
1-Feb-2013	Night	18:00	56,800	8.10	19.1	45,600	7.90	21.2	9.28
		22:00	56,900	8.15	19.5	45,200	7.90	21.8	10.02
2-Feb-2013	Day	9:00	58,200	8.40	14.8	43,800	8.00	23.3	8.21
		15:00	57,300	8.35	19.3	43,400	8.10	26.8	8.16
2-Feb-2013	Night	19:00	57,000	8.21	18.1	43,300	7.99	27.0	8.27
		23:00	56,900	8.37	18.2	43,300	8.10	27.6	8.01
3-Feb-2013	Day	9:00	58,000	8.40	19.4	43,200	8.11	27.9	8.16
		16:00	56,300	8.26	19.5	43,000	7.99	26.3	7.94
3-Feb-2013	Night	22:00	56,800	8.19	19.2	43,200	7.90	26.9	7.76
		2:00	56,200	8.11	18.8	43,100	7.90	27.1	7.56
4-Feb-2013	Day	9:00	57,900	8.50	19.9	43,100	7.90	28.0	7.59
		14:00	56,800	8.34	20.2	43,100	8.00	28.3	7.74
4-Feb-2013	Night	20:00	55,300	8.29	19.6	42,000	8.00	27.8	7.16
		1:00	55,200	8.21	19.1	42,000	8.00	27.9	7.03
5-Feb-2013	Day	9:00	57,800	8.40	19.7	42,100	8.10	28.0	7.00
		16:00	56,000	8.32	20.8	41,900	8.10	27.8	6.84
5-Feb-2013	Night	22:00	55,800	8.31	20.2	41,900	8.10	27.4	6.58
		3:00	55,900	8.26	19.4	41,800	8.00	27.1	6.34
6-Feb-2013	Day	9:00	57,200	8.50	21.5	41,800	8.00	26.8	6.29
		16:00	55,800	8.16	22.3	41,700	7.90	26.4	6.07
6-Feb-2013	Night	20:00	55,600	8.19	22.8	41,700	7.90	25.9	6.25
		4:00	56,300	8.19	23.0	42,100	8.00	25.8	6.35
7-Feb-2013	Day	9:00	57,600	8.60	22.5	41,700	8.05	26.2	6.49
		15:00	55,700	8.28	23.9	42,200	8.00	27.0	6.27
7-Feb-2013	Night	20:00	55,900	8.41	23.5	42,200	8.20	28.0	5.97
		4:00	55,500	8.49	23.1	42,200	8.20	28.1	6.05
8-Feb-2013	Day	9:00	56,000	8.40	22.2	42,200	8.20	28.3	6.38
		14:00	57,100	8.35	23.0	44,200	8.00	25.8	7.84
8-Feb-2013	Night	22:00	57,300	8.24	22.8	44,100	8.00	25.6	7.92
		1:00	57,100	8.23	22.3	44,000	7.90	25.3	8.32
9-Feb-2013	Day	10:00	56,400	8.30	24.3	43,200	7.90	25.0	8.15
		16:00	56,800	8.18	24.8	43,200	7.90	25.0	8.06
9-Feb-2013	Night	19:00	57,300	8.16	24.2	43,800	7.90	24.9	8.24
		23:00	57,300	8.24	24.7	43,600	8.00	25.4	8.19

10-Feb-2013	Day	9:00	57,000	8.30	24.0	44,100	8.07	26.1	8.34
		12:00	56,900	8.20	24.5	44,100	8.00	26.2	8.25
10-Feb-2013	Night	20:00	57,100	8.30	24.3	44,200	8.10	26.9	8.38
		4:00	57,300	8.32	24.2	44,400	8.10	27.4	8.56
11-Feb-2013	Day	9:00	57,900	8.20	24.2	44,200	8.10	27.0	9.20
		14:00	57,400	8.23	25.1	44,400	8.00	26.1	9.13
11-Feb-2013	Night	22:00	57,200	8.21	24.8	44,300	8.00	25.9	8.84
		2:00	57,500	8.20	23.4	44,500	7.90	25.7	8.97
12-Feb-2013	Day	9:00	56,800	8.30	23.7	44,500	7.90	25.5	9.35
		16:00	57,400	8.22	24.1	44,400	8.00	25.5	9.06
12-Feb-2013	Night	20:00	57,200	8.33	23.8	44,300	8.00	25.4	9.29
		3:00	57,700	8.24	23.2	43,900	8.00	25.9	9.37
13-Feb-2013	Day	9:00	56,400	8.30	23.5	43,800	8.00	25.9	8.84
		14:00	58,700	8.34	24.5	45,000	8.13	27.1	8.50
13-Feb-2013	Night	21:00	58,600	8.36	24.3	45,000	8.10	27.2	8.90
		4:00	57,800	8.38	24.1	45,200	8.11	26.9	9.35
14-Feb-2013	Day	9:00	56,700	8.40	24.0	45,100	8.10	26.7	9.47
		16:00	57,900	8.31	24.4	44,800	8.04	26.1	9.29
14-Feb-2013	Night	22:00	58,000	8.24	24.1	44,900	8.02	26.1	9.20
		2:00	57,700	8.21	23.8	44,700	8.02	25.9	9.06
15-Feb-2013	Day	9:00	56,300	8.40	24.4	44,700	8.02	25.0	9.56
		15:00	57,800	8.20	24.8	44,800	8.03	25.0	9.41
15-Feb-2013	Night	21:00	57,600	8.13	24.0	44,700	8.01	25.3	9.63
		1:00	57,400	8.24	22.8	44,400	8.05	24.4	9.80
16-Feb-2013	Day	9:00	57,900	8.30	22.9	48,500	8.10	24.0	10.24
		16:00	58,200	8.41	23.1	48,900	8.20	24.3	10.35
16-Feb-2013	Night	20:00	58,100	8.50	23.4	48,800	8.30	24.3	10.62
		0:00	58,000	8.44	21.7	48,600	8.24	23.6	10.20
17-Feb-2013	Day	9:00	57,100	8.30	23.0	48,500	8.15	23.2	10.00
		14:00	58,100	8.22	23.2	48,500	8.00	22.2	10.06
17-Feb-2013	Night	22:00	58,000	8.21	21.0	48,400	8.00	21.6	10.18
		4:00	57,800	8.11	19.8	48,400	7.90	20.3	10.34
18-Feb-2013	Day	9:00	56,700	8.30	23.5	48,400	7.90	20.2	10.29
		15:00	58,000	8.10	23.2	48,600	7.70	20.1	10.28
18-Feb-2013	Night	22:00	57,900	8.17	23.5	48,500	7.70	21.0	10.19
		1:00	58,000	8.24	22.6	48,500	8.10	22.0	10.34
19-Feb-2013	Day	9:00	56,700	8.20	22.8	48,500	8.00	24.4	10.09
		16:00	57,800	8.37	23.1	48,700	8.20	25.9	10.10
19-Feb-2013	Night	22:00	57,300	8.50	22.9	47,100	8.37	25.7	9.68
		2:00	56,600	8.33	22.0	46,500	8.07	25.0	9.59
20-Feb-2013	Day	9:00	57,800	8.40	22.4	46,300	8.07	25.0	9.36
		14:00	56,900	8.34	22.9	46,400	7.99	24.2	9.29
20-Feb-2013	Night	21:00	56,700	8.38	22.8	46,400	7.99	24.1	9.37
		3:00	56,600	8.24	22.2	46,300	8.06	23.8	9.16

