# Developing New Measuring Technique Controlling Desalination Brine Concentration

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# DEVELOPING NEW MEASURING TECHNIQUE CONTROLLING DESALINATION BRINE CONCENTRATION


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## Abstract

Desalination is an important method and cost effective for producing potable water and is a rapidly growing technology worldwide. According to the International Desalination Association, IDA data base the amount of desalinated water soon will reach the 100 MCM per day, which means double of this amount (200 MCM/day) is called brine discharge or rejected amount. In this study, we planned to follow and control the huge amount of the rejected brine especially at the Gulf region which counts the most production area e.g. more than 45% of the world total amount and the largest desalination plant is also located there with more than one million cubic meter per day.

The early warning system that introduces sea bottom probes (sensors) measuring desalination brine concentration can be good method to start in order to control the discharge at any location. It is great opportunity to the users that can continuously observe the changes of the concentration at the surrounding at any discharge point. For example the alarm signal works for the salt concentration increment for more than 0.5 g/l at the surrounding of any discharge point which is already existed in some places.

The most important part of this plan is to establish the mobile testing instrumentation system from the above idea, which is similar to a mobile desalination plant. Such plants were developed few years ago for emergency cases and can easily sail from one location to another thereby serving many locations. Thus, we have to start mobile testing at existing desalination plants and use the mobile plants to measure and control intake and brine discharge.

# I. INTRODUCTION

Desalination is an important method for producing potable water and is a rapidly growing technology worldwide. Historically, desalination has been a freshwater supply opportunity for a long time, especially at remote locations and on naval ships off shore. With the rapid growth of water desalination technology in recent decades, the development has continued in many arid, semi-arid areas. The capacity of desalination increased rapidly worldwide, from 8000 $m^3$/d in 1970 to about 32.4 million $m^3$/d installed or contracted, over 15,000 industrial-scale desalination unites by 2001, seawater desalination plants of 19.1 million $m^3$/d and non-seawater of 13.3 million $m^3$/d [1,2].

The contracted desalination Plants capacity has also grown to 86 $Mm^3$/d, which represents the output of over 15,600 desalination facilities worldwide while the online capacity almost 80 $Mm^3$/d at the end of 2013 [3]. The total capacity contracted has now reached to 90.1 $Mm^3$/d and the online amount of 85.2 $Mm^3$/d, a rise of about 5 million for both since the 2014-2015 year book [3]. The data presented here is almost at the end of year 2014.

A variety of desalting technologies has been developed over the years, primarily thermal and membrane processes. The cost of desalination, either thermal or membrane, is inversely proportional to the production capacity. The market is also driven by the falling costs of desalination, which are due to the technological advances in the desalination process [4]. The desalination plant size is important when it comes to capital and production cost. Today's desalination plants and methods require large amounts of energy which is costly both in environment impact and money.

The cost estimation is one issue surrounding the desalination industry that should be carried out in an efficient and reliable manner, as costs is a crucial factor in government decision making and planning. Furthermore, how to reduce the cost from different impact factors is the driving force to research on desalination, as well as being paid close attention by industry. Desalination cost estimation is varying from site to site and country to country for the cost ranges per cubic metre [5].

This variability exists because it depends upon many factors, such as the desalination technology, feed water salinity, energy type and availability, plant capacity and plant location. Previous models to calculate cost estimations have the disadvantages that they are complicated and require a vast amount of parameters which are not easily to be collected. In addition, most of the models only focus on single scenario, such as seawater desalination by RO, or desalination using certain energy.

## 1.1. Procedure and Objectives

In this paper, we are discussing the idea of this method in order to measure the brine concentration at any time for each assigned point and to show the collection of data. It is a kind of digital installation and computerised that can read the concentration in each assigned point located front of the discharge point with specific distance between the points. Each point is containing a probe that can measure for example TDS, PH and controlling boron concentration etc.

This study was initiated for desalination capacitates and the effects of brine discharge into any water body especially the Arabian Gulf. It is important to assists the countries around the Gulf due to a huge desalination plants that have been built and the large number of planned projects. The main objectives of this study are to control the desalination brine from any desalination plants start at local discharge area and then larger area for test to see the difference between the small and larger scale desalination plants. The more safe receiving water the less cost is, when we consider the intake quality after this control because the intake and the discharge are so close. Also, other objective of this study is to find out the most efficient way to reduce the impact of brine discharge from desalination plants by improving the mixing conditions in the discharged jet.

