Abu Dhabi
United Arab Emirates
Desalination Plant Security

whitepaper

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Contents

1. Executive Summary

The salinity of the Arabian Gulf is increasing for numerous reasons. This unfortunate situation will continue to cause ever more significant strategic problems in the region. This white paper focuses on the outcome of the Arabian Gulf's salinity increase verses the reliable water production that can be expected from the reverse osmosis (RO) water desalination plants that line the Arabian Gulf. The salinity level that feeds a number of the RO plants in the Arabian Gulf is currently between 45,000 to 47,000 mg/l tds while the average overall gulf salinity hovers at 40,500 mg/l tds. The conclusions in this paper are based on extensive modeling of RO plant performance using the Suez Winflows Membrane System Design Software. Over 300 software simulations using the Suez tool were performed. Software modeling is, by its nature, optimistic. A software model does not account for real world problems such as algal blooms, red tide events, pretreatment hydrocarbon break through, or organic contamination. For these reasons, all conclusions and analysis contained herein should be considered "best case". Another significant understatement in this paper of the issues in the gulf is the paper's conclusions do not factor in any population growth which will accelerate water usage and the continued contamination of the Arabian Gulf. In other words, the significant problems stated herein will most likely occur sooner than is predicted.

The paper's conclusion is that optimistically at 50,000 to 60,000 mg/l tds, depending on the RO plant's design, and operations and feedwater variables, an RO plant will not run effectively or reliably if no modifications to the plant are made. Helios Environmental Advanced Technology (H.E.A.T) produces a water product technology, W-75, that when integrated into an RO plant can extend the reliability and effectiveness of the plant well into higher realms of feedwater salinity. The W-75 also reduces the salt loading to the Arabian Gulf which again will extend the life of existing RO plants in the UAE along with extending the life of the marine animals, aquatic coral, and marine plants in the gulf. Additional components can be added to the W-75 water product to significantly reduce the salt loading from RO plants into the Arabian Gulf and further increase water production. These additions can help reduce the rate of saline damage to the gulf and potentially allow the gulf to start a recovery process. This additional technology is not included in the contents herein, however its performance characteristics are briefly discussed.

The W-75 is the only known technology that can convert high salinity water (up to 300,000 mg/l tds) into water that can be used for human consumption or agricultural use. The application of this technology in demanding applications, such as the processing of oil and gas produced water, is an ideal application. If the oil and gas produced water is converted into an agricultural water source, the load on the RO plants in the gulf would be reduced and would ultimately extend the life of the water making plants on the gulf and the gulf's aquatic life.

One of the primary models utilized in this white paper is the Fujairah 2 plant design. The plant is an innovative and very successful water production vehicle. Due to the plant's location and design, it will live a long and prosperous life with little to no modification. Other plants on the gulf especially in the UAE are not positioned well. They could be in a shutdown condition for single stage RO plants (a minimum number of existing plants) in 2 years. Modern multistage Fujairah 2 RO plant designs in the majority of the UAE and Saudi area will potentially face shutdown or unreliable operations in as short a period as 6 years.

In areas of low saline stress such as the coast of Iran, Iraq, Kuwait and the location of the current Fujairah 2 plant in the Gulf of Oman, modern RO plants with multistages should be able to productively operate for approximately 39 years.

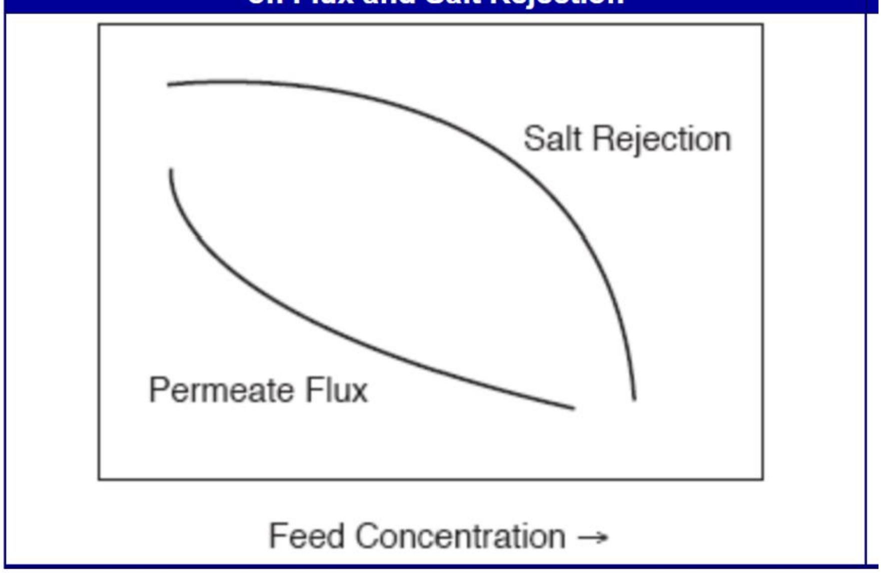
In some cases, the integration of the H.E.A.T technology may be the only or best immediate solution. In many other cases there may be more eloquent short and medium term plant improvements that are possible. In the long term, if the gulf's salinity continues to increase especially at an accelerated rate, which is very possible, the H.E.A.T technology may be the only viable long term solution to increase the reliability and security of the existing RO plants in areas like the UAE. In parallel with the integration of H.E.A.T technology a plant by plant engineering analysis of increased water production security should be executed.