21-Feb-2013	Day	9:00	56,200	8.30	19.9	46,400	8.00	24.0	9.59
		15:00	56,200	8.06	21.5	46,400	7.80	25.2	9.43
21-Feb-2013	Night	20:00	55,900	8.37	22.3	46,400	8.20	25.0	9.27
		2:00	56,100	8.51	21.7	46,400	8.30	25.5	9.36
22-Feb-2013	Day	9:00	56,400	8.40	21.5	46,400	8.10	28.0	8.97
		14:00	56,200	8.19	22.0	46,500	8.00	26.9	8.89
22-Feb-2013	Night	20:00	56,400	8.27	22.8	46,500	8.10	26.6	8.67
		23:00	56,500	8.26	21.9	46,400	8.00	25.9	9.24
23-Feb-2013	Day	10:00	56,100	8.40	22.8	46,400	8.10	25.5	9.16
		16:00	55,800	8.15	22.6	46,500	8.00	25.3	9.57
23-Feb-2013	Night	22:00	55,900	8.20	22.4	46,600	7.90	25.1	8.97
		4:00	55,800	8.01	21.7	46,700	7.80	24.9	8.59
24-Feb-2013	Day	10:00	56,600	8.40	23.1	46,500	7.86	24.8	9.06
		16:00	56,200	8.30	24.2	46,400	8.10	28.0	9.18
24-Feb-2013	Night	20:00	56,300	8.38	24.8	45,100	8.20	28.0	8.88
		2:00	56,500	8.31	23.7	45,200	8.10	27.0	8.76
Average			56,957	8.29	22.4	44,979	8.02	25.5	8.69

Date	Shift	Time	Product Water			Reject Water		
			Conductivity	pH	Temp	Conductivity	pH	Temp
1-Feb-2013	Day	9:00	787	8.50	21.6	75,000	7.60	22.4
		14:00	710	8.70	20.0	74,800	7.70	21.8
1-Feb-2013	Night	18:00	700	8.70	20.0	74,800	7.70	21.4
		22:00	885	8.80	22.0	74,600	7.60	21.6
2-Feb-2013	Day	9:00	1,028	8.80	22.4	79,200	7.90	24.0
		15:00	951	8.11	26.1	74,700	7.83	27.6
2-Feb-2013	Night	19:00	947	8.16	26.3	74,600	7.82	27.8
		23:00	960	8.30	26.9	74,700	7.84	28.2
3-Feb-2013	Day	9:00	973	8.80	27.4	74,700	7.88	28.7
		16:00	919	8.60	25.8	74,200	7.70	27.0
3-Feb-2013	Night	22:00	935	8.70	26.4	74,200	7.70	27.7
		2:00	965	8.77	27.0	74,000	7.74	28.2
4-Feb-2013	Day	9:00	999	8.79	27.5	74,000	7.79	29.0
		14:00	1,015	8.80	27.9	73,900	7.80	29.2
4-Feb-2013	Night	20:00	942	8.75	27.3	72,600	7.60	28.7
		1:00	958	8.80	27.6	72,600	7.70	28.8
5-Feb-2013	Day	9:00	883	8.80	27.9	72,600	7.90	29.0
		16:00	840	8.90	27.5	72,300	7.80	28.6
5-Feb-2013	Night	22:00	821	8.80	27.1	72,300	7.80	28.2
		3:00	797	8.80	26.5	72,200	7.80	27.8
6-Feb-2013	Day	9:00	775	8.80	25.9	72,100	7.80	27.4
		16:00	754	8.70	25.5	72,000	7.70	27.0
6-Feb-	Night	20:00	738	8.70	25.1	71,800	7.70	26.6