## II. SELECTED STUDY AREA

Desalination and brine discharge measurement control is needed in all over the world where desalination project is functioning and the same idea can be used for similar purposes such as discharging from wastewater treatment plant and industrial discharge too. In this proposal we are taking Persian/Arabian Gulf as an example, why? It is considered as semi-enclosed and characterized by a higher salt content due to the high rate of evaporation with low precipitation [6]. The countries bordering the Arabian Gulf are: Iran, Iraq, Kuwait, Saudi Arabia, Qatar, Bahrain, and the United Arab Emirates (as shown in Figure 1). The Arabian Gulf is a shallow sea, with maximum depth less than 100 m over its entire extent and a mean depth of only 35 m [7]. It covers an area of about 240,000 $km^2$, with 1000 km in length and widths ranging from 185 km to 370 km, with a mean of 240 km. The total water volume in the Gulf is approximately 8,400 $km^3$.

### 2.1. General

The Arabian Gulf is considered as semi-enclosed and characterized by a higher salt content due to the high rate of evaporation with low precipitation [6]. The countries bordering the Arabian Gulf are: Iran, Iraq, Kuwait, Saudi Arabia, Qatar, Bahrain, and the United Arab Emirates (as shown in Figure 1). The Arabian Gulf is a shallow sea, with maximum depth less than 100 m over its entire extent and a mean depth of only 35 m [7]. It covers an area of about 240,000 $km^2$, with 1000 km in length and widths ranging from 185 km to 370 km, with a mean of 240 km. The total water volume in the Gulf is approximately 8,400 $km^3$.

The shallowness and humidity lead to the formation of saline, dense water, with maximum salinities as high as 57 g/l in the AG [8]. The numbers in the small table presented in Figure 1 is the fresh water production from desalination in million cubic meters a day for each group separately. Also the total brine discharge from the triangle shown in the southern part of Bahrain is counted about 1 million cubic per day as presented recently in [9]. It was also reported exceptionally high salinity occur in many locations along the southern shores, particularly south of Bahrain in the Gulf of Salwah and inmany others of Saudi Arabia (e.g. [10]), Qatar and the UAE shows some on the Dubai coastline. The relative richness and productivity of these areas is poorly understood; south of Bahrain salinity rises to between 55 and 65 g/l around the Hawar archipelago, yet benthic diversity remains moderately high [11], but where salinity rises to over 60–90 g/l. The ultimate extent is seen where salt crystals appear in inter-tidal regions (salinity >300 g/l; [12]), though even here nematodes clearly visible to the naked eye may thrive.

