Design of Liquid-Solid Separation System for Desalination of Seawater via Distillation

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ABSTRACT

Design of Liquid Solid Separation System for Desalination of Seawater via Distillation

Senior project submitted to the Department of Chemical Engineering

Water covers 71% of the Earth's area, making it one of the most abundant natural resources by volume. However, over 97% of the Earth's water can be found in the oceans. Ocean water is brackish, meaning it contains many minerals such as salt and is hence known as saltwater. A mere 2.78% of the world's water exists as freshwater, which can be used by humans, animals, and for agriculture. The abundance of saltwater versus the scarcity of freshwater is a global water resource problem that humans are working to solve.

The salinity of sea water is due to its containing a variety of dissolved ionic compounds. In summary, we have designed the separation system where we have performed the salt separation from the seawater through self designed distillation technique. We used anti-bumping granules to avoid bumping of residue while water level has been reduced to minimum level. The process produced enough solid residues to analyze its properties. The desalination results showed that the total salt content in obtained samples was little bit lower as compared to other high salinated oceans around the world. The results were analyzed through PH, solution test as well as by measuring the density through hydrometer. The higher density of seawater sample was reduced once the distillate was collected and analyzed with least density as compared to starting materials. The process was followed with the conductivity analysis of the samples before and after the treatment. In particular the salt content of the treated samples was calculated with equation with different water quantity parameters as used in our study. Finally the results were what we had expected from our study. The systematic study of our experimental findings suggested the same high salinity of the local sea water, which approached more that 3% and with varied compositions.
الملخص

تصميم نظام فصل السائل الصلبة ل تحلية مياه البحر عن طريق التقطير

مشروع كبير تقدم إلى قسم الهندسة الكيميائية

تحتوي المياه المالحة على العديد من العناصر مثل الملح و الماء المالح، والتي يمكن استخدامها من قبل البشر، الحيوانات، والزراعة. وفرة من المياه المالحة مقابل ندرة المياه العذبة مشكلة الموارد المائية العالمية. أن البشر يعملون على حلها.

كما تم اقتراح دراسة منهجية للتقطير التجريبية لدينا نفس الملوحة العالمية للبحيرة البحرية، والذي أقرب أكثر من 3% مع الشرائح المتباينة.

من المقرر أن تحتوي على مجموعة متنوعة من المركبات الأيونية المنحل ملوحة مياه البحر. باختصار،

١٧٤ من المساحة الأرضية، مما يجعلها واحدة من الموارد الطبيعية الأكثر وفرة من حيث الحجم. ومع ذلك، أكثر من ١٧٪ من مياه الأرض يمكن العثور عليه في المحيطات. مياه المحيطات المالحة هو، وهذا يعني أنه يحتوي على العديد من المعادن مثل الملح، وبالتالي يعرف باسم المياه المالحة. و مجرد ٢٥٪ من المياه في العالم كما هو معمول به في المياه العذبة، والتي يمكن استخدامها من قبل البشر، والحيوانات، والزراعة. وفرة من المياه المالحة مقابل ندرة المياه العذبة مشكلة الموارد المائية العالمية.

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في جميع أنحاء العالم. وقد تم تحليل النتائج من خلال PH، واختبار الحل وكذلك عن طريق قياس كثافة من خلال قياس تقليل السائل النوري. تم تخفيض كثافة أعلى من عينة مياه البحر مرة واحدة جمعت نوائح التقطير وتحليلها مع أقل كثافة بالمقارنة مع المواد الأولية. وأعقب هذه العملية مع تحليل الموصلية من العينات قبل وبعد العلاج. على وجه الخصوص تم حساب محتوى الملح من العينات تعامل مع المعادلة مع مختلف المعلمات كمية المياه المستخدمة في دراستنا. أخيرا كانت النتائج ما كنا نتوقعه من الدراسة لدينا.
DEDICATION

To my Parents, who, through their financial and moral support were the source of inspiration and the mainstay in my attaining an education, I dedicate this project.
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In the name of Allah, the creator of all creations, all praises due to Him, the most beneficent and merciful. Alhamdulillah, I had completed this work successfully. So I would to thank all those who helped me during this period.

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CHAPTER (1)

1 INTRODUCTION

1.1 Literature review

The large scale production of drinking water from the sea started with the advancement of desalination technologies in the mid-20th century. Today, many countries of the Middle East depend heavily on desalinated water, and many other countries, which so far relied on conventional water supplies, turn to desalination in order to develop and diversify their water supply options in the face of economic and demographic growth, urbanization and climate change. As many of the world’s freshwater reserves are being depleted [1], seawater is often proclaimed as the only truly unlimited water resource.

This is true in so far as 97% of the world’s water is stored in the oceans, and only an infinitesimal small amount of water is removed by desalination processes compared to natural evaporation. A major constraint rather lies in the waste water discharges of desalination plants and their local ecosystem impacts. Many coastal ecosystems and regional seas are already under stress from other anthropogenic activities including land reclamation and habitat degradation, fisheries and maritime shipping, eutrophication and land-based pollution. Desalination is listed among the main sources of land-based pollution in the Gulf and Red Sea areas according to the UNEP regional seas reports [2, 3] and is on the verge of becoming a new coastal-based industry in other parts of the world.

As the need for desalination accelerates and spreads to new markets, it is realized in many parts of the world that a balance between water supply through desalination development and environmental protection must be maintained. While some people portray desalination as the panacea for much of the world’s water woes, others perceive it very negatively, and it remains
even more necessary to gain an objective understanding of the real stakes in desalination within the context of integrated water resource management [4]. Environmental research needs to be emphasized up front [5] and should lead to sustainable development, otherwise the desalination boom is in danger of shifting the problem from water to energy [6], and from the freshwater to the marine ecosystems [7].