2. Desalination Plant Efficiency Upgrade and Water Production Security Program - Overview

Desalination plants are typically based on thermal distillation or reverse osmosis (RO) principals. Modern desalination plants have almost exclusively been shifted to employ RO technology since it is significantly more energy and cost efficient per m^3 of clean water produced. The plant efficiencies and feedwater quality tolerances of distillation technologies versus RO technologies are different. Many water quality and plant design parameters effect a plant's overall efficiency in both cases. To reflect modern investment and simplify this white paper, the data presented relates specifically to modern RO plants.

Modern RO plants effectively stop operating for many reasons at approximately 50,000 to 60,000 Total Dissolved Solids (TDS). The figure below shows a few of the most significant reasons why.

Figure 5 - Effect of Increasing Salt Concentration on Flux and Salt Rejection



Reference: Water Treatment Guide Technical Database "Factors Affecting RO Membrane Performance"

As shown above, salt rejection and permeate flux for a given plant feedwater pressure define the efficiency of water production in an RO plant. The failure of the plant to be able to produce clean water due to high incoming TDS is usually due to the physical limit of pressure on the membrane vessels or salt breakthrough in the product water, which then only produces contaminated water that is not acceptable for human use and eventually agricultural use.

The Arabian Gulf is increasing in TDS. Two water samples recently acquired from different locations show existing values of TDS in the Arabian Gulf of approximately 44,000 and 47,000:

Desalinization Waste Stream Analysis – Arabian Gulf

45,000 to 50,000 TDS is the reasonable operating limit for modern desalination plants

Constituents	Abu Dhabi Coast mg/L
Chloride	24 300
Sulfate	3 420
Bicarbonate	200
Carbonate	--
Sodium	13 900
Magnesium	1 560
Calcium	600
Iron	0.3
Total dissolved solids	**43 980.3**

Sample taken from Zakum Oilfield off the coast of Abu Dhabi

http://enhg.org/bulletin/b29/29_05.htm

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Water Quality KSA, Summer = 47,150 TDS

Table 3

Summary of water quality parameters in the Gulf coast water at Khafji, Saudi Arabia during the four seasons.

Parameters	Summer			Autumn			Winter			Spring		
	Min	Max	Mean[a]	Min	Max	Mean[a]	Min	Max	Mean[a]	Min	Max	Mean[a]
Temperature (°C)	31.5	34.0	32.5	21.4	27.5	24.9	13.0	18.5	16.3	21.5	30.4	25.9
Salinity (‰)	41.8	42.0	41.0	40.9	41.4	41.1	40.4	41.6	41.0	41.0	42.7	41.5
Conductivity (µS/cm)	61600	63400	62850	61400	61900	61600	61200	62500	61642	61500	63400	62450
TDS (mg/l)	42800	47150	45122	44000	46460	45690	43500	46900	45082	45295	45285	45290
Turbidity (NTU)	0.20	0.88	0.53	0.85	9.20	3.78	0.45	6.97	2.82	0.55	1.00	0.78