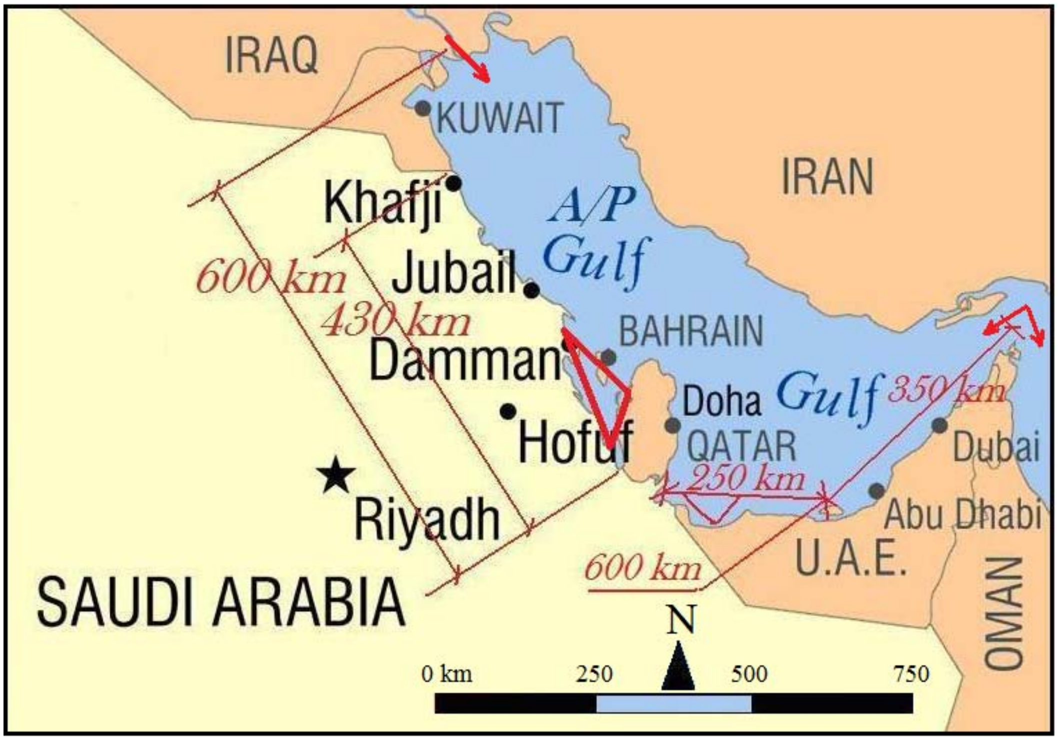


**Fig. 1. A simple map showing P/A Gulf coastline distances (After Wikipedia)**

The freshwater inflows from the Tigris, the Euphrates, and the Karun at the delta of the Shatt al Arab, estimated at 0.2 m/yr over the gulf cross-sectional area, in which fresh water and river inflow equals 48 $km^3$/yr (131.5 $10^6 m^3$/day) [7,13]. The mean annual evaporation rate is estimated at approximately 1.5 m/yr [14]. Rainfall is roughly from October to March over the Gulf. The average annual rainfall is 114.2 mm at Kuwait, 77.9 mm at Doha [15]. Also the annual average rainfall was recorded at Dhahran for 1935-1974 is 72.4 mm and relative humidity is ranged 65-73% during winter and ranged 37-63% in summer [16].

## III. MEASUREMENT AND COLLECTION

In this paper, we are going to discuss the measurement methodology in order to control the coastline (receiving) water quality where the brine is normally discharged from the desalination plants. From this idea we are going to measure the brine concentration at any time for each assigned point and draw the collected data for evaluation (see Figure 2). It is a kind of digital and computerised installation that can read the concentration in each assigned point that located front of the discharge point with specific distance between the points location. Each point is containing a probe that can measure for example TDS, PH, EC, Mg, Ca and boron concentration etc. These points are assigned in a line system parallel to the coastline with 10 meters interval in between and it can take more than one parallel line at farther distance. For instance, the more capacity desalination plants the more testing points will have. It is also possible to replace underwater camera in some point for accurate measurement and view underwater to be able to see the flow and mixing the brine water with receiving. This type of digital camera can measure and take video at the same time with 360 degrees rotation.

The intervals between the points and the parallel lines can also vary from 10 to 50 meters, in which this will be depending on the plant capacity and the discharge quality. It is also planned to have in some cases perpendicular to the outfalls measurement points to see the maximum distance that the high concentrated brine can travel to. The advanced instrument for this measurement and digital control can be designed as digital camera at the same time with measurement of different chemicals. This camera can transfer the views directly to the computer to show the concentrated water mixing and movement inside the receiving. The continuous measurement and video at the measurement points will help us to more understand the flow from the concentrated brines and also with the high temperature such as discharge from MSF.

The most important part of this study is to plan for mobile testing instrumentation in the future, which is similar to a mobile desalination plant. Such plants were developed a few years ago for emergency cases and can easily sail from one location to another thereby serving many locations. Thus, we have to start mobile testing at existing desalination plants and use the mobile plants to measure and control intake and brine discharge.