Sea- and brackish ground water are the single most important sources of drinking water in a few water-scarce but oil-rich countries of the Middle East which depend heavily on desalination, such as Kuwait or the United Arab Emirates. Many industrialized and developing regions, however, have recently also started to use desalination as a way to supplement and diversify their water supply options. Desalinated water has become a commodity for these countries in order to satisfy their growing demand for water.

For the ‘pioneering’ countries, the driving factors were often a lack of surface waters and groundwater coupled with sufficient natural or financial resources to engage in energy-intensive and costly desalination projects. For the newly emerging desalination markets, driving factors are more diverse and include economic and demographic growth, urbanization, droughts and climate change, or declining conventional water resources in terms of quality and quantity due to overuse, pollution or salinisation. Moreover, as conventional water production costs have been rising in many parts of the world and the costs of desalination - particularly seawater desalination - have been declining over the years, desalination has also become economically more competitive.

The selection of the desalination process is typically based on different operational parameters such as the availability of a raw water or energy source (e.g., seawater vs. brackish water or low-cost heat vs. electricity), the product water demand, intended use and product water quality.
specifications (industrial vs. municipal use), or the technical know-how, capacity and costs to build, maintain and operate the plant [19].

This chapter gives a short account of the historical development of desalination technologies, an overview on the presently installed worldwide desalination capacity, distinguishing between different raw water sources, processes and use types. It furthermore discusses regional and future trends, and driving factors such as cost and energy demand. The main objective of this chapter is to set the stage for the following chapters on environmental impacts, by illustrating that desalination is at the brink of becoming a global coastal industry.

1.1.1 Historical development

The extraction of salt from salty water by means of natural evaporation has been practiced for a long time, dating from the time when salt, not water, was the precious commodity [20]. Advanced technologies that mimic natural processes such as evaporation or osmosis in order to extract the water have only been developed in modern times. Basic desalting processes were first used on naval ships in the 17th to 19th century. The island of Curacao in the Netherlands Antilles was the first location to make a major commitment to desalination in 1928, followed by a major seawater desalination plant built in what is now Saudi Arabia in 1938 [5, 20].

Many of the early projects focused on thermal processes. Significant work was completed on construction materials, heat transfer surfaces and corrosion, which was instrumental in assisting the design and construction of the first large distillation systems in the Middle East [5]. The multi-effect distillation (MED) process has been used in industry for a long time, traditionally for the production of sugar and salt. Some of the early distillation plants also used the MED process, however, the multi-stage flash (MSF) process that was developed in the 1950s continually displaced the MED process due to a higher resistance against scaling. A revived interest in MED
can be observed since the 1980s due to a lower operating temperature and energy demand of the process [21].

During the late 1950s, the first asymmetric membrane for desalination was developed by Loeb and Sourirajan, which consisted of cellulose acetate polymer [22]. The electrodialysis (ED) process, which was commercially introduced in the early 1960s, moves salts selectively through a membrane driven by an electrical potential. It was the first cost-effective way to desalt brackish water and spurred a considerable interest in using desalting technologies for municipal water supply, especially in the United States. ED is exclusively applied to low brackish and fresh water desalination, since the energy consumption for seawater treatment would be far too high. Other milestones included the commercialization of reverse osmosis (RO), a pressure-driven membrane process, in the early 1970s [21], followed by the development of a more robust composite aromatic polyamide spiral wound membrane in the 1980s [22].

A wide variety of membrane materials and module configurations have been developed over the years, including hollow fine fibers from cellulosic or non-cellulosic materials, but spiral wound composite polyamide membranes are almost exclusively used today. While cellulose acetate membranes had a specific permeate flux of 0.5 l m\(^2\)/h/bar and a salt rejection of 98.8% in the 1970s, the latest polyamide seawater membranes have a specific flux of more than 1.2 l m\(^2\)/h/bar and a salt rejection of 99.8%. The improvement in specific flux translates into a significant reduction of the specific energy demand of the RO process [22]. Another significant power and cost reduction stems from the development of energy recovery devices, which reduced the total energy demand of seawater RO to 3-4 kWh per m\(^3\) of permeate water using state of the art technology.
To conclude, it took about 50 years from the first land-based distillation plants to a fully
developed industry in the 1980s. By the 1990s, the use of desalting technologies for municipal
water supplies had become commonplace [21]. Today, municipalities are the main end users of
desalinated water and the market continues to grow exponentially, with a doubling of the
installed capacity expected from 2006 to 2015.

1.1.2 Globally installed desalination capacity
The worldwide installed desalination capacity is increasing at a rapid pace. The 20\textsuperscript{th} IDA
Worldwide Desalting Plant Inventory [24] indicates that the production capacity of all
desalination plants worldwide was around 44.1 million cubic meters per day (Mm\textsuperscript{3}/d) by the year
2007. The inventory lists facilities that treat seawater, brine, brackish, river, waste or pure water,
which are either in construction, online or presumed online. The data of the inventory has been
analyzed and interpreted with the following results. Projected growth of the desalination market.
The worldwide installed desalination capacity grew at a compound average rate of 12\% a year
over the past five years, and the rate of capacity growth is expected to increase even further.
Based upon country-by-country analyses involving desalination projects and official data on
water supply and demand from agencies around the world, it is projected that the installed
capacity may more than double to 98 Mm\textsuperscript{3}/d by 2015 [25].