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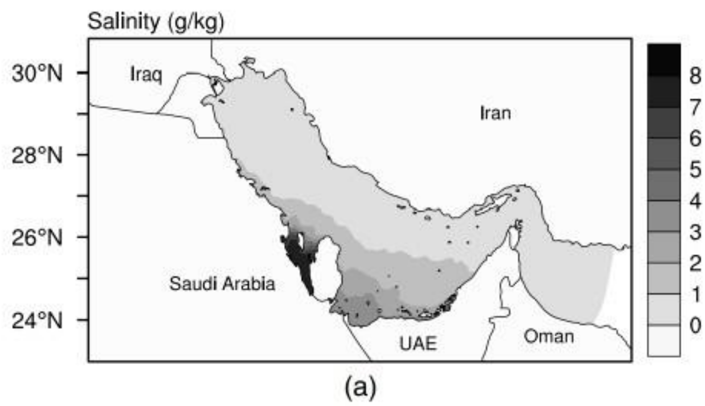
Many experts feel the Arabian Gulf started at a TDS level of approximately 37,000. With the advent of desalination plant's high TDS wastewater being introduced into the gulf on a large scale, and the combined effects of water withdrawal due to population growth in the gulf area and climate change, the average overall saline level of the Arabian Gulf is now approximately 40,500 mg/l. Unfortunately, the localized areas of high salinity (up to 47,000 mg/l) are in the areas of RO plant operations for countries like Saudi Arabia and the UAE.

The first large scale study of the Arabian Gulf's saline TDS trends and projections for its future path was recently commissioned by the King Abdulaziz City for Science and Technology and performed by MIT in the US.

Salt Contamination Model - Catastrophic Prediction

Performed by MIT funded by King Abdulaziz City for Science and Technology (KACST), 2019



Model Results predict modern desalination plants will have very significant problems (stop functioning) due to salinity increase from desalinization plant discharge into the gulf in the next 10 years. Local problems to UAE and Saudi Arabia plants could happen much sooner.

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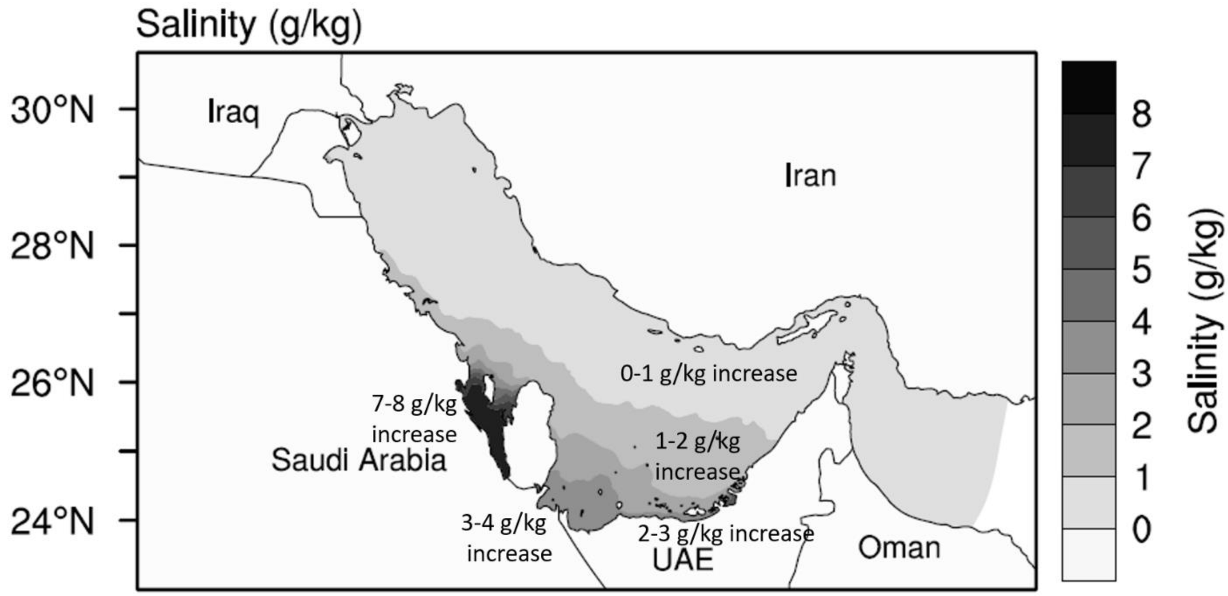
The study considers many factors and concludes local TDS increases near the UAE and KSA shores (where the desalination plant's outlets are) will be significantly higher than the gulf's overall average TDS increase. These areas also have a more saline average existing concentration of between 43,980 to 47,150 mg/l. The report, as can be seen by the above summary drawing, predicts how much increase in the average TDS will occur in the gulf over time assuming no increase in population in the area. Many values for TDS increase per year can be extrapolated from the report. H.E.A.T has tried its best to accurately represent the reports projections in the following plot:



(a)

As is shown above, the areas of low stress for water security netted from RO plants is the Iranian shoreline, the north east shoreline of Saudi Arabia, Kuwait, and the north east shoreline of the UAE including the Gulf of Oman. In these areas if an average nominal saline level of the water is assumed to be 40,500 mg/l and the average yearly increase in saline level is assumed to be at a rate of 500 mg/l, then a single stage RO plant will have an operational life of approximately 19 years and an advanced multistage plant like Fujairah 2 will have an operational life expectancy of 39 years.