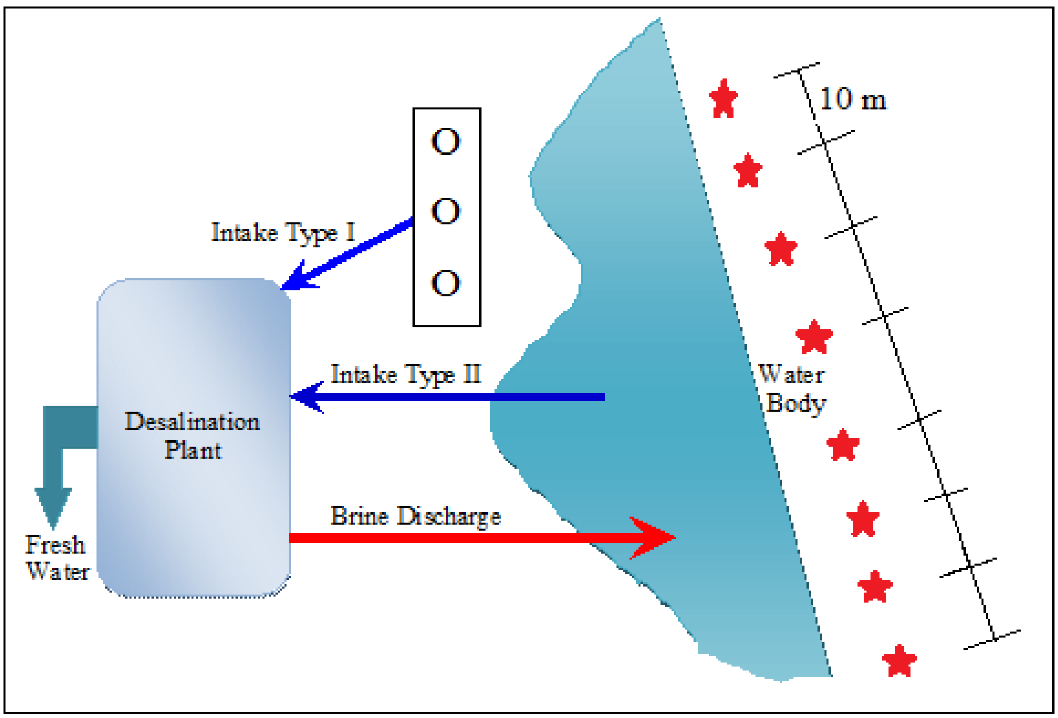


**Fig. 2. Typical desalination plant, intakes, brine discharge and water body diagram**

### 3.1. Desalination and raw water

There are three types of desalination methods used throughout the world for a wide range of purposes, but mainly for potable water production for domestic and municipal use, 1) Membrane Systems: Reverse osmosis (RO) or Electro dialysis and Electro dialysis Reversal (ED), 2) Thermal Processes (TP): Multi-Stage Flash Distillation (MSF) Multiple-Effect Distillation (MED), and Vapor Compression (VC), and 3) Other Desalination Processes: Different types of water can be desalinated through many other processes including small-scale ion-exchange resins, freezing, and membrane distillation (MD)

[17]. For this reason we have to measure all types of desalination technology brine discharge to be able to distinguish and compare them.

The MSF and RO processes dominate the market for both seawater and brackish water desalination, sharing about 86% of the total installed capacity [1]. The distribution of different technology for more than 20 years is presented in Figure 3, and it shows that installed capacity of RO processes increased significantly, while MSF declined steadily, since it cost more energy. Before 2001, there is no or little installed capacity of hybrid, but it increased to 4% in 2015. Nowadays, the RO alone is the main deriving for desalination technology, which mainly because RO has advantages over other technologies. After nearly 40 years development, RO desalination technology is already quite mature. Salt reduction with RO is higher than 99.3%, with the permeable flux, the range of available operating pressure, anti-pollution and anti-oxidation capacity continually increasing. In addition, RO also has smaller investment, less energy consumption, lower cost, and short construction period. After the treatment of RO, water can achieve the WHO standards for drinking water. This makes RO to be the most competitive method of seawater and brackish water desalination [18].