1.1.2.1 Global capacity by source water type
Much of the expected growth of the desalination market will take place in the seawater sector,
although brackish water and wastewater desalination processes will presumably also become
more important in the future. In some regions, such as California and Israel, waste water
exploitation even preceded seawater desalination. 5\% of the present capacity of 44.1 Mm\textsuperscript{3}/d is
produced from waste water, 19\% from brackish water and 63\% from seawater sources (Figure
Desalination of seawater is hence the dominant desalination process and accounts for a worldwide water production of almost 27.9 Mm$^3$/d, which is comparable to the average discharge of the Seine River at Paris (28.3 Mm$^3$/d).

A limited number of plants are being located in estuarine sites, such as the Thames Gateway desalination plant in East London with a capacity of 150,000 m$^3$/d. The plant withdraws brackish water with a maximum salt content of 11,000 mg/l during low tide and therefore requires only about half the energy (1.7 kWh/m$^3$) of seawater RO plants. However, the tidal and seasonal variability of the raw water with regard to dissolved and particulate organic matter requires a complex pretreatment consisting of coagulation, flocculation, clarification, media filtration and ultrafiltration [26, 27]. The lower energy demand is a main benefit of estuarine sites, however, the pretreatment challenge may be the reason why only a limited number of projects have been implemented to date.

![Figure 1.1: Global desalination capacity (in Mm$^3$/d and %) by source water type](image)

Figure 1.1: Global desalination capacity (in Mm$^3$/d and %) by source water type
1.2 Problem Statement

The increases in desalination activity in many sea regions and the growing number of industrial-sized facilities raise concerns over potential negative impacts of the technology on the environment. Environmental impact assessment (EIA) studies are widely recognized and accepted as a suitable approach for identifying, evaluating and mitigating the wide range of potential impacts of new development project on the environment. However, an “internationally agreed environmental assessment methodology for desalination plants does not exist so far and its development would be desirable” [Manuel Schiffer, The World Bank, 4]. Another problem is that there is still “a considerable amount of uncertainty about the environmental impacts of desalination and, consequently, concern over its potential effects” [U.S. National Research Council, 5].

Both, a structured EIA methodology and a basic understanding of the environmental impacts is necessary for a successful EIA process. A range of manuals are available that offer guidance on the EIA process in general, but it is beyond the scope of these documents to cover all the necessary details that are required to carry out an EIA for a specific project in practice. Moreover, difficulties may be experienced in handling the large amounts of complex information that are typically generated by EIA studies in a consistent way for decision making, especially when different project alternatives need to be compared. The development of a systematic EIA methodology and decision support system (DSS) is desirable in order to facilitate the process of impact assessment and decision making for desalination projects in the future.

The first step towards a better understanding of the environmental effects is to systematically document the existing knowledge, followed by further research in the field and laboratory, and a meta-analysis of the effects. Although the number of publications discussing the potential for
negative environmental impacts of effluents from desalination facilities has been steadily increasing over the last years, a surprising paucity of useful experimental data, either from laboratory tests or from field monitoring still exists [5]. To facilitate studies on potential biological or ecological effects at the project level, and thereby improve understanding at the meta level, guidance on field and laboratory studies is needed, such as monitoring and assessment protocols.
CHAPTER 2
DESIGN APPROACH AND METHODOLOGY

2.1. Design Approach

The primary goals of our study are to provide information on the environmental consequences of a project for decision making, and to promote environmentally sound and sustainable development through the identification of appropriate alternatives and mitigation measures. Our goals are usually not limited to environmental aspects, but where appropriate also address public health and socio-economic concerns by providing alternative techniques to address the water problem. As a result, techniques are often multi-stage, multi-disciplinary, and multi-participatory processes. A four step process for desalination projects through distillation has been proposed in this Project. The pre- or initial phase includes the steps of screening and scoping of the project, in which a decision is taken on whether or not an implementation is required for a particular project, and in which the scope, contents and methodologies of the experiment and expert studies are specified in the terms of reference.

The following are the series of steps in a simple distillation set-up. This is one good way to set up a distillation. If you observed seasoned organic chemists in the lab, they would each set it up in a slightly different manner. This series of steps is designed for the best distillation results, to get you started in a logical and safe manner. The Figure 2.1 shows the assembled distillation setup for the desalination process.