2013		4:00	737	8.90	25.4	72,000	7.80	27.4
7-Feb-2013	Day	9:00	734	8.84	25.8	71,600	7.76	27.0
		15:00	737	8.80	26.2	72,000	7.70	27.5
7-Feb-2013	Night	20:00	745	8.80	26.7	72,000	7.70	27.8
		4:00	734	8.70	26.8	72,100	7.60	28.0
8-Feb-2013	Day	9:00	733	8.70	26.4	72,100	7.60	28.0
		14:00	791	8.70	24.8	73,800	7.80	26.3
8-Feb-2013	Night	22:00	795	8.80	24.7	73,900	7.80	26.1
		1:00	788	8.80	24.6	73,600	7.80	25.9
9-Feb-2013	Day	10:00	778	8.70	24.1	73,600	7.70	25.5
		16:00	776	8.70	24.1	73,600	7.70	25.1
9-Feb-2013	Night	19:00	785	8.70	24.1	73,400	7.80	25.4
		23:00	774	8.80	24.8	73,200	7.80	26.1
10-Feb-2013	Day	9:00	812	8.80	25.4	74,000	7.84	26.6
		12:00	813	8.80	24.8	74,000	7.80	26.8
10-Feb-2013	Night	20:00	865	8.80	25.4	74,200	7.90	27.2
		4:00	898	8.86	26.8	74,500	7.89	28.0
11-Feb-2013	Day	9:00	898	8.85	26.4	74,500	7.87	27.6
		14:00	832	8.80	25.5	74,200	7.80	26.7
11-Feb-2013	Night	22:00	830	8.70	25.2	74,300	7.90	26.5
		2:00	828	8.70	24.9	74,300	7.80	26.3
12-Feb-2013	Day	9:00	825	8.60	24.5	74,300	7.80	26.0
		16:00	823	8.60	24.6	74,200	7.80	26.1
12-Feb-2013	Night	20:00	821	8.70	24.7	74,000	7.80	25.9
		3:00	813	8.80	25.5	73,600	7.80	26.5
13-Feb-2013	Day	9:00	815	8.80	26.0	73,400	7.70	26.5
		14:00	872	8.80	25.4	75,200	7.80	27.7
13-Feb-2013	Night	21:00	909	8.80	26.4	75,200	7.80	27.7
		4:00	900	8.80	25.4	75,200	7.80	27.5
14-Feb-2013	Day	9:00	904	8.80	25.3	75,000	7.80	27.4
		16:00	850	8.66	25.1	74,400	7.53	26.7
14-Feb-2013	Night	22:00	850	8.70	25.3	74,400	7.83	26.5
		2:00	818	8.72	24.7	74,500	7.84	26.6
15-Feb-2013	Day	9:00	817	8.72	24.5	74,400	7.83	25.9
		15:00	816	8.50	24.5	74,500	7.83	25.0
15-Feb-2013	Night	21:00	817	8.70	24.2	74,100	7.82	26.1
		1:00	807	8.90	21.2	74,000	7.84	25.2
16-Feb-2013	Day	9:00	914	8.50	22.7	75,800	7.90	24.4
		16:00	948	8.76	23.0	76,200	8.10	24.9
16-Feb-2013	Night	20:00	961	9.25	24.0	76,100	8.10	24.9
		0:00	895	9.00	23.0	75,800	8.00	24.2
17-Feb-2013	Day	9:00	886	9.03	22.3	75,700	8.10	23.9
		14:00	850	8.90	22.0	75,600	8.00	23.5
17-Feb-	Night	22:00	815	8.70	21.8	75,300	7.80	22.3

2013		4:00	790	8.69	20.5	75,100	7.80	20.9
18-Feb-2013	Day	9:00	745	8.60	20.1	75,000	7.75	20.6
		15:00	760	7.80	19.0	75,100	7.60	20.6
18-Feb-2013	Night	22:00	793	8.60	20.7	75,200	7.60	20.9
		1:00	882	8.70	22.2	75,300	7.60	24.0
19-Feb-2013	Day	9:00	925	8.80	23.5	75,500	7.80	25.2
		16:00	1,021	9.00	25.0	75,900	8.00	26.8
19-Feb-2013	Night	22:00	936	9.09	25.2	75,400	8.14	26.5
		2:00	924	9.04	24.5	74,800	7.80	25.5
20-Feb-2013	Day	9:00	920	9.04	24.2	74,700	7.70	25.4
		14:00	843	8.87	23.8	74,500	7.83	24.8
20-Feb-2013	Night	21:00	821	8.90	23.6	74,500	7.82	24.5
		3:00	815	8.90	23.5	74,400	7.81	24.3
21-Feb-2013	Day	9:00	825	8.80	22.9	74,600	7.80	24.6
		15:00	872	8.60	24.2	74,700	7.70	25.6
21-Feb-2013	Night	20:00	800	8.70	26.1	74,600	7.80	24.6
		2:00	800	8.80	25.9	74,600	7.90	25.7
22-Feb-2013	Day	9:00	1,036	8.90	27.9	75,000	8.00	29.0
		14:00	968	8.40	26.2	74,800	7.90	27.5
22-Feb-2013	Night	20:00	964	8.80	26.1	75,200	7.90	27.4
		23:00	930	8.90	25.5	75,000	7.80	26.7
23-Feb-2013	Day	10:00	917	8.81	25.2	74,900	7.79	26.5
		16:00	905	8.70	25.0	74,900	7.80	26.1
23-Feb-2013	Night	22:00	992	8.70	24.7	74,800	7.70	25.9
		4:00	880	8.60	24.2	74,800	7.70	25.6
24-Feb-2013	Day	10:00	878	8.39	23.5	74,600	7.70	25.8
		16:00	1,027	8.70	27.4	75,100	7.90	28.6
24-Feb-2013	Night	20:00	950	9.00	27.3	74,900	8.00	28.8
		2:00	894	8.80	26.3	74,600	7.90	27.6
Average			859	8.74	24.8	74,294	7.80	26.1