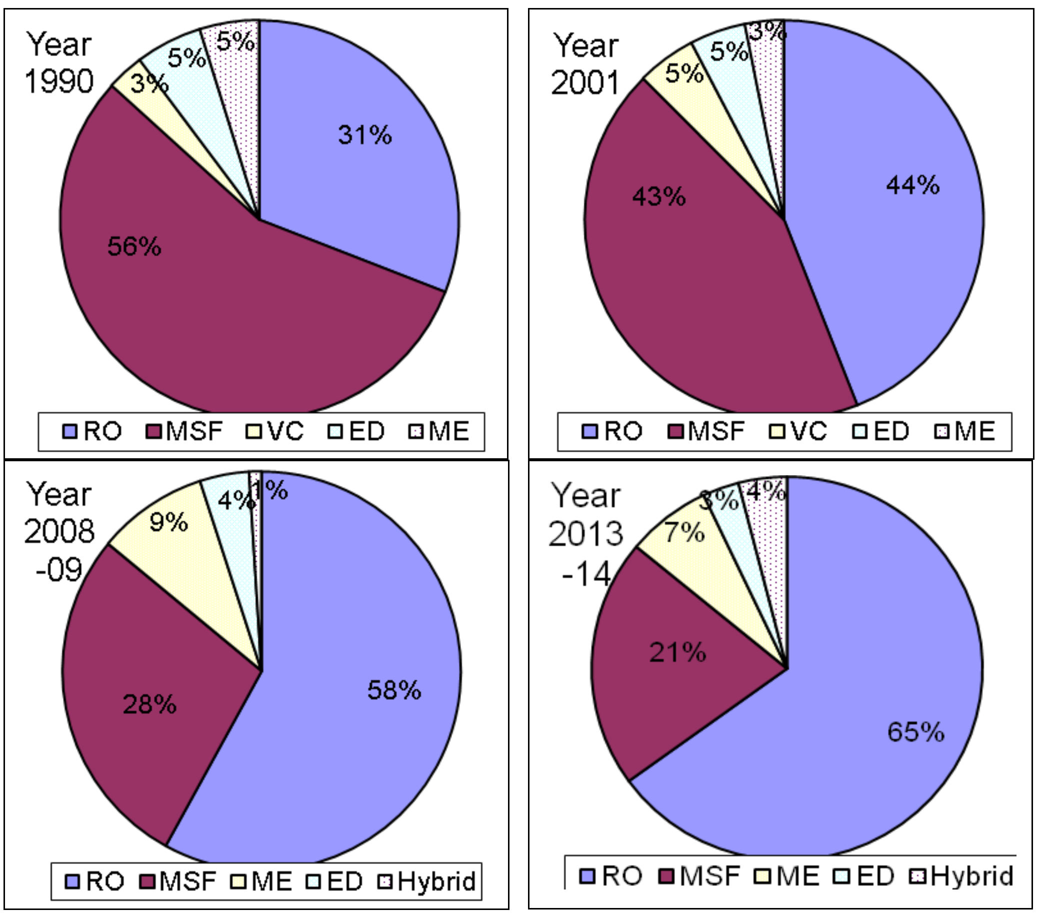


**Fig. 3. Global distributions of technologies from year 1990 to in 2014-15 [1,3,19]**

Ninety –seven percent of the earth's water is found in the ocean, with a salt content of more than 30,000 mg/L. Water, with a dissolved solids (salt) content below about 1000 mg/L, is considered acceptable for a community water supply [20]. The concept of desalination refers to a wide range of processes designed to remove salts from waters of different salinities as collected from different areas. All major water sources can be utilized as raw water supply for desalination, except the Dead Sea and similar concentration as considered as one of the saltiest place on earth. Salinity of the raw water affects the efficiency and the economy of the desalination plants: the more saline raw water sources, the costlier are the production. As an example the salt concentration in the Persian/Arabian Gulf at the Arabian coast is always higher than the Red Sea and the Mediterranean Sea which cost more to desalinate.

Global distributions of fresh water production by different feed water types (raw water) are shown in Figure 4. There is no significant change in the distribution for more than 20 years, started 1990 until today. Seawater and brackish are main water sources. Wastewater should be more important, but in 2009 only 5% of all raw waters have their direct origin from wastewater system. The potential in reusing wastewater is thus very large since it is a stable and considerable source with relatively low salinity.