Begin with a round-bottom flask. This is one of the most critical pieces of glassware in the assembly, since it will hold the liquid to be distilled. You don't want it to fall and break because you would lose your compound and possibly spill a hazardous chemical. To secure your setup, you will need a small three-pronged clamp, two ring stands, and a ring clamp. Place the ring
clamp and three-pronged clamp on the ring stand. The ring clamp goes on the bottom and will
hold the heat source, either a steam bath (no longer used in the organic labs) or a heating mantle.
Secure the round-bottom flask to the ring stand using the three-pronged clamp. The next item to
be added is the Y-adaptor. The Y-adaptor sits on top of the round-bottom flask. The next item to
be added, the condenser, will secure the Y-adaptor to the system. You will also need a Keck
clip and a versatile. Connect the condenser to the Y-adaptor and secure the connection with a
Keck clip. Secure the condenser to the ring stand with a versatile clamp. The next items you will
need are a vacuum adaptor and another Keck clip.
Connect the vacuum adaptor to the condenser and secure the connection with a Keck clip. Add a
couple of boiling chips to the round-bottom flask by dropping them down through the Y-adaptor.
Place a stemmed funnel into the top of the Y-adaptor and pour the liquid to be distilled through it
so that it goes into the round bottom flask. The flask should be between 1/2 full and 2/3 full.
When done, remove the funnel. This picture is only different from the last in that an Erlenmeyer
flask has been placed under the vacuum adaptor. This is the receiving flask. A beaker, vial or graduated cylinder could also be used. In a vacuum distillation, a round bottom flask is used as the receiving flask, and it is securely attached with either a clamp or a yellow clip. The next items to be added are the thermometer adaptor and thermometer. The thermometer is always added last because it is large and susceptible to breakage.
Here is all the glassware properly assembled. The thermometer and thermometer adaptor are
connected on top of the Y-adaptor. Note the correct placement of the thermometer - this is vital
for correct measurement of boiling point. The collection flask has been temporarily removed to
protect it during the addition of the heat source, which could cause an unsecured flask to fall and
break. Collect two pieces of Tygon tubing for the condenser. If you are using a steam bath for the
heat source, you will need four lengths. Place the heat source on the ring under the round-bottom flask. Adjust the height of the apparatus as necessary. Connect two pieces of Tygon tubing to the condenser. The tubing to the lower connection goes to the water source, the upper connection goes to the drain. Remember, in through the bottom, out through the top. If you are using a steam bath, connect it to two pieces of Tygon tubing: one to the lower and one to the upper connection. The tubing at the upper connection goes to the steam source; the lower one goes to the drain. Make sure all of the glass and tubing joints are tight before turning on the cooling water and the steam. Begin heating the round-bottom flask carefully.

Figure 2.1: An assembled Distillation setup for the desalination of sea water
2-2 Design Methodology

2.2.1 Requirements:

*Things that are needed for the experiments*

- Salt
- Beakers
- Pipette
- Petri dish
- Graduated cylinder
- Deionized water
- Thermometer
- Dropper
- Burette
- Stirrer

- AgNO₃ solution (50 gm of AgNO₃ dissolved in 1000mL of deionized water)
- K₂CrO₄ solution (3.5gm of K₂CrO₄ dissolved in1000mL of deionized water)

2.2.2. Experimental

2.2.2.1. Distillation

(1) Set up the distillation apparatus as described previously and shown in Figure 2.1. Have a demonstrator check it before you start the distillation.

(2) Pour 75 mL of salt water or deionised water into a 100 mL round-bottomed flask and add 3 anti-bumping granules to encourage smooth boiling.
(3) Place a clean dry 100 mL conical flask under the end of the delivery tube and begin heating the flask with a heating mantle. Heat the flask until you have collected about 60 mL of water at a rate of about 2 drops per second. Record the temperature of the boiling water vapour.

(4) Turn off the heating mantle and allow the flask to cool.

(5) Save the distillate (i.e. the liquid that has distilled over) in the 100 mL conical flask for a later part of the experiment. Seal it with plastic wrap and label the flask with its contents and your names.

2.2.2.2. Determination of the salt concentration in salt water

(1) Weigh a clean 250 mL beaker containing another 3 fresh anti-bumping granules and covered with an 8 cm watch glass.

(2) Pour approximately 30 mL of salt water into the beaker. Reweigh the beaker with the granules, watch glass and now including the water. Calculate the mass of salt water.

(3) Put the beaker on a stirrer hotplate and heat to boiling point. Maintain the correct setting to promote steady boiling. When the volume has been reduced to about 70 %, place the watch glass partially over the beaker to prevent splashing and continue to heat the beaker until all the water has just evaporated.

(4) Carefully remove the beaker using metal tongs and place on a fibre glass mat to cool.

(5) Allow the beaker to cool and then weigh the beaker and its contents along with the watch glass.

2.2.2.3. Density of salt water

(1) Measured the densities of deionised water and salt water using the hydrometers in the fume hood. The Figure 2.2 below shows the measurement of different salinity water samples.
2.2.2.4. Conductivity of distilled water compared with salt solutions

To investigate the conductivity of a liquid, a voltage is applied across it. A small light globe included in the circuit glows if a current flows, and the brightness of the globe gives a qualitative assessment of the degree of conductivity of the liquid. If there is no conduction, the globe doesn’t glow.

(1) Place about 50 mL of the distillate you obtained from the distillation of sea water in a clean, dry beaker. Set up a circuit as shown in Figure 2.3, with the probe electrodes placed in the water in the beaker. Switch the current on and check for an indication of conduction. Record your observations in your logbook. Don’t discard the distillate. You’ll need it again latter in the experiment.

(2) Repeat the same procedure using salt water instead of distilled water. Again record your observations, noting in particular any differences between the behavior you observed for the distilled water.

(3) Repeat the same procedure again with a solution made by dissolving a spatulaful of sodium chloride in 50 mL of deionised water.

(4) Repeat the procedure once more on a solution made by dissolving a spatulaful of sucrose (sugar) in 50 mL of deionised water.
2.2.2.4. Electrolysis of distilled water

(1) Mix 50 mL of the distillate you obtained from above part with 5 mL of 5 M H₂SO₄.

(2) Place the solution in the electrolysis unit (Figure 2.4). Bend the rubber tubing over on the top of each arm of the electrolysis unit and clamp it to avoid gas escaping.

(3) Connect the power to the electrodes. When you have collected at least 2 cm of gas in each arm, disconnect the power from the electrodes.

(4) Estimate the relative volumes of gas at each electrode.

(5) Test the gas at the cathode by placing an inverted test-tube over the end of the cathode outlet tube and releasing the gas into the test-tube. Light a long thin candle and then hold it under the mouth of the still-inverted test-tube.

(6) Reconnect the power and continue the electrolysis until the gas from the anode fills the collection chamber. Disconnect the power from the electrodes.