ANNEX – 7

DAILY WATER ANALYSIS FROM 20 MARCH TO 4 MAY 2013

Date	Shift	Time	Sea Water		
			Conductivity	pH	Temp
20-Mar-2013	Day	12:00	56,000	8.50	25.4
		16:00	55,400	8.60	26.4
20-Mar-2013	Night	20:00	55,100	8.40	26.1
		0:00	55,000	8.30	25.9
21-Mar-2013	Day	8:00	55,700	8.50	25.9
		12:00	55,600	8.60	26.2
21-Mar-2013	Night	22:00	54,300	8.60	26.4
		2:00	54,100	8.50	25.9
22-Mar-2013	Day	9:00	56,400	8.50	25.5
		13:00	55,300	8.40	26.1
22-Mar-2013	Night	0:00	55,100	8.40	25.8
		4:00	55,200	8.40	25.4
23-Mar-2013	Day	12:00	56,000	8.60	26.3
		18:00	56,200	8.40	25.7
23-Mar-2013	Night	19:00	56,600	8.60	26.7
		23:00	55,900	8.60	26.9
24-Mar-2013	Day	8:00	56,400	8.50	26.3
		11:00	54,400	8.50	26.8
24-Mar-2013	Night	1:00	54,200	8.50	25.6
		4:00	54,500	8.40	25.1
25-Mar-2013	Day	8:00	56,800	8.50	26.6
		12:00	55,100	8.60	25.8
25-Mar-2013	Night	20:00	55,500	8.40	25.7
		23:00	55,400	8.50	25.5
26-Mar-2013	Day	11:00	56,400	8.40	27.2
		16:00	55,600	8.40	26.7
26-Mar-2013	Night	20:00	56,000	8.50	26.4
		23:00	56,100	8.50	25.8
27-Mar-2013	Day	8:00	56,800	8.50	26.5
		14:00	56,000	8.50	26.2
27-Mar-2013	Night	22:00	56,100	8.50	26.3
		4:00	56,200	8.60	26.5
28-Mar-2013	Day	7:00	55,900	8.60	27.2
		11:00	55,800	8.60	26.4
28-Mar-2013	Night	20:00	55,600	8.60	26.2
		1:00	55,500	8.60	25.8
29-Mar-	Day	8:00	55,800	8.60	27.9

2013		10:00	56,200	8.50	26.7
29-Mar-2013	Night	0:00	55,000	8.60	25.8
		4:00	56,000	8.50	26.1
30-Mar-2013	Day	8:00	56,900	8.50	27.1
		14:00	56,200	8.60	27.0
30-Mar-2013	Night	22:00	56,300	8.60	26.8
		4:00	56,100	8.60	26.6
31-Mar-2013	Day	11:00	56,100	8.50	26.6
		17:00	56,600	8.50	26.4
31-Mar-2013	Night	0:00	56,700	8.50	26.2
		4:00	56,900	8.60	26.1
1-Apr-2013	Day	10:00	56,400	8.60	25.6
		14:00	57,000	8.60	27.4
1-Apr-2013	Night	20:00	56,800	8.60	26.4
		23:00	57,400	8.50	25.5
2-Apr-2013	Day	9:00	56,400	8.50	25.8
		14:00	57,200	8.50	25.3
2-Apr-2013	Night	18:00	57,400	8.40	24.9
		22:00	57,100	8.30	24.4
3-Apr-2013	Day	10:00	56,700	8.60	27.3
		16:00	56,800	8.50	26.4
3-Apr-2013	Night	20:00	56,600	8.40	25.8
		2:00	56,700	8.40	25.5
4-Apr-2013	Day	8:00	56,000	8.20	24.0
		11:00	56,700	8.30	24.5
4-Apr-2013	Night	22:00	56,000	8.40	24.3
		4:00	56,700	8.50	24.1
5-Apr-2013	Day	10:00	56,200	8.60	25.8
		14:00	57,500	8.60	26.4
5-Apr-2013	Night	22:00	56,100	8.60	25.3
		4:00	56,000	8.60	24.8
6-Apr-2013	Day	10:00	56,300	8.40	24.7
		16:00	56,200	8.50	25.1
6-Apr-2013	Night	20:00	56,100	8.50	25.5
		0:00	56,300	8.50	25.1
7-Apr-2013	Day	9:00	56,000	8.40	25.8
		13:00	56,100	8.40	25.9
7-Apr-2013	Night	22:00	56,800	8.50	24.8
		2:00	56,600	8.40	24.5
8-Apr-2013	Day	9:00	56,100	8.50	26.6
		15:00	56,800	8.40	26.4
8-Apr-2013	Night	21:00	56,400	8.30	24.0
		3:00	57,600	8.50	25.6
9-Apr-	Day	8:00	56,200	8.40	24.9