If the more stressed area of the UAE and the balance of the Saudi shoreline is examined, which is where many of the major RO plants are located, unfortunately a different future exists. In the gulf there are over 800 water making plants. For this white paper only the large modern RO plants are being studied. If an average saline level for the gulf area described is 45,000 mg/l and the rate of saline increase is projected to be 2,500 mg/l on average, then a single stage RO plant will only have a projected life of 2 years without H.E.A.T technology incorporated into the plant. And a modern 2 stage Fujairah 2 style RO plant will have a 6 year projected life before it is crippled with operational issues. Again, these projections are optimistic since they do not factor in population growth.

3. Operational Plan

H.E.A.T invents and builds advanced tools that change the world in beneficial ways. The H.E.A.T W-75 water product can purify water at TDS levels over 300,000 ppm. No other known technology exists that can accomplish this task.

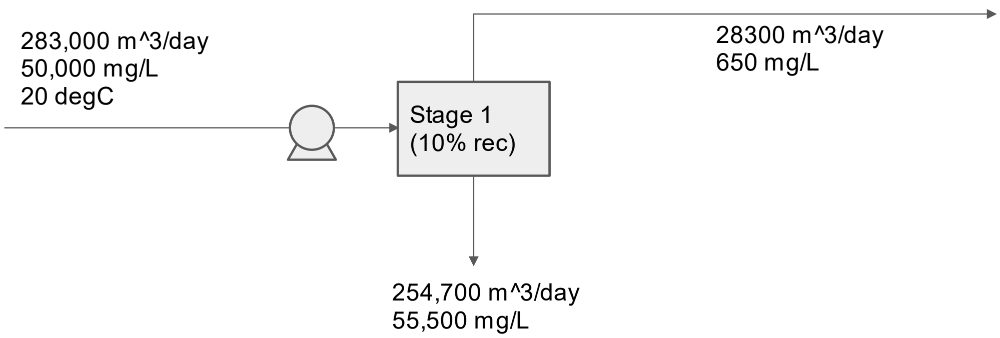
The first set of models shown below were derived from a simple 1 stage RO plant attempting to operate at 50,000 TDS. The second set of models is a copy of the design of the Fujairah 2 RO plant in Abu Dhabi. The Fujairah 2 plant design was modeled because it has been a very successful plant throughout its operation. When built and commissioned in 2011, it was one of the largest RO plants in the world. It reflected many RO innovations and has enjoyed an enviable plant operational up time (availability). Fujairah 2 has many advanced features that most RO plants do not have such as the pre-heating of feedwater from an integrated power plant and the blending of MED permeate from the close coupled plant. To exploit the plants advantageous design features without limiting the H.E.A.T models to only the Fujairah 2 location, the feedwater pre-heat and MED blending capabilities were ignored. The balance of the model presented closely resemble the Fujairah 2 operating principals.

As an overview, the Fujairah plant is a 2 stage RO plant with over 10,000 first pass membranes and over 1,500 second pass membranes. The plant goal is to produce 180 mg/l to 300 mg/l tds finished product. The plant has extensive pre-treatment capability including DAFs filters, chlorinators, coagulation and flocculation capability, anti-scale additives and bisulfate systems as needed.

The plant currently replaces its membranes every 5-8 years. The plant is fortunate to be operating in the Gulf of Oman which has low salinity water of approximately 40,500 mg/l tds. For the gulf, this water quality is very good. By comparison nominal sea water around the world is at a saline level of 34,000 mg/l tds. At the projected tds levels in the gulf of 50,000 to 60,000 tds the aging of the membranes and their needed replacement will accelerate rapidly. As noted above, the Suez software only projects aging degradation utilizing conventional sea water (approximately 34,000 tds) and no plant upsets such as algal blooms, red tide events, hydrocarbon breakthroughs, or organic breakthroughs are factored in. The aging factor of membranes is one of the problems that significantly effects RO plant efficiency and reliability. The aging factors used in the models below are for all of the above reasons extremely optimistic.