(7) Light a long thin candle with a match and then blow it out so that there are still some embers glowing. Immediately hold it near the rubber tube at the top of the anode chamber. Release the
gas from the chamber (without allowing the solution to flow out) so that it passes over the embers.

Figure 2.4. An electrolysis setup for the measurement of electrolysis of distilled water obtain after the desalination process.
CHAPTER 3
THEORETICAL BACKGROUND

The large scale production of drinking water from the sea started with the advancement of desalination technologies in the mid-20th century. Today, many countries of the Middle East depend heavily on desalinated water, and many other countries, which so far relied on conventional water supplies, turn to desalination in order to develop and diversify their water supply options in the face of economic and demographic growth, urbanization and climate change. As many of the world’s freshwater reserves are being depleted [1], seawater is often proclaimed as the only truly unlimited water resource.

This is true in so far as 97% of the world’s water is stored in the oceans, and only an infinitesimal small amount of water is removed by desalination processes compared to natural evaporation. A major constraint rather lies in the waste water discharges of desalination plants and their local ecosystem impacts. Many coastal ecosystems and regional seas are already under stress from other anthropogenic activities including land reclamation and habitat degradation, fisheries and maritime shipping, eutrophication and land-based pollution. Desalination is listed among the main sources of land-based pollution in the Gulf and Red Sea areas according to the UNEP regional seas reports [2,3] and is on the verge of becoming a new coastal-based industry in other parts of the world.

3.1. Design Specification and assumption

As the need for desalination accelerates and spreads to new markets, it is realized in many parts of the world that a balance between water supply through desalination development and environmental protection must be maintained. While some people portray desalination as the panacea for much of the world’s water woes, others perceive it very negatively, and it remains
even more necessary to gain an objective understanding of the real stakes in desalination within the context of integrated water resource management [4]. Environmental research needs to be emphasized up front [5] and should lead to sustainable development, otherwise the desalination boom is in danger of shifting the problem from water to energy [6], and from the freshwater to the marine ecosystems [7].

Sea- and brackish ground water are the single most important sources of drinking water in a few water-scarce but oil-rich countries of the Middle East which depend heavily on desalination, such as Kuwait or the United Arab Emirates. Many industrialized and developing regions, however, have recently also started to use desalination as a way to supplement and diversify their water supply options. Desalinated water has become a commodity for these countries in order to satisfy their growing demand for water.

For the ‘pioneering’ countries, the driving factors were often a lack of surface waters and groundwater coupled with sufficient natural or financial resources to engage in energy-intensive and costly desalination projects. For the newly emerging desalination markets, driving factors are more diverse and include economic and demographic growth, urbanization, droughts and climate change, or declining conventional water resources in terms of quality and quantity due to overuse, pollution or salinisation. Moreover, as conventional water production costs have been rising in many parts of the world and the costs of desalination - particularly seawater desalination - have been declining over the years, desalination has also become economically more competitive.

The selection of the desalination process is typically based on different operational parameters such as the availability of a raw water or energy source (e.g., seawater vs. brackish water or low-cost heat vs. electricity), the product water demand, intended use and product water quality.
specifications (industrial vs. municipal use), or the technical know-how, capacity and costs to build, maintain and operate the plant [19].

3.1.1. Measurement of Salinity by Various Experimental Methods

Salinity is a measure of the total dissolved salts in seawater. This sounds simple enough, but measuring salinity becomes a problem when we realize that some of the salts do not simply dissociate into ions but chemically react with water to form complex ions, and some of the ions include dissolved gases such as CO$_2$ (which converts to carbonic acid, H$_2$CO$_3$, bicarbonate, HCO$_3^-$, and carbonate, CO$_3^{2-}$).

Duxbury (1971) defines salinity as:

"The total amount in grams of solid material dissolved in 1 kilogram of seawater when all the carbonate has been converted to oxide, all of the iodine and bromine have been replaced by chlorine, and all the organic matter has been completely oxidized."

For this laboratory we will use a simpler definition: The total amount in grams of solid material dissolved in 1 kg of seawater.

Normally, salinity is expressed in parts per thousand (ppt), often written as º/₀₀. It is also sometimes abbreviated as per mil, much the same as parts per hundred is abbreviated as percent (%). For example, if you had 1000 g of seawater that contained 35 grams of dissolved salt, you would have a 3.5% salt solution or a salinity of 35 parts per 1000 (35º/₀₀).

\[
\text{percent solution: } \frac{35\text{ grams salt}}{1000\text{ grams } H_2O} \times 100\% = 3.5\%
\]

\[
\text{per mil solution: } \frac{35\text{ grams salt}}{1000\text{ grams } H_2O} \times 1000\text{‰} = 35\text{‰}
\]

\(\Rightarrow (1)\)

In this laboratory our salt water is the seawater from the outskirts of Jazan city. We only have two elements of the 11 commonly found in seawater (and the dozens that are present in trace
amounts); however, the methodologies we use here will work for natural seawater as well as for our artificial seawater.

**Why is the sea salty? Why do we care?**

The salt in the ocean comes primarily from the weathering of rocks on land. When rocks are exposed at the surface of the Earth, minerals are weathered chemically to produce various solid compounds as well as free ions such as calcium (\(\text{Ca}^{2+}\)), potassium (\(\text{K}^+\)), and sodium (\(\text{Na}^+\)). Volcanic eruptions produce \(\text{CO}_2\), hydrochloric acid (HCl), and sulfur dioxide (SO\(_2\)), all of which are soluble in water. These solutes are brought to the ocean by precipitation and by river transport. Evaporation of water concentrates these materials, bringing the salinity of the oceans well above the salinity found in rivers and lakes. Some materials (such as calcium and potassium) are gradually removed from the ocean by organisms that use them as nutrients. Other materials are lost through sediment interactions: the sediments at the ocean’s bottom behave much like a water filter, adsorbing various ions associated with salinity and locking them away.