2013		12:00	58,600	8.60	27.4
9-Apr-2013	Night	21:00	57,400	8.40	24.7
		2:00	57,300	8.40	24.7
11-Apr-2013	Day	9:00	57,100	8.40	26.8
		16:00	56,400	8.60	25.3
11-Apr-2013	Night	20:00	56,600	8.30	25.1
		2:00	56,500	8.30	25.0
12-Apr-2013	Day	9:00	56,600	8.20	24.7
		15:00	56,800	8.20	25.1
12-Apr-2013	Night	22:00	56,700	8.30	25.3
		4:00	56,900	8.50	25.4
13-Apr-2013	Day	9:00	56,700	8.60	26.7
		16:00	56,500	8.60	27.0
13-Apr-2013	Night	21:00	56,600	8.50	25.7
		2:00	56,400	8.40	25.1
14-Apr-2013	Day	8:00	56,200	8.40	24.8
		12:00	56,300	8.30	25.5
14-Apr-2013	Night	19:00	56,600	8.40	24.7
		3:00	56,700	8.50	24.4
15-Apr-2013	Day	8:00	55,700	8.50	26.3
		14:00	58,000	8.60	26.0
15-Apr-2013	Night	20:00	56,200	8.40	24.2
		2:00	55,800	8.40	24.6
16-Apr-2013	Day	10:00	56,100	8.50	26.3
		16:00	56,900	8.50	26.8
16-Apr-2013	Night	22:00	56,400	8.40	25.3
		2:00	56,200	8.50	24.8
17-Apr-2013	Day	10:00	56,800	8.30	26.9
		16:00	56,200	8.60	26.2
17-Apr-2013	Night	21:00	55,800	8.40	24.6
		4:00	55,700	8.50	25.4
18-Apr-2013	Day	10:00	56,500	8.40	25.5
		15:00	56,700	8.50	26.9
18-Apr-2013	Night	21:00	56,600	8.40	25.5
		3:00	55,900	8.40	26.0
19-Apr-2013	Day	10:00	56,100	8.50	28.3
		16:00	56,700	8.40	26.7
19-Apr-2013	Night	22:00	56,600	8.30	26.0
		4:00	56,300	8.30	25.8
20-Apr-2013	Day	10:00	57,800	8.40	26.8
		14:00	57,100	8.40	27.2
20-Apr-2013	Night	20:00	56,900	8.50	26.5
		0:00	56,700	8.40	26.0
21-Apr-	Day	10:00	56,900	8.60	27.9

2013		16:00	58,000	8.50	27.8
21-Apr-2013	Night	22:00	57,400	8.40	26.6
		3:00	56,300	8.50	26.4
22-Apr-2013	Day	10:00	56,900	8.50	28.0
		15:00	57,900	8.50	27.9
22-Apr-2013	Night	21:00	56,700	8.40	26.4
		2:00	56,400	8.30	26.7
23-Apr-2013	Day	10:00	57,300	8.30	27.0
		14:00	57,100	8.30	28.0
23-Apr-2013	Night	22:00	56,500	8.40	27.8
		4:00	56,600	8.30	26.8
24-Apr-2013	Day	8:00	56,800	8.30	26.5
		14:00	57,100	8.20	26.7
24-Apr-2013	Night	20:00	56,700	8.10	24.9
		2:00	56,300	8.20	25.1
25-Apr-2013	Day	8:00	56,700	8.40	26.2
		12:00	56,500	8.30	25.6
25-Apr-2013	Night	19:00	56,400	8.20	23.8
		2:00	56,500	8.30	23.9
26-Apr-2013	Day	7:00	56,900	8.20	24.5
		11:00	57,000	8.30	24.6
26-Apr-2013	Night	20:00	56,100	8.40	24.3
		1:00	56,200	8.30	24.1
27-Apr-2013	Day	8:00	56,400	8.10	24.6
		14:00	56,300	8.10	24.5
27-Apr-2013	Night	20:00	56,500	8.20	23.8
		2:00	56,400	8.20	23.6
28-Apr-2013	Day	10:00	56,200	8.30	24.3
		14:00	56,500	8.40	24.7
28-Apr-2013	Night	20:00	56,300	8.30	23.7
		1:00	56,400	8.30	23.4
29-Apr-2013	Day	10:00	56,700	8.30	24.5
		15:00	56,800	8.40	24.9
29-Apr-2013	Night	22:00	56,400	8.40	23.8
		4:00	56,300	8.30	23.2
30-Apr-2013	Day	10:00	56,700	8.40	24.8
		16:00	56,800	8.40	25.2
30-Apr-2013	Night	21:00	56,400	8.20	23.1
		2:00	56,300	8.30	22.9
1-May-2013	Day	10:00	56,500	8.60	26.9
		14:00	57,100	8.50	27.1
1-May-2013	Night	20:00	56,300	8.40	25.8
		2:00	56,700	8.30	25.6
2-May-	Day	10:00	55,900	8.50	27.9

2013		13:00	56,600	8.50	28.6
2-May-2013	Night	21:00	56,500	8.30	25.7
		1:00	56,600	8.30	25.2
3-May-2013	Day	10:00	56,400	8.60	27.6
		15:00	56,500	8.40	25.1
3-May-2013	Night	22:00	56,400	8.30	23.9
		3:00	56,500	8.20	23.5
4-May-2013	Day	10:00	56,500	8.60	25.7
		16:00	56,320	8.40	25.0
4-May-2013	Night	23:00	56,100	8.30	24.1
		4:00	56,000	8.40	23.8
Average			56,380	8.43	25.7