As noted above, the first model developed was a simple 1 stage RO plant. The model was developed to show the simplest case of high salinity RO plant operation with and without the integration of the H.E.A.T W-75 water technology. The process flow diagram and mass balance for the simple 1 stage RO plant with no enhancements is as follows:

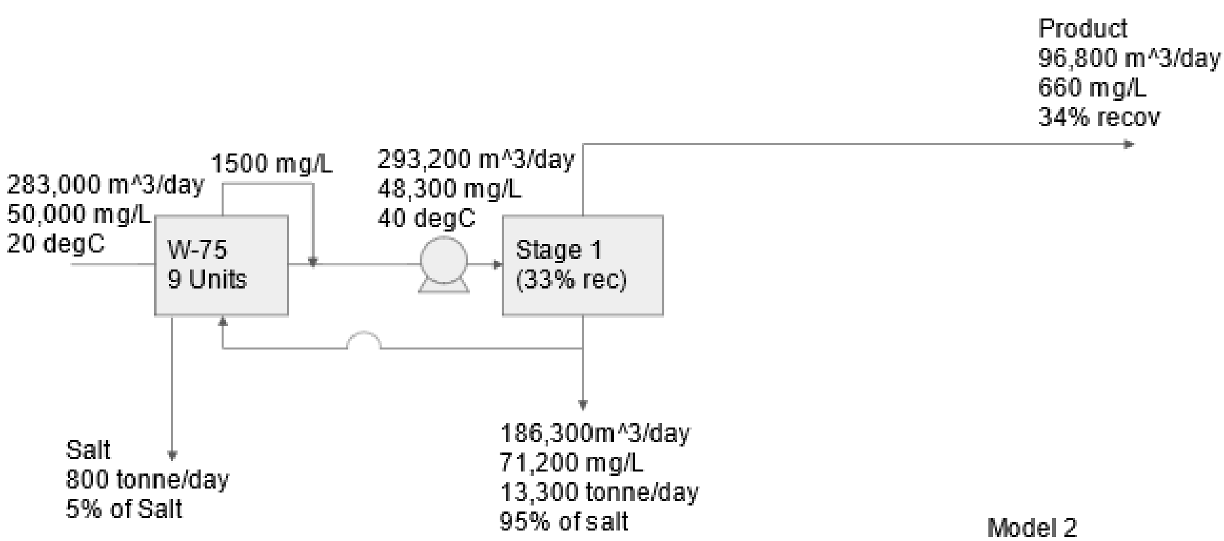
Single Stage RO, Idealized 6 Year aged Membranes



Model 1

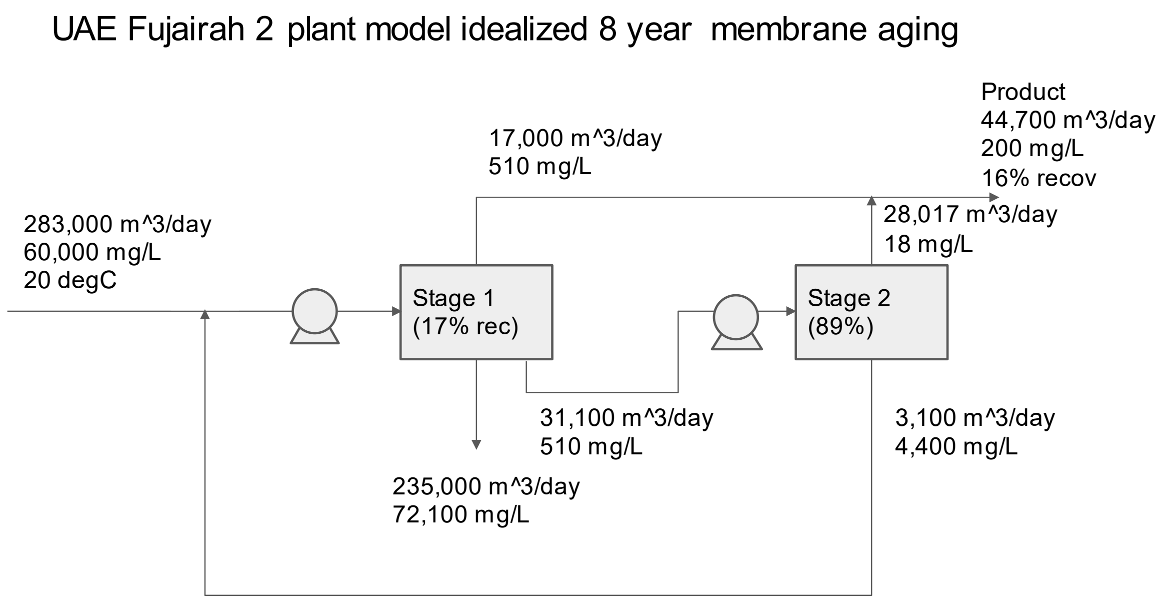
The significant information to be harvested from Model 1 is at a saline content of 50,000 tds in the feedwater the plant idealized efficiency is 10%. In other words, with 283,000 M^3/day of 50,000 tds feedwater the plant only produces 28,300 M^3/day of permeate or fresh water. The water quality is also very bad. Most experts feel 200 tds is the ideal limit for human use of water. Above that level humans are able to taste the salt content. At 650 mg/l tds the water taste would be unacceptable to the majority of humans and even for sanitary use (i.e., showers) the salt would make itself obvious. The operating maintenance at these plant conditions would also be hugely challenging. The 6 year idealized membrane aging would most likely be reached must faster at 1 to 3 years. In the author's opinion, this is the point in time where it no longer makes sense to operate the plant.