These processes of adding salt to the oceans, concentrating it through evaporation, and removing it through various chemical and biochemical processes, have been active on Earth for billions of years; the average salinity of the ocean is therefore a function of the rates of these various processes, and has changed little through Earth’s history. The water's salt content is one of the primary reasons that study of the ocean is different from the study of fresh water lakes (known as limnology).

Water circulation is also affected by salinity. In estuaries, fresh water can "float" on saltier, denser ocean water and even set up a current pattern which is based on the difference in density between the two water types. In the deep ocean, high salinity water is often the densest and will sink and flow along the ocean floor under the influence of gravity. Physical oceanographers, by
knowing the salinity and temperature fields of the ocean, can make predictions about the velocity and direction of these density-driven currents.

### 3.1.2. Measuring Salinity

In this laboratory we will investigate five analytical methods for determining salinity. Some methods are straightforward and some are complicated, some are simple but imprecise and some are difficult but precise. As you perform these tests, pay particular attention to the results – the different methods produce different levels of precision and accuracy, since the components of salinity vary in their effects on the different measurement techniques. Care in your technique should produce repeatable results, but do not expect that each technique will produce exactly the same numbers.

Methods of salinity determination:

- Evaporation of seawater
- Conductivity of seawater
- Measurement of water density by hydrometer
- Refraction of light through seawater
- Titration of the chloride ion (Cl-)

For each method you will be measuring the salinity of two samples: one known sample, whose salinity is 35%/°, and a sample A whose salinities are to be determined by you.

*Fill two beaker with water having salinity (35%/°) and unknown A*

### 3.1.2.1. Determination of salinity by evaporation

As we have defined salinity as the total mass of dissolved salts (measured in grams) in one kilogram of seawater, the most straightforward way to measure salinity is to measure exactly one kilogram of seawater, evaporate the water, and weight the salt that precipitates out. Evaporating
a full kilogram of water would take more time than we have today however, so we will shorten
the process by evaporating a small fraction of a kilogram.

- Label two beakers for the two samples: $35^\circ/o$, and unknowns A.
- Label two Petri dishes (with the same labels as the sample beakers) and weigh each to the
  nearest 0.01 gram.
- Using a pipette, transfer about 10 mL of each of the two salt solutions to the corresponding
  labeled Petri dishes. Weigh each Petri dish with the water to the nearest 0.01 gram and
  record the masses on the answer sheet. Determine the mass of the water samples by
  subtracting the weight of the dish only, and record the masses.
- Carefully bring the Petri dishes to the back of the room, where your instructor will place
  them in the drying oven. Leave them in the oven until dry – this will take the majority of
  the lab period. You will be doing exercises B through E while waiting for the samples
dry.
- Once the samples are dry allow them to cool for a few minutes, then weigh each Petri dish
  and record the results on the answer sheet (dish + salt). Subtract the masses of the dishes
to determine the mass of each of the salt samples and record the results on the answer
  sheet.
- Determine the salinity of each sample using equation below.

\[
\text{Salinity} = \frac{\text{weight of salt}}{\text{weight of water}} \times 1000\% = \frac{0.39 \text{ grams}}{10.60 \text{ grams}} \times 1000\% = 37\%
\]  

\( (2) \)

3.1.2.2. Determination of salinity by electrical conductivity

Take a conductivity meter reading of each sample to compare the relative salinity of each
sample. Conductivity is a measure of the ability of water to pass an electrical current and is
affected by the presence of dissolved solids. As the level of the total dissolved solids (TDS) rises, the conductivity (electrolytic activity) will also increase.

If you drink seawater, you will become dehydrated. The sodium concentration in sea water is several times higher than the concentration in blood. The body has to excrete the extra salt in the urine and more water is required to get rid of the salt than was in the sea water in the first place. Therefore, you will literally "dry up" drinking sea water as your neuron-muscular reactions become erratic. Some sea birds, like penguins, sea gulls and albatross, can drink sea water but they have special glands in their heads to excrete the excess salt. Think about your salty tears.

In Miami USA, saltwater has intruded into the water supply of some coastal communities. Coconut Grove is an example of a community where the groundwater is unfit for human consumption due to elevated levels of dissolved solids from seawater intruding into the aquifer.

NOTE: It is important to dilute the sample using only deionized water, as tap water contains ions such as sodium and calcium that will alter the salinity of our sample and skew the results of the experiment.

Conductivity meters can be made to measure a variety of salinity conditions. Unfortunately devices that can handle the high salt concentrations found in the world’s oceans (and in today’s lab) are quite costly. The device we used is only accurate at much lower salinities so we had to dilute our samples by a known amount in order to make our measurements.

• Measure the water’s temperature (allow 30-60 seconds for the thermometer to equilibrate) and record the temperature.

• Measure the electrical conductance of the water (the units of conductance are Siemens/cm – the reciprocal of electrical resistance). Place the meter into the beaker (be sure that the probe sensors
are completely submerged) and allow at least 30 seconds for the readout to equilibrate. Record the conductance.
The design of the present desalination system involves many steps to create an environmental as well as economical friendly technology to deliver for the betterment of the society in particular and for world as whole. The design requires providing complete mechanism to give a way for better desalination process within a suitable time. The main things to keep in consideration are to develop the plant horizontally to pave way for better distillation and enough distillate collection. The other important aspect must be considered is the energy source and its economical consumption.