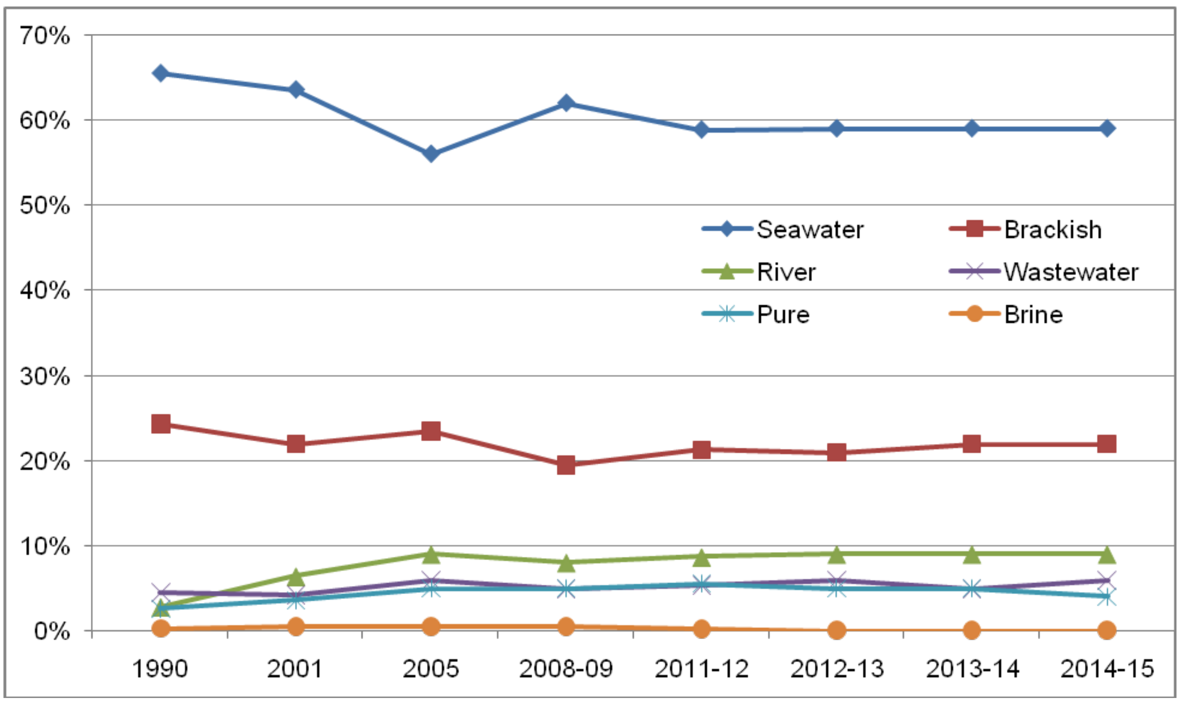


**Fig. 4. Global distributions of feed water from year 1990 to in 2014-15 [1,3,19]**

The specific energy need for desalination of seawater reverse osmosis (SWRO) has decreased with the development of energy reuse systems. One cubic meter of desalinated water consumes 3.7 kwh of energy, mainly electricity [21]. According to associated document [5], desalination system is divided into two categories 1) conventional source of energy (gas,oil,electricity) and 2) renewable energy sources (wind solar, etc.). Also it can be seen that the desalination relies heavily on fossil fuels (conventional energy), because the cost of fresh water produced from desalination using conventional energy is much lower at present.

## IV. DISCUSSIONS AND RECOMMENDATIONS

The direct measurement and control of the brine discharge is considered as the first priority to be handled and discussed in this part. In desalination, high-salinity brine is produced that needs to be discharged into a receiving water body with a minimum impact. Nowadays, brine discharge from desalination plants is the concern of all countries producing fresh water from desalination with different technologies. The brine is typically discharged as a turbulent jet [22] with an initial density that is significantly higher (salinity 4%–5%) than the density of the receiving water (ambient e.g. seawater). Thus, a rapid mixing of the discharged brine is desirable to ensure minimum impact, which requires detailed knowledge of the jet development. Since the density of the jet is greater than the density of the receiving water, the jet is negatively buoyant and it will impinge on the bottom some distance from the discharge point depending on the initial momentum, buoyancy, and angle of the discharge, as well as the bathymetric conditions.

The water intake to most of the world's desalination plants is located close to where the brine is discharged. Some chemicals and other parameters have to be considered as a function of the brine discharge from desalination plants to assist people from environmental problems, e.g. fishing problems could increase in the future. In this study, the measurement priority will be given to the most important chemicals in the brine discharge from the desalination plant that can be harmful for the receiving. Some of the analytical results from the beginning of the study period are presented in Table 1 (Ca, Mg, Cl, $SO_4$, Na, pH, K, Electrical Conductivity, Alkalinity, and TDS).