Single Stage RO with W-75 (6 year old)



Model 2

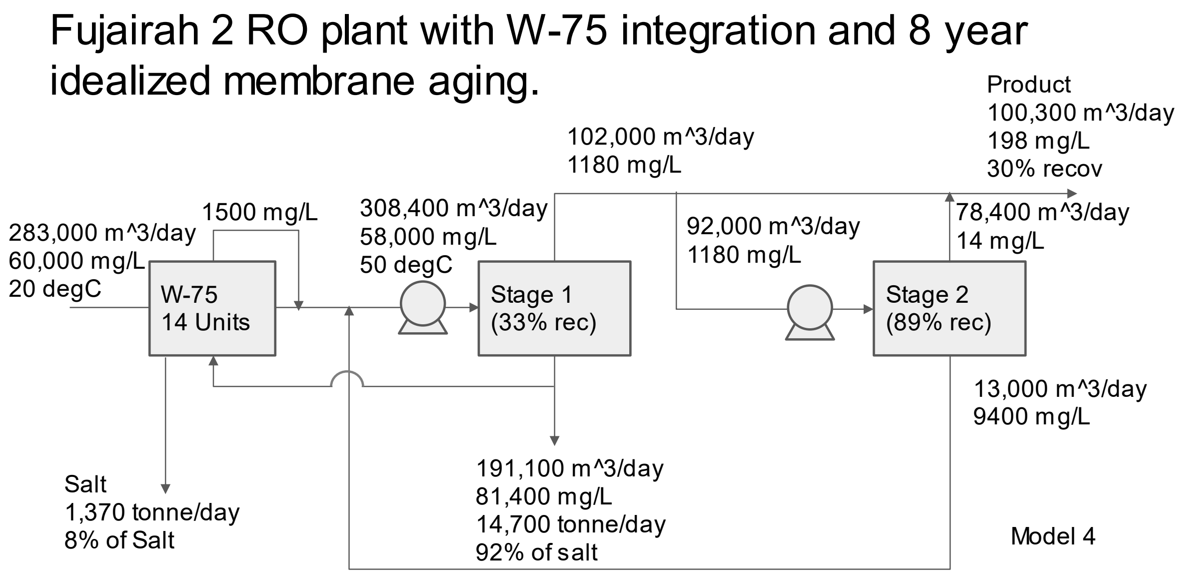
Model 2 above shows the same plant with W-75 water units integrated. The burdened cost per unit of water produced is less in model 2 than in model 1. It is cheaper to make water with the W-75 technology in this case. This is due to many reasons. The effective feedwater for the plant is also reduced in salinity to 48,300 with 9, W-75 units integrated. This will aid plant reliability. In this configuration 800 tonnes per day of salt or approximately 5% of the total salt would be kept from entering the gulf. With additional technology components applied to the W-75 units, up to approximately 20% of the salt (3,200 tonnes per day) can be kept from entering the gulf. If capital efficiency was not a primary goal up to 100% of the salt could be diverted from the gulf using modified W-75 technology. It should be noted that approximately 3.4 original ineffective plants (model 1) at this saline level would be needed to produce the same amount of water as 1 W-75 upgraded plant (model 2). The stress applied to the gulf by running 3.4 ineffective plants would only accelerate the eventual demise of the gulf with the added salt and chemical pretreatment pollution (biocides, etc.) expelled by RO plants.