Date	Shift	Time	Feed Water				Product Water		
			Conductivity	pH	Temp	SDI	Conductivity	pH	Temp
20-Mar-2013	Day	12:00	41,400	8.40	30.2	6.93	926	8.90	28.6
		16:00	41,400	8.43	29.8	6.84	935	9.20	29.1
20-Mar-2013	Night	20:00	41,200	8.20	28.2	6.89	950	9.00	26.1
		0:00	41,100	8.10	28.0	6.85	768	9.20	27.3
21-Mar-2013	Day	8:00	39,000	8.30	28.1	6.73	708	9.20	27.0
		12:00	39,200	8.40	29.2	6.56	750	9.20	28.8
21-Mar-2013	Night	22:00	40,500	8.37	28.7	6.81	826	9.10	27.8
		2:00	40,300	8.20	28.2	6.90	804	9.10	27.7
22-Mar-2013	Day	9:00	40,000	8.17	28.0	6.79	776	9.20	27.3
		13:00	40,600	8.19	28.6	6.73	922	9.00	28.2
22-Mar-2013	Night	0:00	41,200	8.16	28.1	6.94	945	9.00	28.1
		4:00	41,300	8.18	27.6	6.93	936	9.00	28.0
23-Mar-2013	Day	12:00	41,600	8.20	28.2	7.02	740	9.00	24.0
		18:00	39,000	8.20	26.9	6.85	708	9.10	26.4
23-Mar-2013	Night	19:00	39,100	8.40	29.5	6.76	788	9.10	29.1
		23:00	39,200	8.40	29.9	6.49	850	9.10	29.5
24-Mar-2013	Day	8:00	40,200	8.30	28.6	6.84	839	9.10	28.1
		11:00	40,300	8.30	29.2	6.88	873	8.80	28.6
24-Mar-2013	Night	1:00	40,400	8.20	27.5	7.03	793	8.90	26.9
		4:00	40,700	8.10	26.9	7.06	779	8.90	26.2
25-Mar-2013	Day	8:00	40,500	8.30	27.2	7.13	775	8.90	26.6
		12:00	41,200	8.40	27.8	7.09	852	9.00	28.0
25-Mar-2013	Night	20:00	41,500	8.10	28.0	7.15	747	9.10	26.6
		23:00	41,500	8.20	27.7	7.23	746	9.10	24.8
26-Mar-2013	Day	11:00	41,100	8.40	27.6	6.97	851	9.00	28.0
		16:00	41,500	8.10	28.0	7.00	766	9.10	26.9
26-Mar-2013	Night	20:00	41,900	8.29	28.7	7.16	846	8.15	27.2
		23:00	41,900	8.26	28.0	7.04	837	9.04	27.1

27-Mar-2013	Day	8:00	41,900	8.26	29.0	6.94	828	9.00	27.8
		14:00	41,800	8.20	28.4	6.86	864	9.00	28.2
27-Mar-2013	Night	22:00	41,900	8.30	28.8	7.24	929	9.10	29.6
		4:00	41,900	8.30	29.1	6.85	936	9.10	29.2
28-Mar-2013	Day	7:00	41,800	8.40	29.3	7.16	955	9.10	28.0
		11:00	41,700	8.40	28.6	7.21	856	9.02	28.0
28-Mar-2013	Night	20:00	41,600	8.40	28.5	7.10	855	9.00	28.0
		1:00	41,500	8.40	27.9	6.95	851	9.00	28.0
29-Mar-2013	Day	8:00	41,800	8.40	30.8	7.23	1,348	9.10	30.9
		10:00	41,600	8.50	30.7	6.99	1,362	9.20	30.2
29-Mar-2013	Night	0:00	41,200	8.40	27.2	7.00	830	9.17	26.2
		4:00	41,900	8.30	28.5	6.82	852	8.16	27.5
30-Mar-2013	Day	8:00	42,000	8.30	28.7	7.21	860	9.14	28.2
		14:00	42,000	8.38	29.4	7.16	905	8.90	29.2
30-Mar-2013	Night	22:00	42,000	8.40	29.3	7.19	887	9.19	28.8
		4:00	42,000	8.39	28.9	7.22	872	9.15	28.5
31-Mar-2013	Day	11:00	42,500	8.40	28.9	7.34	714	9.20	28.1
		17:00	42,400	8.30	28.5	7.28	760	8.90	28.0
31-Mar-2013	Night	0:00	42,600	8.20	28.4	7.36	1,025	8.90	28.9
		4:00	42,700	8.39	28.5	7.42	1,042	9.00	30.0
1-Apr-2013	Day	10:00	42,700	8.40	28.5	7.28	1,065	9.10	30.4
		14:00	42,800	8.40	30.1	7.37	1,002	9.10	29.5
1-Apr-2013	Night	20:00	42,700	8.32	28.9	7.19	948	9.12	28.4
		23:00	43,200	8.30	27.6	7.37	815	9.12	27.1
2-Apr-2013	Day	9:00	43,100	8.29	27.0	7.44	803	9.09	26.7
		14:00	43,000	8.29	27.2	7.49	804	9.09	26.8
2-Apr-2013	Night	18:00	43,100	8.18	26.8	7.52	783	9.04	26.3
		22:00	43,100	8.10	26.4	7.47	782	9.04	26.4
3-Apr-2013	Day	10:00	43,200	8.15	26.4	7.37	787	9.00	26.2
		16:00	43,500	8.20	26.6	7.43	790	9.00	25.9
3-Apr-2013	Night	20:00	43,300	8.20	27.2	7.57	795	9.00	26.5
		2:00	43,400	8.20	27.8	7.51	831	9.09	27.5
4-Apr-2013	Day	8:00	43,600	8.00	26.5	7.46	834	9.09	27.4
		11:00	43,200	7.10	26.8	7.42	824	9.10	26.8
4-Apr-2013	Night	22:00	43,600	8.30	26.9	7.46	816	9.10	26.1
		4:00	43,600	8.30	26.8	7.49	810	9.10	26.0
5-Apr-2013	Day	10:00	43,700	8.40	26.8	7.58	790	9.10	25.8
		14:00	43,700	8.40	26.6	7.56	782	9.00	25.7
5-Apr-2013	Night	22:00	43,600	8.40	26.5	7.52	778	9.00	25.6
		4:00	43,600	8.40	26.5	7.68	778	9.00	25.6
6-Apr-2013	Day	10:00	43,900	8.18	26.3	7.62	786	9.00	25.7
		16:00	43,800	8.30	27.2	7.60	796	9.15	26.6
6-Apr-2013	Night	20:00	43,700	8.30	27.8	7.35	844	9.00	27.0
		0:00	43,700	8.30	27.5	7.46	824	9.00	27.8