4.1. Design Procedure

The procedure for the design is rather simple but delicate in processing the work. The care must be taken in each step to connect each and everything in suitable and designed places. This will give better and quick results within the specified time and quantity of the initial source sample. The complete design is shown Figure 4.1. To setup the things alright we need to take the following steps to proceed.

Figure 4.1. Schematic Diagram of the design of desalinated plant using distillation method
1. Begin with a round-bottom flask. This is one of the most critical pieces of glassware in the assembly, since it will hold the liquid to be distilled. You don't want it to fall and break because you would lose your compound and possibly spill a hazardous chemical. To secure your setup, you will need a small three-pronged clamp, two ring stands, and a ring clamp.

2. Place the ring clamp and three-pronged clamp on the ring stand. The ring clamp goes on the bottom and will hold the heat source, either a steam bath (no longer used in the organic labs) or a heating mantle. Secure the round-bottom flask to the ring stand using the three-pronged clamp. The next item to be added is the Y-adaptor. The Y-adaptor sits on top of the round-bottom flask. The next item to be added, the condenser, will secure the Y-adaptor to the system. You will also need a Keck clip and a versatile. Connect the condenser to the Y-adaptor and secure the connection with a Keck clip. Secure the condenser to the ring stand with a versatile clamp. The next items you will need are a vacuum adaptor and another Keck clip.

3. Connect the vacuum adaptor to the condenser and secure the connection with a Keck clip. Add a couple of boiling chips to the round-bottom flask by dropping them down through the Y-adaptor.

4. Place a stemmed funnel into the top of the Y-adaptor and pour the liquid to be distilled through it so that it goes into the round bottom flask. The flask should be between 1/2 full and 2/3 full. When done, remove the funnel. This picture is only different from the last in that an Erlenmeyer flask has been placed under the vacuum adaptor. This is the receiving flask. A beaker, vial or graduated cylinder could also be used. In a vacuum distillation, a round bottom flask is used as the receiving flask, and it is securely attached with either a clamp or a yellow clip. The next items to be added are the thermometer adaptor and thermometer. The thermometer is always added last because it is large and susceptible to breakage.
5. Here is all the glassware properly assembled. The thermometer and thermometer adaptor are connected on top of the Y-adaptor. Note the correct placement of the thermometer - this is vital for correct measurement of boiling point. The collection flask has been temporarily removed to protect it during the addition of the heat source, which could cause an unsecured flask to fall and break.

6. Collect two pieces of Tygon tubing for the condenser. If you are using a steam bath for the heat source, you will need four lengths. Place the heat source on the ring under the round-bottom flask. Adjust the height of the apparatus as necessary. Connect two pieces of Tygon tubing to the condenser. The tubing to the lower connection goes to the water source, the upper connection goes to the drain. Remember, in through the bottom, out through the top. If you are using a steam bath, connect it to two pieces of Tygon tubing: one to the lower and one to the upper connection. The tubing at the upper connection goes to the steam source; the lower one goes to the drain. Making sure all of the glass and tubing joints are tight before turning on the cooling water and the steam. Begin heating the round-bottom flask carefully.

4.2. Design Implementation

4.2.1. PH observation test

The resulted samples of water were put on PH test to check the quality of water before and after the distilled process. The point should be noted here that the other water types such as drinking water and tap water were separately analyzed before and after distillation for the comparative reason. The PH of sea water as we used was observed around 8.1 before the desalination process. This drastically decreased 6.8 after taking all solid out in the form of salts through distillation process. The results are shown in the table 4.1.
Table 4.1: PH value of processed water before and after distillation

<table>
<thead>
<tr>
<th>Sample</th>
<th>PH before</th>
<th>PH after</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Water</td>
<td>8.1</td>
<td>6.8</td>
</tr>
<tr>
<td>Tap Water</td>
<td>7.6</td>
<td>6.4</td>
</tr>
<tr>
<td>Drinking Water</td>
<td>7.2</td>
<td>6.9</td>
</tr>
<tr>
<td>Distilled water</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

4.2.2. Salt Content

The desalinated seawater has produced a varied amount of salt content on distillation process. The quantities were approximately maintained similar weight ration when used different quantities of water samples. The salt content was about 35 gms when 1000ml of seawater was desalinated, which was calculated on the basis of Equation (1) above. Similarly on using the 100 ml seawater produced 3.5 gms of salt content after complete removal of moisture. In addition to that many other varied quantities gave us the matching results with that of standard ones. The salt content of different water quantities used are listed in table 4.2 below.

Table 4.2 : Salt contents in used seawater samples with percentage.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Seawater Quantity (ml)</th>
<th>Salt Content (gm)</th>
<th>Salt Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>1000</td>
<td>35</td>
<td>3.5</td>
</tr>
<tr>
<td>2.</td>
<td>500</td>
<td>17.5</td>
<td>3.5</td>
</tr>
<tr>
<td>3.</td>
<td>100</td>
<td>3.5</td>
<td>3.5</td>
</tr>
</tbody>
</table>
CHAPTER 5
FEASIBILITY STUDIES AND MARKET NEEDS

Although freshwater as a water resource might be plentiful and fully accessible to some populations, for others this is not the case. Natural disasters and atmospheric and climate conditions can cause drought, which can be problematic for many who rely on a steady supply of water. Arid areas around the world are most vulnerable to drought due to high annual variations in rainfall. In other cases water overconsumption can lead to problems that affect entire regions both environmentally and economically.