Table 1 presents the expected measurements for all required chemicals during full-capacity brine discharge in order to compare these measurement with the standard receiving water concentration in which this will be done with respect to time. As seen in (Figure 2), the measurement locations are appointed previously in fixed places with the measuring instrument. The sampling locations were assigned with respect to an x and y axis; x is the location of each point towards seawater and perpendicular to the coastline and y is the location assigned parallel to the coastline. In the first parallel measuring line number one point ($M_{0m}$) was located directly in front of the outlet at the middle of the line (open channel or pipe outlet system) with the purpose of determining the initial concentration of the brine discharge.

At the y-axis will measure eight locations at the first line with four points to the left and four points to the right of the middle point separated with a distance of 10m between each point. The four to the left hand side were denoted ($L_{10}$, $L_{20}$, $L_{30}$ and $L_{40}$), on the right hand side ($R_{10}$, $R_{20}$, $R_{30}$ and $R_{40}$). Considering the small variation of the receiving concentration we have to fix all measuring point locations at the same depth inside the receiving water.

In general, the higher concentrations will always be shown closer to the outlet, whereas they are quite uniformly distribution in the rest of the study area. Thus, in previous studies it was observed that the total concentration of the effluent takes place over a short distance which could be explained by the initial dilution of the brine discharge before and after the desalination plant using the seawater for intake and return [23]. It is also kind of observation for the chemical concentration mixing behaviour after the brine being released from the outfall with higher concentrations around the outlet with distance of about 10m away from the outlet.

It was also found that the effect of the desalination plant in the Arabian Gulf from the brine discharge in 1996 is equivalent to the peak salinity increased by 0.42 ppt, in 2008 increased by 0.93 ppt, and in 2050 by 2.24 ppt [24]. This increase in concentration is a result of high amount of brine discharge towards the Gulf that is high enough to be worried about the whole Gulf and the desalination countries at the Arabian coastline of the Gulf e.g. KSA, UAE, Kuwait, Bahrain and Qatar.

**Table 3: Sample Measurement of Different Parameters in Different Locations**

| Sample Name Line 1 | Coordinates | | Concentrations, ppm | | | | | | El. Cond. μS/cm |
|---|---|---|---|---|---|---|---|---|---|
| | X (m) | Y (m) | TDS | Ca | Mg | Cl | Na | $SO_4$ | EC |
| $M_{0m}$ | 0 | 0 | | | | | | | |
| $R_{10}$ | 0 | 10 | | | | | | | |
| $R_{20}$ | 0 | 20 | | | | | | | |
| $R_{30}$ | 0 | 30 | | | | | | | |
| $R_{40}$ | 0 | 40 | | | | | | | |
| $L_{10}$ | 0 | 10 | | | | | | | |
| $L_{20}$ | 0 | 20 | | | | | | | |
| $L_{30}$ | 0 | 30 | | | | | | | |
| $L_{40}$ | 0 | 40 | | | | | | | |

## V. CONCLUSIONS

The purpose of this study is concerning about the brine discharge from desalination plants existing and contracted projects. The safety of the receiving water such as the Persian/Arabian Gulf is important for the desalination future in order to build more and more plants due to shortage of fresh water in the Gulfs countries. In order to be able to determine the properties of different brine discharges concentration with regard to the safety of the recipient to be as clean as possible we have to establish some rules and regulations controlling the brine discharge such as new measurements technique.

Considering the improvement in desalination technology, attention must be given to evaluate desalination from environmental, technical, and economical perspective. The two-dimensional spatial distributions of various chemicals have to be drawn from this measurement technique. After recording the measurement with the help of 2-D drawing we can avoid the increment of the concentration by having some other solution from previous studies. For example, we have to control the brine discharge if the TDS value has 0.5ppt (g/l) higher than that normal receiving water (Gulf) and so on for the rest of the measurements.

In this work we have discussed the possible environmental impacts associated with the discharge of brine from a desalination plant that can be minimized by means of planning more outlets or longer pipelines towards the sea. Changing the direction of the brine discharge could also minimize the impact on the coastline and other solutions such as multiport discharge or/and multi open channel flow with the changing of flow direction over time

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