7-Apr-2013	Day	9:00	43,700	8.20	27.6	7.48	826	9.00	27.8
		13:00	43,700	8.20	27.6	7.28	822	9.00	27.3
7-Apr-2013	Night	22:00	43,300	8.20	27.1	7.29	812	8.80	26.8
		2:00	43,100	8.10	26.8	7.34	808	8.90	26.5
8-Apr-2013	Day	9:00	43,700	8.20	28.6	7.36	834	8.80	26.7
		15:00	43,300	8.10	28.8	7.39	826	8.70	26.9
8-Apr-2013	Night	21:00	43,500	8.00	26.4	7.45	816	8.60	26.4
		3:00	43,700	8.20	27.5	7.33	809	8.60	26.1
9-Apr-2013	Day	8:00	43,800	8.10	27.0	7.55	841	8.90	25.9
		12:00	43,900	8.30	28.9	7.59	826	9.10	26.8
9-Apr-2013	Night	21:00	44,000	8.10	26.7	7.50	823	8.70	26.4
		2:00	43,900	8.10	26.5	7.41	834	8.90	26.7
11-Apr-2013	Day	9:00	43,800	8.10	28.2	7.57	829	8.70	26.3
		16:00	44,000	8.30	27.3	7.40	844	8.80	26.4
11-Apr-2013	Night	20:00	44,200	8.00	27.5	7.60	820	8.70	26.7
		2:00	44,200	8.00	27.3	7.69	806	8.70	26.4
12-Apr-2013	Day	9:00	44,200	7.80	26.7	7.65	807	8.30	25.8
		15:00	44,300	7.88	27.1	7.68	810	8.38	26.5
12-Apr-2013	Night	22:00	44,300	8.00	27.6	7.72	861	8.71	27.3
		4:00	44,400	8.30	28.8	7.58	914	8.98	28.4
13-Apr-2013	Day	9:00	44,200	8.36	29.0	7.63	921	9.10	28.5
		16:00	44,100	8.40	29.3	7.48	939	9.15	28.7
13-Apr-2013	Night	21:00	44,100	8.20	27.9	7.56	867	8.90	27.1
		2:00	44,000	8.20	27.0	7.48	790	9.12	26.4
14-Apr-2013	Day	8:00	43,800	8.10	26.4	7.44	793	8.70	25.5
		12:00	44,000	8.10	26.7	7.53	781	9.00	25.4
14-Apr-2013	Night	19:00	44,200	8.20	26.9	7.55	807	9.00	26.2
		3:00	44,200	8.30	27.7	7.64	855	9.10	27.0
15-Apr-2013	Day	8:00	43,300	8.20	28.6	7.38	834	9.00	27.1
		14:00	44,300	8.30	28.4	7.42	859	9.10	27.3
15-Apr-2013	Night	20:00	43,800	8.10	26.5	7.33	841	9.10	27.4
		2:00	43,400	8.10	26.8	7.36	853	9.00	27.1
16-Apr-2013	Day	10:00	43,600	8.20	28.4	7.45	859	9.00	27.4
		16:00	44,300	8.20	29.1	7.57	836	9.10	27.2
16-Apr-2013	Night	22:00	43,900	8.10	27.3	7.60	778	9.00	25.9
		2:00	43,800	8.20	27.0	7.37	914	9.00	27.5
17-Apr-2013	Day	10:00	44,100	8.00	29.1	7.67	911	9.00	26.0
		16:00	43,800	8.30	28.4	7.38	998	8.80	27.6
17-Apr-2013	Night	21:00	43,400	8.10	26.3	7.58	857	8.90	27.4
		4:00	43,300	8.20	27.8	7.55	864	8.70	27.6
18-Apr-2013	Day	10:00	44,000	8.10	27.9	7.64	873	8.80	27.7
		15:00	44,100	8.20	29.1	7.60	881	8.60	27.1
18-Apr-2013	Night	21:00	44,000	8.10	27.4	7.62	912	8.90	27.3
		3:00	43,500	8.10	28.1	7.54	857	8.70	27.2