Efforts to promote agriculture in semi-arid Central Asia during the mid- and late-20th century depleted the Aral Sea's water significantly. The Soviet Union wanted to grow cotton in relatively dry parts of Kazakhstan and Uzbekistan so they constructed channels to divert water away from rivers to irrigate crop fields. As a result, water from the Syr Darya and Amu Darya reached the Aral Sea with significantly less volume than before. Exposed sediments from the formerly submerged sea bed scattered in the wind, causing damage to crops, nearly eliminating the local fishing industry, and negatively affected the health of the local residents, all putting excessive strain on the region economically.

Accessing water resources in under-served areas can also cause problems. In Jakarta, Indonesia residents who receive water from the city's pipe system pay a small fraction of what other residents pay for lesser quality water from private vendors. Consumers of the city's pipe system pay less than the price of supply and storage, which is subsidized. This similarly occurs worldwide in areas where water access greatly varies in a single city.

Another solution for water resource shortages is desalination, which turns saltwater into freshwater. This process, as described by Diane Raines Ward in her book Water Wars has been
used since the time of Aristotle. Seawater is often boiled, the steam produced is captured and separated from the remaining salt and other minerals in the water, a process known as distillation.

Additionally, reverse osmosis can be used to create freshwater. The seawater is filtered through a semipermeable membrane, which sieves out salt ions, leaving behind freshwater. While both methods are highly effective in creating freshwater, the desalination process can be quite expensive and require a great deal of energy. The desalination process is mainly used for creating drinking water rather than for other processes such as agricultural irrigation and industry. A few countries such as Saudi Arabia, Bahrain and the United Arab Emirates rely heavily on desalination for creating drinking water and utilize the majority of the current desalination processing plants.

One of the most effective methods to manage existing water supplies is conservation. Technological developments have helped farmers build more effective irrigation systems for their fields where runoff can be recovered and used again. Regular audits of commercial and municipal water systems can help identify any problems and potential for reduced efficiency in processing and delivery. Educating consumers about household water conservation can help decrease household consumption and even help keep prices down. Thinking of water as a commodity, a resource meant for proper management and wise consumption will help ensure a constantly available supply worldwide.

So desalination through the distillation process is one of the economical process to produce fresh water with high volumes at limited time. This process is quite challenging rather to compare with all other present day technology to get the fresh water from the sea water in the sense that the
process directly produces the fresh water without using any filtration or membrane to separate the salt. Which is one of the great advantages over other processes?

Table 5.1: Different seawater quantities with observed salinity content

<table>
<thead>
<tr>
<th>Seawater Quantity (ml)</th>
<th>Salt Quantity (gm)</th>
<th>Salt (%)</th>
<th>Observed Value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000</td>
<td>350</td>
<td>3.5</td>
<td>3.7</td>
</tr>
<tr>
<td>1000</td>
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<td>3.7</td>
</tr>
<tr>
<td>100</td>
<td>3.5</td>
<td>3.5</td>
<td>3.7</td>
</tr>
</tbody>
</table>

6. Conclusion and Recommendations

6.1 Conclusion

In summary, we have designed the separation system where we have performed the salt separation from the seawater through self designed distillation technique. We used anti-bumping granules to avoid bumping of residue while water level has been reduced to minimum level. The process produced enough solid residue to analyze its properties. The desalination results showed that the total salt content in obtained samples was little bit lower as compared to other high salinated oceans around the world. The results were analyzed through PH, solution test as well as by measuring the density through hydrometer. The higher density of seawater sample was reduced once the distillate was collected and analyzed with least density as compared to starting materials. The process was followed with the conductivity analysis of the samples before and after the treatment. In particular the salt content of the treated samples was calculated with equation with different water quantity parameters as used in our study. Finally the results were what we had expected from our study.
6.2 Recommendations

In recommendation the major factor we must go through is the complete composition investigation of solid residue, which includes different metal ions in addition to commonly found NaCl salt. This composition property needed to further investigate the Solid residue on larger scale with some advanced equipments to be used for. The study was the beginning of the analysis of local seawater, but needs to be expanded to analyze the ionic compositions in comparison to high salinity waters around the globe. Another thing to be considered in future should be the analysis of water resulted from the system to make it drinkable by enriched it with specific ion and minerals needed for the better human health.

References

[5] Committee on Advancing Desalination Technology. Desalination: A national perspective. Water Science and Technology Board, National Research Council of the National Academies,


Appendixes

A- CAPSTONE DESIGN PROJECT

Project Submission
and

ABET Criterion 3 a-k Assessment Report

Project Title: DESIGN OF LIQUID-SOLID SAPERATION SYSTEM-DESALINATION OF LOCAL SEAWATER VIA DISTILLATION

DATE: 12-7-1435

PROJECT ADVISOR: Dr. Mehraj-ud-din Naik
Team Leader: Hassan Yahya Mohammed Alshareef

Team Members: Abdullah Ibrahem Abdu Abutaweel
Bassem Mohammad Maqbool Janduli
Hani Mohammed Esa Wafi
Esa Ali Musa Bakri

Design Project Information

Percentage of project Content- Engineering Science 30%
Percentage of project Content- Engineering Design 70%
Other content 0 %

All fields must be added to 100%
B. Project Budget and Expenses to date

**Budget & Expenditures Sheet**

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<th>Description</th>
<th>Estimated Price SR</th>
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<td>1</td>
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<td>Gas Burner</td>
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</tr>
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<td>3</td>
<td>Water circulation pump</td>
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<td>4</td>
<td>Anti-bumping Granules</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>Water storage unit</td>
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<td>8</td>
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