Model 3

Model 3 is an approximate representation of the Fujairah 2 RO plant. As previously mentioned, the heated feedwater function of the attached Fujairah power plant has been ignored to make model 3 relevant to the majority of existing RO plants in the gulf. The 20 degree C feedwater point was chosen since it represents a stressful temperature for an RO plant that occurs in the colder seasons of the UAE.

The conditions shown are optimistic at best since they were generated from an idealized Suez membrane software tool. The actual aging in the membranes may be less than 4 years at this high 60,000 mg/l saline level. The plant will be difficult to maintain and keep operational with the conditions shown. As noted above, the overall plant efficiency is only 16% even in an idealized model. The condition in model 3 may be the point where the plant no longer can be considered a viable asset. The total amount of water produced would be 44,700 M^3/day at the targeted quality level for human use of 200 mg/l tds.



Model 4 shows H.E.A.T W-75 technology integrated into the Fujairah 2 plant. The plant efficiency increases to 30% and 100,300 M^3/day of clean water for human use is produced. It should be noted that 2 unmodified Fajairah 2 plants (model 3) would be required to achieve a similar level of water production. The second plant would double the salt stress and chemical pollution (biocides, etc.) on the gulf for the water produced.

The reduction in incoming feedwater tds (model 4) will also make the plant more reliable. In this model 8% of the salt or 1,370 tonnes/day will be diverted away from the gulf. Up to 100% of the salt could be diverted if capital efficiency were not a primary goal.

4. General Plant Economics

The strategic value of not being able to supply the UAE region with clean water has not been considered in this analysis.

A separate paper will develop a financial model of the RO plant upgrades with the H.E.A.T W-75 units. The general plant economics that will be developed into a financial model are;

Model	Plant Description	Feedwater Processed in M^3/day	Daily Plant Cost in US$	Natural Gas cost at US$5 / MMBtu	Clean Water Produced per day M^3/day	Cost of clean water per M^3/day with Natural Gas	Cost of clean water per M^3/day with out Natural Gas
Model 1	1 stage Base case	283,000	127,350	0	28,300	$4.50	$4.50
Model 2	W-75 modified 1 stage	283,000	127,350	129,600	96,800	$2.65	$1.32
Model 3	Fujairah Base case	283,000	127,350	0	44,700	$2.85	$2.85
Model 4	Fujairah with W-75	283,000	127,350	201,600	100,300	$3.28	$1.27

It can be seen that as the salinity goes up and the RO plants get closer to the limits of their ability to produce clean water, the plants modified with W-75 units become less expensive to operate per M^3 of water produced. Model 1, with no modifications, requires $4.50 per M^3 of water produced whereas model 2, modified with W-75 units, only requires $2.65 including the cost of natural gas. The column on the right side of the table shows that the cost of natural gas applied to this strategic RO plant modification significantly affects the final cost per M^3 of water produced.

5. Conclusions

The continual salinity increase in the Arabian Gulf will potentially pose a significant potable water security and supply risk for most of the coastal areas where current RO plants exist in the UAE and Saudi Arabia. For modern 2 stage plants this cascading dilemma will potentially start to make its presence known by reducing the viability of existing modern RO plants in the next 6 years. Single stage plants will have viability issues much sooner.

The H.E.A.T W-75 technology when integrated into existing RO plants will extend the viability of these plants. It will also reduce the rate at which the gulf will deteriorate. In the example of a modern RO plant the addition of the H.E.A.T technology will reduce the salt loading to the gulf by a factor of greater than 2 (less than ½ of the salt will be returned to the gulf). This loading is compared against conventional solutions of just pushing existing RO plants harder with ever decreasing plant efficiency. In the case of single stage plants, the salt loading to the gulf will be a factor of over 3.5 times less stress on the gulf. It should be noted that all the chemical pollution from biocides, etc. will also be reduced to the gulf by the same ratios.

Finally, since additional RO plants will not have to be built just to maintain the current plant's water production the H.E.A.T technology is also significantly carbon negative when compared to the integration of conventional technology.