19-Apr-2013	Day	10:00	43,700	8.20	29.8	7.37	853	8.70	27.4
		16:00	44,200	8.10	27.9	7.54	852	8.90	27.3
19-Apr-2013	Night	22:00	44,000	8.00	28.2	7.46	843	8.70	27.4
		4:00	43,900	8.00	28.1	7.52	829	8.60	27.3
20-Apr-2013	Day	10:00	44,100	8.10	28.8	7.38	850	8.90	27.8
		14:00	44,500	8.10	29.4	7.49	867	8.80	27.4
20-Apr-2013	Night	20:00	44,300	8.20	28.7	7.68	853	8.90	27.1
		0:00	44,200	8.10	28.0	7.74	849	8.60	27.2
21-Apr-2013	Day	10:00	44,100	8.30	30.0	7.68	869	8.70	27.5
		16:00	44,300	8.20	30.5	7.54	876	8.70	27.7
21-Apr-2013	Night	22:00	43,800	8.10	29.2	7.52	857	8.90	27.3
		3:00	43,900	8.20	28.7	7.46	823	8.80	27.0
22-Apr-2013	Day	10:00	44,200	8.20	30.1	7.43	841	8.80	27.4
		15:00	44,300	8.20	30.0	7.49	843	8.70	27.6
22-Apr-2013	Night	21:00	44,200	8.10	27.7	7.53	836	8.80	27.0
		2:00	43,900	8.00	29.0	7.51	934	8.80	27.5
23-Apr-2013	Day	10:00	44,600	8.10	27.2	7.55	953	8.90	28.6
		14:00	44,400	8.00	28.3	7.40	938	8.90	28.8
23-Apr-2013	Night	22:00	44,100	8.20	29.2	7.38	928	8.90	28.2
		4:00	44,200	8.00	28.1	7.36	881	8.90	27.6
24-Apr-2013	Day	8:00	44,200	8.10	26.7	7.46	910	8.50	26.1
		14:00	44,400	8.00	26.9	7.41	915	8.50	27.9
24-Apr-2013	Night	20:00	44,200	7.90	24.7	7.53	822	8.70	23.8
		2:00	43,900	7.90	27.3	7.52	809	8.60	23.9
25-Apr-2013	Day	8:00	44,100	8.15	28.3	7.44	1,206	8.90	28.4
		12:00	44,000	8.10	27.9	7.42	930	8.70	26.8
25-Apr-2013	Night	19:00	44,000	8.00	25.8	7.49	873	8.80	25.0
		2:00	44,000	8.00	25.3	7.57	849	8.80	24.4
26-Apr-2013	Day	7:00	44,300	8.00	26.4	7.63	950	8.90	24.9
		11:00	44,400	8.00	26.5	7.68	941	8.70	25.2
26-Apr-2013	Night	20:00	43,800	8.20	26.8	7.48	920	8.90	26.1
		1:00	43,900	8.10	26.4	7.35	899	8.90	25.6
27-Apr-2013	Day	8:00	44,000	7.80	24.2	7.40	800	8.60	23.5
		14:00	44,000	7.80	24.2	7.37	779	8.60	23.8
27-Apr-2013	Night	20:00	44,000	8.00	24.8	7.41	852	8.80	24.5
		2:00	44,000	8.00	24.6	7.49	840	8.90	24.2
28-Apr-2013	Day	10:00	43,900	8.05	24.3	7.35	805	8.90	23.7
		14:00	44,100	8.12	24.7	7.69	816	8.90	24.3
28-Apr-2013	Night	20:00	44,000	8.10	25.8	7.72	880	8.80	24.8
		1:00	44,000	8.00	25.1	7.38	860	8.80	24.1
29-Apr-2013	Day	10:00	44,200	8.09	25.6	7.46	837	8.97	25.2
		15:00	44,300	8.19	26.6	7.42	888	9.01	26.3
29-Apr-2013	Night	22:00	44,000	8.20	27.0	7.29	941	8.94	26.3
		4:00	44,000	8.10	26.4	7.34	895	8.89	25.4

30-Apr-2013	Day	10:00	44,200	8.20	25.9	7.64	940	9.06	26.7
		16:00	44,300	8.10	26.3	7.52	961	9.08	27.1
30-Apr-2013	Night	21:00	44,000	8.00	25.0	7.44	853	8.70	24.1
		2:00	44,000	8.00	24.9	7.41	847	8.70	24.0
1-May-2013	Day	10:00	44,000	8.18	28.0	7.56	1,000	8.97	27.3
		14:00	44,000	8.10	28.0	7.58	986	8.90	26.8
1-May-2013	Night	20:00	44,000	8.10	28.2	7.53	884	8.70	25.6
		2:00	44,200	8.00	26.1	7.43	902	8.80	25.3
2-May-2013	Day	10:00	43,600	8.20	28.9	7.38	900	8.70	26.2
		13:00	44,100	8.20	29.5	7.34	924	8.60	25.4
2-May-2013	Night	21:00	44,100	8.00	25.8	7.29	873	8.76	24.9
		1:00	44,100	8.00	25.3	7.37	866	8.80	24.4
3-May-2013	Day	10:00	43,900	8.00	24.9	7.40	857	8.80	23.9
		15:00	44,000	8.05	25.2	7.52	870	8.80	24.3
3-May-2013	Night	22:00	44,100	8.00	25.8	7.44	873	8.76	24.9
		3:00	44,100	8.00	25.3	7.50	866	8.80	24.4
4-May-2013	Day	10:00	44,000	8.10	28.4	7.46	1,007	8.70	27.8
		16:00	44,000	8.20	27.2	7.57	996	8.60	27.6
4-May-2013	Night	23:00	43,900	8.00	26.5	7.43	876	8.60	26.7
		4:00	43,800	8.10	25.9	7.36	892	8.60	25.8
Average			43,164	8.17	27.6	7.36	864	8.90	26.9